FHWA-WFL/TD-07-005 November 2007

Roadside Revegetation

An Integrated Approach to Establishing Native Plants

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Technology Deployment Report

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ROADSIDE REVEGETATION

AN INTEGRATED APPROACH TO ESTABLISHING NATIVE PLANTS

Technology Deployment Program
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Federal Highway Administration
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Vancouver, WA 98661

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16. Abstract

Native plants are a foundation of ecological function, affecting soil conservation, wildlife habitat, plant communities, invasive species, and water quality. Establishing locally-adapted, self-sustaining plant communities can also support transportation goals for safety and efficiency.

Past obstacles to establishing native plant communities on roadsides have been technical, informational, and organizational. Effective strategies and practical techniques for revegetating the disturbed conditions with limited resources must be made available to practitioners. Multiple disciplines, ranging from engineering to soil science, ecology, botany, and wildlife science, must be able to work cooperatively, not in isolation.

This report offers an integrated approach to facilitate the successful establishment of native plants along roadsides and other areas of disturbance associated with road modifications. It guides readers through a comprehensive process of: 1) initiating, 2) planning, 3) implementing, and 4) monitoring a roadside revegetation project with native plants.

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SI* (MODERN METRIC) CONVERSION FACTORS

APPROXIMATE CONVERSIONS TO SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
in	inches	25.4	millimeters	mm
ft	feet	0.305	meters	m
yd	yards	0.914	meters	m
mi	miles	1.61	kilometers	km
		AREA		
in^2	square inches	645.2	square millimeters	mm^2
ft^2	square feet	0.093	square meters	m^2
yd^2	square yard	0.836	square meters	m^2
ac	acres	0.405	hectares	ha
mi^2	square miles	2.59	square kilometers	km^2
		VOLUME		
fl oz	fluid ounces	29.57	milliliters	mL
gal	gallons	3.785	liters	L
ft^3	cubic feet	0.028	cubic meters	m^3
yd^3	cubic yards	0.765	cubic meters	m^3
		NOTE: volumes greater than 1000 L shall be shown in m^3		
		MASS		
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams (or “metric ton”)	Mg (or “t”)
		TEMPERATURE (exact degrees)		
°F	Fahrenheit	5 (F-32)/9 or (F-32)/1.8	Celsius	°C
		ILLUMINATION		
fc	foot-candles	10.76	lux	lx
fl	foot-Lamberts	3.426	candela/m^2	cd/m^2
		FORCE and PRESSURE or STRESS		
lbf	poundforce	4.45	newtons	N
lbf/in^2	poundforce per square inch	6.89	kilopascals	kPa

APPROXIMATE CONVERSIONS FROM SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
mm	millimeters	0.039	inches	in
m	meters	3.28	feet	ft
m	meters	1.09	yards	yd
km	kilometers	0.621	miles	mi
		AREA		
mm^2	square millimeters	0.0016	square inches	in^2
m^2	square meters	10.764	square feet	ft^2
m^2	square meters	1.195	square yards	yd^2
ha	hectares	2.47	acres	ac
km^2	square kilometers	0.386	square miles	mi^2
		VOLUME		
mL	milliliters	0.034	fluid ounces	fl oz
L	liters	0.264	gallons	gal
m^3	cubic meters	35.314	cubic feet	ft^3
m^3	cubic meters	1.307	cubic yards	yd^3
		MASS		
g	grams	0.035	ounces	oz
kg	kilograms	2.202	pounds	lb
Mg (or “t”)	megagrams (or “metric ton”)	1.103	short tons (2000 lb)	T
		TEMPERATURE (exact degrees)		
°C	Celsius	1.8C+32	Fahrenheit	°F
		ILLUMINATION		
lx	lux	0.0929	foot-candles	fc
cd/m^2	candela/m^2	0.2919	foot-Lamberts	fl
		FORCE and PRESSURE or STRESS		
N	newtons	0.225	poundforce	lbf
kPa	kilopascals	0.145	poundforce per square inch	lbf/in^2

*SI is the symbol for the International System of Units. Appropriate rounding should be made to comply with Section 4 of ASTM E380. (Revised March 2003)

ROADSIDE REVEGETATION:
AN INTEGRATED APPROACH TO ESTABLISHING NATIVE PLANTS

TABLE OF CONTENTS

LIST OF ACRONYMS:

AASHTO – American Association of State Highway and Transportation Officials
AMF – Arbuscular mycorrhizal fungi, formerly called endomycorrhizae
AOSA – Association of Official Seed Analysts
AOSTA – Association of Seed Technologists Association
AWHC – Available Water-Holding Capacity
BFM – Bonded Fiber Matrix
BLM – Bureau of Land Management
CCE – Calcium Carbonate Equivalent
CEC – Cation Exchange Capacity
CRF – Control-Release Fertilizers
COTR – Contracting Officer's Technical Representative
DEQ – Department of Environmental Quality
DFC – Desired Future Condition
DGRC – Dorena Genetic Resource Center
DOT – Department of Transportation
EA – Environmental Analysis
EMC – Ectomycorrhizal Fungi
EPA – U.S. Environmental Protection Agency
ECRM – Erosion Control Revegetative Mats
ET – Evapotranspiration Rate
FHWA – Federal Highway Administration
FS – U.S. Forest Service
GIS – Geographic Information System
LCL – Lower Confidence Limit
HWY – Highway
IBDU – Isobutylidene Diurea
IRVM – Integrated Roadside Vegetation Management
MTDC – Missoula Technology Development Center
NAPT – North American Proficiency Testing
NEPA – National Environmental Policy Act
NPDES – National Pollutant Discharge Elimination System
NRCS – Natural Resources Conservation Services
OM – Organic Matter
OHV – Off-Highway Vehicle
PAM – Polyacrylamides
PIR – Project Identification Report
PLS – Pure Live Seed
PMS – Plant Moisture Stress
PVC – Polyvinyl Chloride
RECP – Rolled Erosion Controlled Products
RGP – Root Growth Potential
ROW – Right-of-Way
RQD – Rock Quality Design Index
SME – Saturated Media Extract
SMP – Shoemaker-McLean-Pratt buffer
SRI – Soil Resource Inventory
STA – Seal of Testing Assurance
TAWHC – Total Available Water-Holding Capacity
TEUI – Terrestrial Ecological Unit Inventory
TMECC – Test Methods of the Examination of Compost and Composting
TRM – Turf Reinforcement Mats
TZ – Tetrazolium Test
UCL – Upper Confidence Limit
USDA – U.S. Department of Agriculture
USFS – U.S. Forest Service
UTM – Universal Transverse Mercator
WFLHD – Western Federal Lands Highways Division

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1 INTRODUCTION

1.1 INTRODUCTION

Integrating societal goals for safe, efficient transportation with goals for ecological health is a crucial issue that is receiving increased attention (Forman and others 2003; NRC 2005). Today, most road projects involve modifications to existing roads rather than new construction (NRC 2005). As roads are modified or updated section by section, a tremendous opportunity presents itself to remedy the oversights of the past, mitigating environmental impacts and improving conditions for healthy ecosystems.

Native plants are a foundation of ecological function, affecting soil conservation, wildlife habitat, plant communities, invasive species, and water quality. Establishing locally-adapted, self-sustaining plant communities can also support transportation goals for safety and efficiency. Protecting existing native vegetation during construction and establishing native plants on roadsides following disturbance is key to integrating road systems into natural systems.

Past obstacles to establishing native plant communities on roadsides have been technical, informational, and organizational. Effective strategies and practical techniques for revegetating the disturbed conditions with limited resources must be made available to practitioners. Multiple disciplines, ranging from engineering to soil science, ecology, botany, and wildlife science, must be able to work cooperatively, not in isolation. Finally, improved interagency cooperation and planning processes that consider ecological effects at every step are necessary.

This report offers an integrated approach to facilitate the successful establishment of native plants along roadsides and other areas of disturbance associated with road modifications. It guides readers through a comprehensive process of: 1) initiating, 2) planning, 3) implementing, and 4) monitoring a roadside revegetation project with native plants.

1.2 THE ECOLOGICAL EFFECTS OF ROADS

The ecological effects of roads are widespread. The road system of the United States is over 4 million miles long, paved roadways covering roughly 0.5% of the total land area of the country (NRC 2005). The total road corridor (paved road plus roadside or right-of-way) covers over 1% of the nation's surface, an area equal to the size of South Carolina (Forman and Alexander 1998). If unpaved roads are also included, the percentages dramatically increase. The ecological effects of roads extend into a zone far beyond the edge of the pavement, with impacts including habitat fragmentation, wildlife mortality, noise and chemical pollution, disruption of hydrologic cycles and water quality, increased erosion, and the potential creation of transportation corridors for noxious and invasive weeds that can invade adjacent lands. With these considerations, the estimate is that 15% to 20% of the United States is ecologically impacted by roads (Forman and Alexander 1988). The enormous challenge of understanding and mitigating the ecological effects of roads deserves attention and dedication on local, regional, and national scales.

Figure 1.1 *– Beginning revegetation with native species on scenic highway to Mt. Bachelor, OR.*

1.2.1 Past Oversights

Much of the existing road network was designed and constructed prior to the 1970s, before ecological health became a widespread concern among American citizens and before ecological science had evolved to address large-scale issues (Forman and others 2003). Safety and efficiency were the primary goals of transportation programs in the past, and the ecological impacts were largely overlooked in road planning, construction, and maintenance efforts. The impacts of roads on natural systems (habitat fragmentation, interruption of natural flows of water, and disturbances to animals, plants, soils, and other resources) were not well understood or considered. Lack of awareness about these factors led to a largely antagonistic perception of the relationships between natural systems and road systems. For example, without effective revegetation of the road disturbance with desirable plants, undesirable vegetation encroaches on the roadway. Undesirable vegetation can disrupt safety and visibility, leading to expensive and potentially hazardous maintenance measures. Conflicts with neighboring land uses could result if corridors for invasive weeds are established or if vegetation control measures are viewed as a health or safety concern by the community. These are all issues that arise when integration of ecology and road design is not considered during road construction or modification. Eventually, poorly integrated natural processes can threaten the function and structural integrity of the road itself, leading to premature deterioration of the road's infrastructure (Berger 2005).

1.2.2 Present Awareness

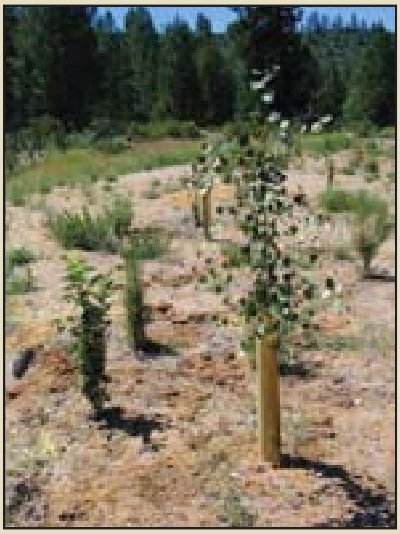
For over twenty years, the ecological effects of roads have been increasingly recognized by the Federal Highway Administration and by state and county transportation agencies (NRC 2005). Today, road effects on ecology are major concerns among private citizens, land management agencies, and the transportation community. Attempting to integrate ecological concerns into all phases of road design and construction processes is an emphasis. For example, legislation in some areas now requires road modification and construction projects to restore aquatic connectivity; fish passages have been built to reconnect natural water flows under roads. Other projects have dealt with roads that were deemed particularly dangerous to endangered species. These roads are being made more permeable to wildlife, greatly reducing losses by improving habitat connectivity, ensuring better visibility for drivers and animals, and creating safer underpasses or overpasses for wildlife (Forman and others 2003). Efforts to limit inappropriate road expansion and to obliterate unnecessary roads remain important. Where modification and increased capacity are needed, ecological health, safety, and efficient transport should not be seen as mutually exclusive goals. Understanding roadside environments, how they interface with adjoining lands, and how to minimize environmental impacts has become a key focus of the Federal Highway Administration (Fekaris 2006). Given political will and proper levels of attention, integration of environmental concerns with transportation can result in significant gains.

***Figure 1.2** – Most existing roads were constructed prior to 1970, before ecological health became a widespread concern.*

1.2.3 Trends in Road Construction

Roads are widespread, fairly permanent fixtures on the landscape and in the culture of the United States. Given current trends, road networks are expected to persist and expand over time. Current modifications predominantly involve updating infrastructure to increase capacity and to improve safety, including widening roads, replacing bridges, and reducing or altering curves and grades to make the road safer for motorists (NRC 2005). The opportunity to integrate ecological goals with transportation was largely overlooked when the road networks were originally constructed. However, as the nation's roads are being updated and modified, the opportunity cannot be ignored. While attempts to integrate ecological factors are positive, much of the potential for improved integration is still largely unrealized. This has been due, in part, to a shortage of practical information and the absence of an integrated approach to the challenge. The question is, what can be done to balance societal desires for safe, efficient transport with requirements for a healthy environment? In other words, what can be done to help road systems function better with natural systems?

***Figure 1.3** – Most road projects today do not involve building new roads, but rather modifying or obliterating existing roads. This photo shows recently planted trees on an obliterated section of highway in Oregon.*



1.2.4 Challenges and Opportunities

The fact that the nation's road networks are in varying states of updates, repairs, and maintenance presents an opportunity to improve road systems so that they integrate better with natural systems. Planners and practitioners strive to understand detrimental effects associated with roads and how to mitigate them by minimizing the ecological footprint of roads and maximizing potential ecological benefits. Many groundbreaking resources have emerged to support these efforts. *Road Ecology: Science and Solutions* (Forman and others 2003) places the challenges into comprehensive frameworks, illuminating goals and principles for an ecological approach to transportation issues. Multiple intervention points are identified to help road systems function better with natural systems, integrating transportation goals for safety and efficiency with approaches to protect water, soil, vegetation, wildlife, and aquatic life. The Federal Highway Administration published a landmark book called *Roadside Use of Native Plants* (Harper-Lore and Wilson 2000) that brought the issue of native plant communities on roadsides to the forefront, highlighting the importance of native plants and their ranges of use. The National Research Council of the National Academies of Science built on the frameworks identified in Forman and others (2003) in their publication, *Assessing and Managing the Ecological Impacts of Paved Roads* (2005). Processes and procedures within the Federal Highway Administration, state departments of transportation, and other agencies are being improved for better integration.

In addition to these advances and other publications directly related to roads, many advances in the field of restoration ecology have distilled essential principles applicable to severely degraded sites (e.g., Munshower 1994; SER 2004; Clewell and others 2005; Claassen 2006). Also vegetation specialists within many federal agencies have come to consensus about what truly defines a "native" plant and have developed seed collection, transfer, and propagation guidelines to ensure that locally adapted materials are used for optimum results (Withrow-Robinson and Johnson 2006). In both the public and private sectors seed and plant producers and installers have been developing innovative methods to meet unique site conditions.

While the publications above assess the best available conceptual and theoretical information, each also recognizes extensive needs for further work, particularly in developing practical approaches to integrating ecological needs with transportation goals. Central to ecosystem function is native vegetation (SER 2004). However, much of the pertinent information related to protecting and establishing native plants on roadsides has been scarce, scattered, unexamined, or not translated into practice. This report is intended to bridge some of the informational, technical, and organizational gaps to facilitate successful roadside revegetation with native plants. An integrated approach is offered to support both planners and field-based practitioners in successfully revegetating roadsides and obliterated roads with native plant communities.

1.2.5 Why Revegetate Roadsides With Native Plants?

Long-term economic and ecological advantages can be gained by establishing desirable native plant communities on roadsides (Berger 2005). Desirable vegetation can support safety goals by reducing headlight glare, reinforcing the road alignment, serving as crash barriers, protecting view planes and visibility, controlling snow drifts, and reducing wind speeds (Forman and others 2003). Vegetation can improve the experience of the road user by creating natural beauty and diversity along the roadside. A self-sustaining native plant community on a roadside stabilizes slopes, protecting water and soil quality. Also, the establishment of healthy native plant communities is often the best long-term defense against invasive and noxious weeds. Maintenance costs for managing problematic vegetation are reduced, as is the pollution and controversy that sometimes results from roadside herbicide use (Berger 2005). Establishing healthy roadside vegetation can also help sequester carbon dioxide, one of the factors responsible for global climate change (Palumbo and others 2004).

Using desirable vegetation supports every aspect of the goals identified as Best Management Practices by the transportation community for road design. These include goals to:

- Produce a safe, cost effective, environmentally friendly, and practical road design that is supported by and meets the needs of the users;
- Protect water quality and reduce sediment loading into water bodies;
- Avoid conflicts with land use;
- Protect sensitive areas and reduce ecosystem impacts;
- Maintain natural channels, natural stream flow, and passage for aquatic organisms;
- Minimize ground and drainage channel disturbance;
- Control surface water on the road and stabilize the roadbed driving surface;
- Control erosion and protect exposed soil areas;
- Implement needed slope stabilization measures and reduce mass wasting;
- Avoid problematic areas; and
- Stormproof and extend the useful life of the road (Keller and Sherar 2003 p.3).

Clearly, the goals of safe and efficient transportation and the goals of establishing and protecting native vegetation overlap; when properly integrated, native vegetation supports road objectives. At the same time, considering vegetation as part of road planning processes aids in minimizing and mitigating the ecological footprint of roads during and after construction. Native plants can provide wildlife habitat and improved connectivity for the length of the road (Forman and others 2003). Understanding vegetation and forage preferences, and careful design that accounts for visibility and safety, can guide animals to safe passageways for travel while minimizing dangerous interactions with vehicles. The presence of birds and small animals can be enhanced when appropriate plant species are established. Processes that work for roadside revegetation are also applicable to the process of obliterating roads where roads are no longer needed.

Despite the potential benefits, many past attempts at roadside revegetation have not succeeded. Although revegetation was considered important, some efforts emphasized seeding of exotic plants; these species were perceived as cheap, readily available, and easy to establish on disturbed sites. This practice has not been effective or self-sustaining; either the exotic grasses spread to become problematic weeds, or failed to persist because they were not locally appropriate species. Once established, exotics may preclude reintroduction of desirable natives. In other cases, little consideration was given to establishing roadside vegetation during or after construction; if vegetation was considered, it was often as an afterthought. A short-term approach to revegetating roadside disturbances often predominated past efforts, while efforts toward long-term development of native plant communities did not receive adequate consideration. The ineffectiveness of revegetation efforts in the past has resulted

***Figure 1.4** – Steep slopes are often difficult to revegetate and many past attempts at roadside revegetation did not succeed. Inexpensive and readily-available exotic plants either failed to establish or became weeds. Integration of revegetation techniques into road planning and implementation increases the chances of success.*

***Figure 1.5** – Past shortcomings can often be attributed to a lack of an integrated approach and proper coordination. This photo shows an area recently revegetated with native plants that has been sprayed with herbicide.*

in such problems as erosion and sediment loading, affecting soil and water quality. Visually, unvegetated road disturbances diminish the experience of the road user and economically translate into high costs associated with ongoing maintenance.

Past shortcomings may be attributed to past approaches. Past approaches were often piecemeal, lacking the cooperation and coordination of disciplines necessary to fully integrate native vegetation into the road planning and construction processes. Revegetation specialists typically worked in isolation from engineers, and sometimes even the biological specialists (soil scientists, botanists, wildlife biologists) failed to coordinate their knowledge and efforts. Success will require both practical and technical information and a systematic, comprehensive approach.

1.3 OBJECTIVES OF THIS REPORT

This report brings theoretical and practical information to bear on the challenge of revegetating roadsides with native plants. Written by and for field-based practitioners and planners, it synthesizes a comprehensive, holistic approach that can be utilized to effectively revegetate roads. Given the unique ecological factors at play on each project, the report is not prescriptive, but rather provides principles and a step-by-step process for practitioners to use in the field to generate and implement their own locally-appropriate, context-sensitive revegetation plan. Examples and proven strategies are offered to serve these goals. Topics covered include how to:

- Improve interagency cooperation in order to think ecologically about road modifications and make revegetation an integral part of road design;
- Coordinate information and efforts to bring multiple disciplines like soil science, botany, ecology, wildlife science, and engineering together for a holistic approach to revegetation;
- Integrate goals for native vegetation establishment with transportation goals for safety, function, and efficiency;
- Mitigate harsh, drastically disturbed conditions of road disturbance areas to enable native plants to establish through natural colonization and/or active replanting; and
- Apply a step-by-step planning, implementation, and monitoring process, including mid-course corrections, to overcome potential pitfalls, resulting in cost-effective, successful establishment of native plants.

1.4 SCOPE

The complexity of ecologically-sensitive road design, implementation, and maintenance will require increasing cooperation from multiple sectors of society and multiple fields of practice and expertise. This report should be of interest not only to field-level practitioners and planners in both public and private sectors, but also to transportation and planning professionals, land managers, policy-makers, owners and operators of roads on county, state, and federal scales, and concerned citizens. Any agency or organization involved in altering, developing, operating, maintaining, or decommissioning roads will find this publication useful. The report is especially intended to serve field-based practitioners and planners of diverse backgrounds whose goal is to establish locally appropriate, low-maintenance native plant communities on roadsides.

Because integration of multiple sources of expertise is necessary for effective long-term revegetation, this report does not assume that the reader has a particular specialized background. Rather, the "revegetation specialist" addressed in the text may have a background in botany, ecology, soil science, engineering, biology, or other related areas of study. It is generally recommended that one practitioner be in charge of all the aspects of the revegetation project. This "revegetation specialist" will probably involve one or more other specialists during the planning process, depending on the project's complexity. The report states where specific expertise is required (genetics, soil diagnosis, and so on). In all cases, the input and cooperation of the individuals and agencies involved with the road project is assumed. Key milestones for communication and integration between engineers and non-engineers are highlighted.

The approach in this report is applicable to any type of road-related project that involves disturbances to soil and vegetation. Revegetation of roadsides adjacent to dirt, gravel, and paved roads would involve similar processes, although differences in scale and intensity of efforts would be required. This report applies to new construction or reconstruction and modifications of existing roadways. The principles and practices will also be applicable in revegetating other drastically disturbed sites with similar limiting factors to roadsides, such as gas, oil, or powerline rights-of-way, mine reclamation projects, and so on.

This report focuses on opportunities for intervention during road construction or modification. Long-term maintenance and management of established roadsides is discussed briefly, with references to related management practices and guidelines such as *Integrated Roadside Vegetation Management (IRVM)* (Berger 2005). Roads must be made more permeable to natural flows of water, animals, and plants if the road disturbance is to heal and not expand. Efforts to improve habitat connectivity and road permeability, as well as storm water drainage and created wetlands, can be supported by the revegetation practices described in this report. However, specific mitigations for these important topics are beyond the scope of this publication. Also beyond the scope are the myriad other potential ecological and social issues that affect, and are affected by, the engineering and transportation planning processes. Issues of social justice and community planning are not addressed. Larger policy-making and planning procedures are also beyond the scope of this report.

1.5 APPROACH

The establishment of native plant communities in order to re-initiate natural processes of succession is a cornerstone of most ecological restoration work (Dorner 2002). Effective revegetation on highly disturbed roadsides aims to initiate or accelerate processes of natural succession following disturbances. Three aspects are generally considered: 1) health (the functional processes of the ecosystem); 2) integrity (species composition and community structure); and 3) sustainability (resistance to disturbance and resilience) (Clewell and others 2005). While restoring plant communities to a pre-disturbance state is not a goal (or even a feasible idea) on highly disturbed roadsides, each of the above three ecosystem aspects can be improved with appropriate roadside revegetation practices. Establishing reference sites, or natural models for the desired recovery process, is key to identifying and overcoming limiting factors and accelerating succession by establishing native plants.

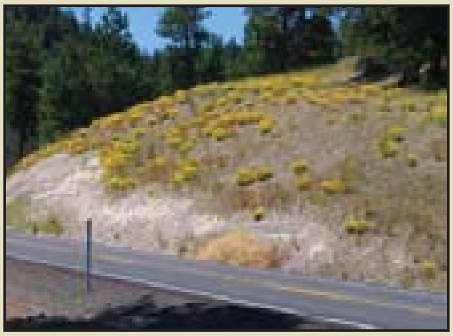
Native species play an important role in ecosystem development. If native species can colonize and become established on a disturbance, the processes of succession, including soil genesis and nutrient cycling, are initiated (Brown and Amacher 1999). In most cases, native plants are established on roadsides through seeding or planting, although sometimes passive revegetation (natural colonization) is possible where native seed banks are nearby and limiting factors are mitigated.

1.5.1 What is the "Roadside"?

In this report, the term "roadside" refers to any area of disturbance associated with road maintenance, modification, or construction, including waste areas and source pits associated

***Figure 1.6** – The establishment of native plant communities is the cornerstone of ecological restoration.*

***Figure 1.7** – "Roadside" refers to disturbed areas resulting from road construction, modification, or improper maintenance.*



with construction. The roadside includes the sides of the road corridor beyond the paved road (shoulders and verges), including impacted or maintained roadside areas within the right-of-way (ROW). The roadside area to be considered is sometimes narrow, but sometimes extends several hundred feet or more beyond the edge of the road surface, depending on the project. In some situations, revegetation efforts may encompass areas beyond the ROW that are affected by or affect the road. The area where the revegetation specialists will be focusing their efforts is usually dependent on two factors: ownership of the ROW and surrounding lands, and areas of disturbance (construction footprint). Most roadsides represent drastically disturbed environments, where soil may be severely compacted and consist of a mixture of subsoil and parent material. Beneficial microorganisms, nutrients, and organic matter necessary to sustain plant growth may be absent or severely depleted. Often, slopes can be very steep and inaccessible, exposed to the erosive effects of wind and water. These environments represent a revegetation challenge of high intensity and magnitude.

1.5.2 What are Native Plants?

"Native plants," as defined in this report, are locally-adapted, genetically appropriate native plant materials (Withrow-Robinson and Johnson 2006). These plants are best suited evolutionarily to the local conditions, and generally require less maintenance and persist longer than non-local species. When properly established, they form plant communities with the potential to be self-sustaining and self-perpetuating over time, requiring little or no input from humans to persist.

Recent Policies Mandating Native Plants for Revegetation

Many land management agencies have policies mandating the use of native plants as the first choice in revegetation efforts. For example, the USDA Forest Service has the following policies in place applicable to road projects on Forest Service lands:

1) **National Native Plant Materials Policy:** "Native plant materials are the first choice in revegetation…" (USFS 2005)
2) **BAER Manual** (FSM 2523): "…when practical, use genetically local sources of native species…" (USFS 2003)
3) **National Fire Plan Strategy:** "…promote the establishment of local sources of native seed and other plant material…" (USFS/USDI 2001)
4) **R6 Revegetation Policy:** "…use local native plants to the extent practicable…" (USFS 2004)
5) **NW Forest Plan; *Interior Columbia Basin Ecosystem Management Project:*** "…maintain and restore native species and ecosystems…" (USFS/USDI 1994; USFS 2006)
6) **Federal Register Notices:** "…promote the use of native plant materials in revegetation for restoration and rehabilitation… native plant materials are the first choice in revegetation for restoration and rehabilitation efforts." (FRN 2006)

Figure 1.8 *– Roadsides are often drastically disturbed and infertile environments with no topsoil, severe compaction, and a lack of beneficial microorganisms. They include obliterated roads and borrow sites as shown in this photograph.*

Challenges to establishing native plants on roadsides are significant, partially due to difficulties in obtaining appropriate materials. However, the technological capacity of native plant propagation and outplanting efforts in both private and public sectors has increased significantly in the past decade. Innovative stocktypes and application methods have made roadside revegetation more effective. Recent policy mandates from many federal agencies that manage roads now require the use of native plant materials as the first choice in revegetation efforts, thereby making roadside revegetation an important and expanding frontier for native plant suppliers.

1.5.3 Goal-Oriented, Context-Sensitive, and Integrated

The overall approach in every aspect of this report is: 1) goal-oriented, 2) context-sensitive, and 3) integrated (Clark and others 2001). The goals of establishing and protecting native plant communities are considered along with transportation goals, including safety, efficiency, and cost-effectiveness for the life of the road. This is not an idealistic approach; while recognizing that resources are limited and conditions are degraded, the approach is technically and economically feasible and still enables roads to integrate with ecological processes.

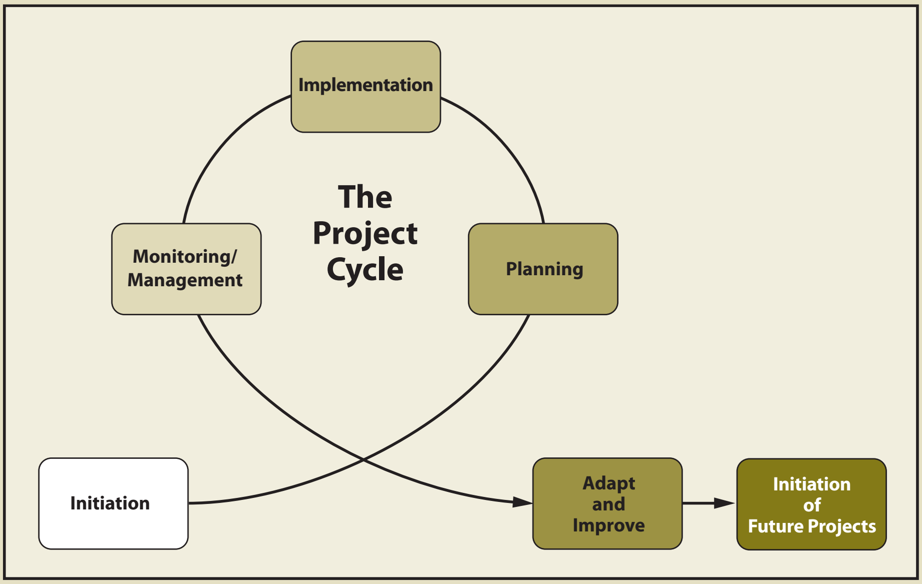
Sensitivity and appropriateness to the local context is an essential part of successful revegetation. This report is intended to facilitate the process of developing locally appropriate, context-sensitive prescriptions on a project-by-project basis, integrating top-down and ground-up information to meet the specific challenges at hand. For this reason, the report does not provide cookbook-type "recipes" or specific prescriptions. For example, no one-size-fits-all seed mix exists for roadside revegetation. Any information source emphasizing generalized prescriptions should be treated with suspicion. The process and tools needed to arrive at context-sensitive solutions are not difficult to apply; by following the steps outlined in this report, practitioners will be able to generate the information they need.

The approach integrates multiple disciplines and the efforts of multiple agencies and participants from both private and public sectors in a comprehensive process for effective revegetation with native plants. The report was written with inputs from specialists in soil science, botany, ecology, plant pathology, environmental management, and engineering, and is based on experiences in revegetating a range of diverse projects in the Pacific Northwest. The principles and methods used are broadly applicable nationwide.

1.6 HOW THIS REPORT IS ORGANIZED

The process of roadside revegetation consists of four stages: 1) initiation, 2) planning, 3) implementation, and 4) monitoring and management. In Initiation, the revegetation specialist must gain an understanding of the agencies and cooperators involved in order to develop key relationships and navigate through the decision-making process. Synchronizing timelines for revegetation with road planning and construction is essential to ensure that conservation and revegetation is an integral part of the process. The Initiation chapters also help the reader to effectively interpret engineered road plans and communicate using standard terminology. The Planning chapters guide the reader through the process of understanding project objectives, assessing the site, designing mitigating treatments, strategizing revegetation procedures, and creating a revegetation plan. The Implementation chapters provide information on how to

Figure 1.9 – The project cycle consists of four phases: initiation, planning, implementation, and monitoring/management.



make the project unfold in the field, including coordinating contracts, budgets, and schedules. Implementation Guides provide practical "how-to" information for working with soil and site treatments, obtaining plant materials, installing plant materials, and caring for plants in the field. Finally, the Monitoring chapters describe how to assess the overall effectiveness of the revegetation project to contribute to adaptive management and future knowledge, and to correct any shortcomings in order to achieve project objectives. A summary of the process is provided in Figure 1.9 and Table 1.1.

1.6.1 Initiation Overview

Effective roadside revegetation requires not only technical skills, but an ability to cultivate relationships and navigate the decision processes so a project will run smoothly. Road construction, alteration, or decommissioning involves a variety of land management agencies, programs, and regulations. The process of initiating a project is discussed in two parts. Initiation Part One orients the reader to learn about agency procedures for the organizations involved with road projects. Timelines, budgetary issues, and interface opportunities are outlined to enable the revegetation specialist to integrate revegetation efforts with the overall process of road planning and construction. Attending meetings and coordinating with key contacts within agencies are important tasks in the early stages of the project.

Initiation Part Two provides the revegetation specialist with information to understand the current project site conditions, as well as predict the future condition of the project site following road construction. The revegetation specialist will become familiar with reading and interpreting road plans and understanding terminology. This ability enables the specialist to communicate effectively about engineering plans, contribute fully to minimizing the adverse environmental impacts, and ensure that revegetation is an integral part of the efforts.

1.6.2 Planning Overview

Planning forms the foundation of future work. The Planning section of the report guides the reader through a comprehensive, holistic process culminating in the production of a revegetation plan. The process of planning is organized into four phases.

Phase One involves defining four essential aspects of the project: 1) the project objectives; 2) the management areas (revegetation units); 3) the models (reference sites); and 4) the specific goals for each revegetation unit (desired future conditions, DFCs). Defining these steps requires a preliminary assessment of site characteristics, including vegetation, climate, and soil.

***Table 1.1** – Overview of Roadside Revegetation Report.*

Section	Chapter	Goal	Tasks
Initiation Part One	Chapter 2	*Understand cooperators and decision processes*	Set up recordkeeping
			Identify cooperators: Who is involved?
			Define cooperator processes, timelines, and milestones
			Define objectives: What is the project trying to accomplish?
Initiation Part Two	Chapter 3	*Understand road plans and terminology*	Read and interpret road construction plans
			Understand key concepts and terminology
Planning Phase One	Chapter 4	*Orient to the project*	Determine revegetation objectives
			Define revegetation units
			Select reference sites
			Define the desired future conditions
Planning Phase Two	Chapter 5	*Assess site*	Identify limiting factors
			Consider mitigating measures for limiting factors
			Assess site resources
Planning Phase Three	Chapter 6	*Analyze vegetation*	Complete vegetation assessment
			Create a comprehensive species list
			Define plant communities and successional processes
			Determine which species and groups of species will be used on the project
			Identify target plant requirements
			Create menu of potential stocktypes and plant establishment methods
Planning Phase Four	Chapter 7	*Integrate and strategize*	Finalize revegetation units and DFCs
			Integrate survey information and develop potential revegetation strategies
			Compare and select revegetation strategies
			Assemble revegetation plan
	Chapter 8	*Example plan*	Example revegetation plan
Implementation	Chapters 9 and 10	*Implement*	Review plans with construction engineer
			Review revegetation treatment details and timelines
			Develop contracts
			Install treatments
			Keep good records
			Carry out quality control
			Implement early maintenance and monitoring
Monitoring & Management	Chapters 11 and 12	*Monitor, evaluate, correct, improve*	Revisit project objectives and DFCs
			Develop monitoring strategy and protocols
			Record data and observations
			Evaluate data and apply any corrective measures
			Organize and file project results
			Share lessons learned

Phase Two defines site attributes and limiting factors. Factors critical for plant establishment, such as soil and climate, are assessed. Obstacles to revegetation, as well as available resources, are examined. A field investigation of each revegetation unit describes the site in depth and reveals how site characteristics will either support or limit achieving the DFCs. Based on the determination of limiting factors, a menu of possible mitigating measures for assuring plant establishment (short-term) and plant community development (long-term) is developed.

Phase Three matches plant species, genetic sources, stocktypes, and planting methods to the environmental conditions of the site. The vegetation is surveyed and analyzed. From a comprehensive list of species and plant communities present on the reference sites, the revegetation specialist determines which species are best adapted to the site and best suited to revegetation needs. Options for sources, stocktypes, and application methods are considered in order to achieve the desired results.

Phase Four combines all elements into a comprehensive strategy for revegetation. The possible options for site mitigation and revegetation methods are compared and considered, and the most promising are selected. Choices will be based on site factors and plant needs, and on other considerations, such as costs and availability of materials and services. There are always several ways to meet the revegetation objectives, and different options are considered in Phase Four. When preferred strategies have been selected, budgets and schedules are developed and recommendations are compiled and presented in the Revegetation Plan.

1.6.3 Implementation Overview

Implementation involves coordinating and cooperating with different contractors and agency personnel before, during, and after construction of the road. Treatments for soils and site conditions, obtaining plant materials, and installing and caring for plants are part of the implementation process. These chapters will help the reader to review plans with engineers, finalize treatment details and timelines, and develop the contracts necessary to successfully carry out the treatments. Keeping good records and carrying out quality assurance and early maintenance activities are essential aspects of the implementation phase. In all cases, coordinating the revegetation work with road construction or modification processes is a major challenge, and a key opportunity to improve conditions for native plants.

Implementation Guides are short sections illustrating how to implement and/or contract for a particular treatment or mitigation measure. Guides are provided for: 1) working with soil/site treatments, 2) obtaining plant materials, 3) installing plant materials, and 4) caring for plants.

1.6.4 Monitoring and Management Overview

Monitoring is necessary to determine if goals defined at the outset of the project have been met. Scope, methods, and parameters for monitoring are determined on a project-by-project basis. These must be developed so that sufficient and meaningful information is obtained efficiently and interpreted properly. Keeping written records throughout the process of roadside revegetation is essential to evaluate each project.

Monitoring continues several years after implementation, providing a chance to assess effectiveness and correct any shortcomings. In the Planning section, project objectives describe an overall vision for the project. The desired future conditions refined the objectives into specific, measurable goals for the project site. Monitoring is an opportunity to evaluate the effectiveness of the revegetation efforts as they relate to objectives and goals.

Monitoring is essential for adaptive management of the project. Adaptive management is a systematic approach to good management guided by a process of regularly assessing and learning from what works and does not work on a project. As a project develops, monitoring can be used to assess progress and plan any necessary corrections.

When statistical methods will be necessary, Monitoring Protocols describe statistical sampling design, data collection techniques, and analysis methods for quantifiable parameters to determine success of roadside revegetation projects.

Revegetating roadsides with native plant communities is a developing field. Practitioners are encouraged to share lessons learned, including successes and failures, to improve the knowledge base for future work.

Figure 1.10 – Native roadside revegetation in Glacier National Park. Photo by Tara Luna.

1.7 SUMMARY

Balancing ecological health with safe and efficient transportation is an enormous challenge. To protect environmental health and sustain the native plant communities of roadsides, conservation and revegetation efforts must be an integral part of road design and construction. The process of roadside revegetation requires communication, interdisciplinary practice, and interagency cooperation. This report guides the reader through a comprehensive process for initiating, planning, implementing, and monitoring a project in order to successfully establish and perpetuate native plant communities on roadsides. It is hoped that this report will advance the science and technology of this field and lead practitioners to more successful projects.

2 INITIATION PART ONE: COOPERATORS AND PROCESSES FOR ROAD PROJECTS

2.1 INTRODUCTION

Incorporating ecological thinking into all aspects of road design, construction, modification and maintenance is a goal of the transportation community (NRC 2005; Forman and others 2003). The Federal Highway Administration, state departments of transportation, and other federal, state, and county agencies that work with roads seek to meet this goal. One way this goal is being addressed is to integrate issues of native plant revegetation (including protection of existing vegetation) into the larger design and construction processes of road projects. Considering revegetation in isolation from, or as an appendix to, the larger road project is a trend of the past that often resulted in failure. Instead, revegetation planning is now an integral part of road planning.

To ensure successful integration of revegetation issues with the overall road project, as the revegetation specialist and a field-based practitioner you need to define the cooperators and agencies involved, know how their processes and timelines work, and get involved at the appropriate times and with the appropriate people. You should expect to be involved in planning and construction processes whenever soil and vegetation disturbances are planned. Agency schedules, milestones, and budgetary issues must be defined to effectively synchronize the revegetation efforts with road development and construction.

Road projects may be administered from local, state, or federal levels, or sometimes from a combination of all three levels. In terms of timing, road projects can be complex and span many years, whereas other projects are streamlined and quick. It is beyond the scope of this manual to cover all the specific procedures and processes for every agency involved in road projects. This chapter, however, provides an overview to successfully navigate the various processes for your project. Your involvement and input is important from the inception of a project through completion. The earlier you can get involved, the more input you will have. The preliminary steps for initial involvement are:

- Set up recordkeeping.
- Identify cooperators: Who is involved?
- Define cooperator processes, timelines, and milestones.
- Define objectives: What is the project trying to accomplish?

This chapter provides an overview of each of these steps, followed by a discussion of typical road development processes which include key points of involvement.

2.2 PRELIMINARY TASKS OF INITIATION

Roadside revegetation is a complex process, involving many agencies and individuals. A single revegetation specialist should be appointed to coordinate the planning, implementing, and monitoring/adaptive management of the revegetation aspects of the road project. You may enlist specialists from other natural resource disciplines to help with the revegetation planning so that expertise in botany, soil science, engineering, hydrology, wildlife biology, geology, and ecology is available for the project as necessary. You should be the coordinator of the technical and organizational aspects of the revegetation project, as well as the contact between revegetation efforts and the other aspects of road planning and construction.

2.2.1 Initiate Recordkeeping

When initiating a project, it is important to set up a good system for keeping records and documenting the progress. Starting a diary with regular entries of meetings and site visits is a good, basic start. As the project progresses, narratives, data, photos, contracts, specifications, and other information will need to be organized and stored. The diary can begin to serve as a case history for the project. The information will be invaluable when implementing and later assessing the project. For now, start a folder in the computer (to include all e-mails and electronic documents) and a folder in the filing system for hardcopies, plan drafts, notes, and a daily journal.

2.2.2 Identify Cooperators and Agencies: Who is Involved?

The process for road development will vary depending on the location of the road, which road-related programs and agencies are involved, and the complexity of the project. Interagency cooperation will almost always be part of the process. You must identify the agencies and individuals involved in the road construction project and their respective roles and responsibilities. It is especially important to identify: 1) who is the land owning agency, 2) who maintains the road, 3) who will be carrying out the road construction project, and 4) who is funding the project. All agencies and individuals involved have the responsibility to abide by rules and regulations as they work with the road.

2.2.3 Define Cooperator Processes, Timelines, and Milestones

Once you have identified the cooperators, you need to understand their processes, timelines, and milestones so that you can be involved with the right people at the right time. The timing, responsibilities, and, most important, processes associated with each agency will vary. While this may seem complicated, many agencies have a procedural manual that describes how a project is carried out from conception to completion, defining the timelines, milestones, roles and responsibilities, terminology, and how funding works. Locate these documents and agency manuals and use them. Initial meetings are also an ideal time to clarify these processes, when you first begin working with agency personnel.

Each agency has certain approvals and procedural activities, including some that involve fulfilling environmental regulations. You need to define these activities and determine how your work fits with them. The steps in the approval process are often important milestones for the agency, and must be understood so that you can be part of decisions while there is still room for your input. Defining appropriate roles is essential so that you can coordinate with the proper people, follow protocols, and avoid duplicating efforts.

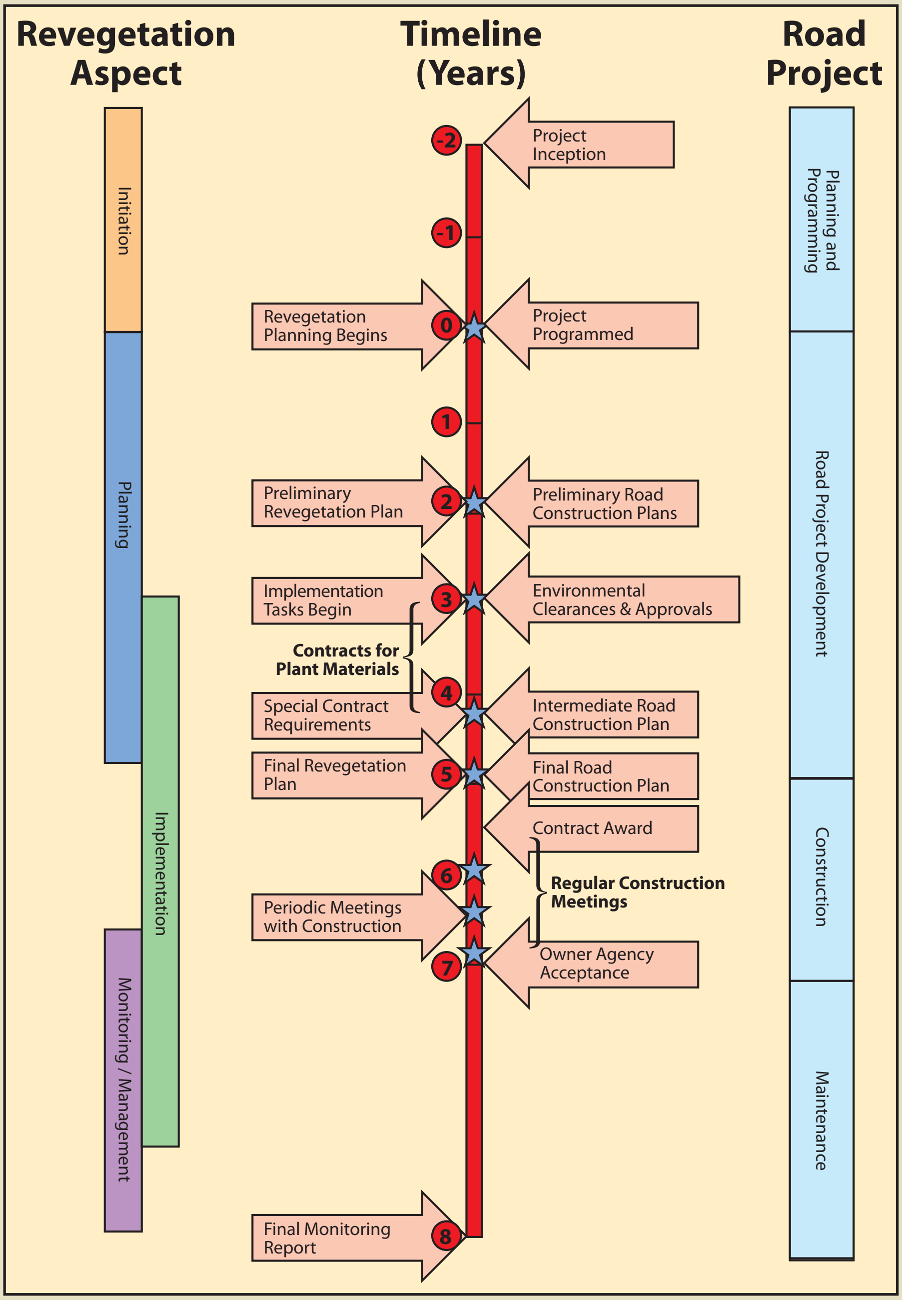
Many variables affect the overall timelines from inception to construction. Timelines vary depending on the complexity of the project, the amount of controversy involved, and the availability of funds. Some projects take less than two years, while some can take over ten years. In all cases, the earlier you can get involved in the process, the better opportunities you will have to develop your plan and acquire the materials and support you need. This chapter, Figure 2.1, the agency procedural manuals, and your contacts within agencies can help you develop your own schedule and contact list specific to your project. Reviewing Figure 2.1 with the assigned road project engineer and discussing milestones, timelines, procedures, budgets, and roles is an effective approach to getting yourself oriented to the complex process of road development.

2.2.4 Define Objectives: What is the Project Trying to Accomplish?

Once you understand the agencies and processes for each phase of the project, you need to understand how your work relates to the overall objectives of the project. Objectives can be found in the programming documents that originally identified the need for the project. These objectives often center around improving safety or updating the road infrastructure. Phase One of the planning process (See Chapter 4) describes how to identify the objectives of the road project and translate them into specific goals for revegetation.

Environmental protection and maximizing the ability of the roadside to regenerate native vegetation will be one goal. The revegetation specialist should be involved when disturbances to soil and vegetation are planned. You are the key link to understanding the potential disturbances that might be caused and how to best minimize or mitigate them. Your input can help planners because you will know what types of disturbances can be feasibly revegetated with native plants. If a disturbance to soil and vegetation will not allow for revegetation, alternatives to that type of disturbance will need to be considered. Your input is crucial for assessing potential strategies and alternatives. The project objectives also help you determine the types of native vegetation that are most appropriate for your work. Are you working in a wildlife corridor? Is it a scenic drive? Is it an ecologically sensitive area with more intensive recovery needed? Are the slopes very steep?

Figure 2.1 *– Coordinating revegetation with the larger processes of road construction is essential. While the timelines and agencies involved will vary, this figure illustrates some of the key opportunities for communication and integration.*



Recognize that safety, efficiency, and protecting and enhancing environmental health are all important priorities in road projects. While safety concerns may at times limit what is appropriate in roadside revegetation (e.g., tall trees along a roadside may be a desirable choice environmentally, but not from a safety or visibility standpoint), these concerns should not be viewed as an impediment to successfully revegetating roadsides. Instead, you simply need to be aware of how your revegetation work can complement safety objectives. Gain an understanding of safety issues, particularly regarding visibility and the ability of drivers to recover if they drive off the road and into the roadside area. (See discussion of how to define roadside revegetation zones in Chapter 4.)

2.3 THE PROCESS OF ROAD DEVELOPMENT

While each road agency will divide up and define tasks differently, in general the process of road development has four stages: 1) planning and programming, 2) project development, 3) construction, and 4) maintenance. There are many opportunities for integration at each of these phases. For revegetation work, the implementation phase often begins well before road construction begins (with the collection of plant materials for propagation). Revegetation efforts continue after road construction is completed. Figure 2.1 compares the revegetation process with the overall road development process, showing process steps where interface is crucial.

During road project development, a number of meetings will take place involving representatives from the agencies and interests involved with the project. During the planning phase, meetings usually take place at the preliminary, intermediate, and final stages of the road plan. Ideally, the revegetation specialist should attend all these meetings. This ensures that good communication takes place and that trust is built during the road planning process. Meetings also ensure that regulations and requirements are met and that proper channels are utilized to get the job done. During the construction phase, the construction engineer and other key players carrying out the project will probably meet on a weekly basis. Attending some of these meetings is valuable so you can both learn and contribute as the project progresses. Clarify with your key contacts (such as the construction engineer) the most appropriate times to attend meetings. Contractors, inspectors, and other stakeholders may also be at meetings or at the field site at any given time; clarify with your key contact the channels for you to communicate with other individuals who are involved with the project.

2.3.1 Road Planning and Programming

The process of deciding when to modify or build a section of road is often lengthy. Transportation planners identify and prioritize functional, structural, and safety issues regarding roads. If an issue is becoming problematic, alternatives to address it will be considered (FHWA 2005). Once it has been determined that a road will be modified or updated, a budget and schedule are created. At this point, the project has been "programmed" for a specific delivery year. This process usually identifies the following:

- Project purpose and need;
- Roles and responsibilities of partnering agencies;
- List of project alternatives established;
- Primary contacts for project;
- Preliminary project delivery schedule with milestones;
- Collection and analysis of traffic data (accident history, average daily traffic [ADT] volumes, etc.);
- Preliminary construction cost estimate; and
- Environmental concerns for the project (cultural and natural resource) and estimation of the affected environment (WFLHD 2005 p. 8).

A revegetation specialist will probably not be involved in a project until after it is programmed, although at times one might be called in to assess the feasibility of various alternatives.

Roadside Vegetation and Driver Safety

Greater safety for the traveling public is the primary objective of many road projects. As the revegetation specialist, you do not want to propose vegetation strategies that might make the roadway less safe. Integrating revegetation goals with safety goals requires an awareness of visibility issues, wildlife interactions, and other factors. Many road developers are interested in the concept of a "forgiving" roadside: a roadside environment that allows a driver to recover safely if they drive off the road into the roadside. Typically there will be a zone adjacent to the road where low grassy surfaces, or shrubs instead of trees, will be desirable for safety reasons. The roadside distance you need to consider to make a roadside forgiving depends on the speed limit of the highway and the traffic volume. If both of these are high, a forgiving roadside will be a safety priority.

2.3.2 Road Project Development

The road project development process begins after the project is programmed and ends when construction begins. Depending on environmental concerns and right-of-way issues, the project development process may take between one and five years.

The road project development phase usually has three sub-phases. These involve developing, analyzing, and considering approaches and alternatives to the project until a strategy and specifications of how to best proceed are shared in the final plan. The process usually involves:

- Preliminary (road construction plans 30% complete);
- Intermediate (road construction plans 50%-70% complete); and
- Final (road construction plans 70-100% complete, hand off to construction).

2.3.2.1 Preliminary Phase

The preliminary development phase involves collecting information and initiating contacts with parties who are interested in or affected by the road construction (local and adjacent landowners, resource agencies, regulatory agencies, and any other potentially affected parties). The preliminary phase is necessary to refine purpose and need, to develop a range of alternatives to address purpose and need, and to obtain the approvals and clearances to allow the project to proceed. This includes commitments for environmental mitigation. The preliminary phase takes the road construction plans to about 30% completion. Once approvals and clearances are obtained, funds can typically be committed to continue development of the project.

Usually the preliminary phase will include the development and identification of:

- Preliminary construction plans (usually drafts about 30% complete) of the proposed alternatives (plan/profile sheets, typical sections, major work items identified and located);
- Preliminary construction cost estimates for alternatives;
- Resource surveys (wetlands, archeological sites, and biological assessments);
- Preliminary construction schedule;
- Identification of impacts and mitigation;
- Environmental approvals and selection of alternatives for implementation; and
- List of contacts for the project.

For the revegetation specialist, the preliminary phase is a crucial one. This phase represents the best opportunity for input regarding issues associated with revegetation, including disturbances planned for existing soil and vegetation on the site. Significant features of the preliminary revegetation plan should be incorporated during this road planning phase. By the time of environmental approvals, the vegetative concepts and the necessary commitments of resources and funds should be integrated with the plan, as revegetation will be an important aspect of environmental protection and mitigation. The appropriate level of detail for the revegetation plan during the preliminary phase depends on the project. For the revegetation specialist, environmental guidelines may be predetermined by legislation that specifies goals for the project regarding issues of soil stabilization, percent native vegetative cover, and protection of water quality. The revegetation specialist must be aware of these guidelines, and design them into the final revegetation plan. Approvals are key milestones for the revegetation specialist regarding availability of funds to carry out site assessments and revegetation planning work including preliminary mapping and seed collections.

2.3.2.2 Intermediate Phase

The next phase of road development moves towards 50-70% completion of the road construction plans. This phase involves refining plans, obtaining rights-of-way and permits, and creating detailed plans and profile sheets. The intermediate set of plans will include major budget items and quantities, information pertaining to environmental concerns (such as erosion control plans), and major elements such as grading, drainage, and other issues defined. At the intermediate stage, the revegetation specialist should be far along in the development of the revegetation plan. Mitigating measures have been identified for impacted areas and contracts for seed and seedling production have begun. The intermediate set of road plans will include specifications for how the road project will be carried out. These specifications and contract requirements are key tools for the revegetation specialist.

2.3.2.2.1 Special Contract Requirements: A Key Tool for Revegetation

In every phase of road development, there are two key components: 1) plans (drawings) and 2) specifications (contract descriptions). The plan sheets are drawings, blueprint-like visual representations of the proposed work as described in Chapter 3. Specifications are standards, provisions, and requirements that each agency provides to contractors or employees to carry out the work. A "special contract requirement" is a type of specification. In general, special or standard specifications are written descriptions of intent, preferred methodology, timing, and standards for accomplishing the work. Standard specifications are uniformly carried out for most projects. Special requirements address context-sensitive concerns for a particular project. Special contract requirements are modifications of existing specifications found within the agency manual, or newly written specifications that are designed to address special concerns not adequately addressed in the standard contract specifications. For example, a standard specification may exist for chipping woody debris; however, the standard specification does not address size requirements of the chipped material. On your project, you may require a uniform size of material that should be shredded and screened, rather than chipped, to create optimal mulch for the project. To meet this requirement, you can create a specification about required size (such as three inches or less in diameter) and processing needs (such as shredded and screened rather than chipped). Careful research is often needed to adequately develop and describe a special contract requirement, but it is essential in order to achieve the desired results in the field. In the future, generically applicable special contract requirements may become adopted as standard requirements if they come to be utilized on most projects.

Special contract requirements are an important tool for revegetation specialists to communicate special expectations with contractors and to set standards for performance. You can specify to contractors what the requirements are, and how requirements might be met, measured, and paid for. Special contract requirements will be part of the contract, not an afterthought. By the intermediate phase, attention should have been given to modifying or creating contract

Example of an Environmental Regulation Requirement

"Final Stabilization" Regulation (adapted from EPA 2006)

"Final stabilization" means that all soil disturbing activities at the site have been completed and that a uniform perennial vegetative cover with a density of at least 70% of the native background vegetative cover for the area has been established on all unpaved areas and areas not covered by permanent structures, or equivalent permanent stabilization measures.

"Final Stabilization" (adapted from EPA 2006) means that:

1) All soil disturbing activities at the site have been completed and either of the two following criteria are met:
    a) a uniform (i.e., evenly distributed, without large bare areas) perennial vegetative cover with a density of 70% of the native background vegetative cover for the area has been established on all unpaved areas and areas not covered by permanent structures, or
    b) equivalent permanent stabilization measures (such as the use of riprap, gabions, or geotextiles) have been employed.
2) When background native vegetation will cover less than 100% of the ground (e.g., arid areas, beaches), the 70% coverage criteria is adjusted as follows: if the native vegetation covers 50% of the ground, 70% of 50% (0.70 X 0.50 = 0.35) would require 35% total cover for final stabilization. On a beach with no natural vegetation, no stabilization is required.
3) In arid and semi-arid areas only, all soil disturbing activities at the site have been completed and both of the following criteria have been met:
    a) Temporary erosion control measures (e.g., degradable rolled erosion control product) are selected, designed, and installed along with an appropriate seed base to provide erosion control for at least three years without active maintenance, and
    b) The temporary erosion control measures are selected, designed, and installed to achieve 70% vegetative coverage within three years.

requirements to meet the revegetation needs of the project. When specifications are not available for what you are trying to achieve, you need to be able to describe the work in terms of where, when, what needs to happen. Special contract requirements are included in the final contract for the road construction project.

2.3.2.3 Final Phase

The final set of road plans will include the design elements of the Revegetation Plan, as well as all the details for road construction. Plan sheets and contract specifications will be fully developed. Final cost estimates will be provided along with a comprehensive schedule. The work of the revegetation specialist in developing the revegetation plan, as well as efforts to reduce the construction footprint and protect native vegetation on the project site, will be an integral part of the road construction plan. At this point, finalizing the revegetation plan will be necessary. It is also time to coordinate with contractors and agencies in order to time availability of plants with outplanting windows.

2.3.3 Construction

Following project development, the construction phase begins. Road construction can take one to three years. Sometimes there is a formal milestone when the project is handed off to construction personnel. If so, the construction engineer becomes an essential contact for the revegetation specialist, who may attend some of the weekly meetings that will take place during road construction. The construction phase of a road is completed when there is a formal acceptance of the road by the road owning agency. For the revegetation specialist, implementation and monitoring phases of revegetation may begin before road construction (with ordering plant materials, etc.) and continue following completion of construction.

2.3.4 Maintenance

Following construction of the road, the work of the revegetation specialist will usually continue for an additional one to three years until the revegetation is fully implemented. Also, the activities centered on monitoring and adaptive management of the establishing vegetation will continue to take place. These types of activities may continue for up to five years after the road construction is complete. The submission of a final monitoring report is the milestone marking the end of the revegetation specialist's efforts on the project. Coordination with the road owning agency and the individuals who carry out road maintenance will be essential to ensure that native vegetation continues to thrive on the site. For example, the agency taking ownership, often the county, could have maintenance methods that may ultimately undo portions of the revegetation, such as blanket herbicide use as standard practice along roadsides. It is essential to check what maintenance methods are utilized and to coordinate efforts to ensure that management is appropriate for the native vegetation. The transportation agencies will continue to monitor the road to ensure that the problem that led to the road modification (infrastructure decay, safety issues, etc.) was adequately addressed by the project.

2.4 NEXT STEPS

Effective integration of revegetation requires an understanding of the key agencies, programs, and relationships involved, as well as how decision processes work to move a road project forward. Successful navigation of the decision processes requires not only technical skills, but an ability to cultivate relationships and get involved at the appropriate times and with the appropriate people. Road construction, alteration, or decommissioning involves a variety of land management agencies, programs, and regulations. Understanding the procedures, timelines, and organizational structure of the agencies involved in a road project is essential in order for the revegetation specialist to contribute effectively throughout the process of road planning and construction. Attending meetings and coordinating with key contacts within agencies are important tasks. The revegetation specialist is usually involved at the beginning when the project is programmed, and continuing through and following construction. It is important to note (as illustrated on the timeline) that the implementation phase of revegetation begins while the overall project development process is still underway. Waiting until construction begins is not feasible because locally-adapted native plant materials almost always must be propagated in advance. The next step is to acquire the engineering plans for the road and to begin designing for revegetation.

3 INITIATION PART TWO: ROAD PLANS AND TERMINOLOGY

3.1 INTRODUCTION

Road construction often results in the drastic alteration of the surrounding landscape. In order to define what these alterations will be and how to best plan revegetation, you need to be able to interpret road construction plans and terminology. This will enable you to define the current site conditions and to visualize the future condition of the site following road construction. This chapter explains how to read and interpret:

- Plan views,
- Profile views,
- Cross-section views,
- Typical views, and
- Summary of quantities tables.

The chapter then explains how to use these engineering views for revegetation planning, including determining the vegetation zones that begin where the pavement ends. A glossary with illustrations is provided in order to understand technical concepts and terminology for effective communication with others involved in road design and construction.

3.2 READING PLANS

The plan consists of construction drawings and specifications for each section of road. The four most common views of plans for the revegetation specialist are plan views, cross-section views, profile views, and typical views. Each of these is defined in Table 3.1. Examples and guides for interpreting each of these views are provided below. Each engineering plan you receive will include a legend defining both abbreviations and symbols used throughout; learn to read these. Another invaluable component of the engineering plan is the tabulation of plan quantities table.

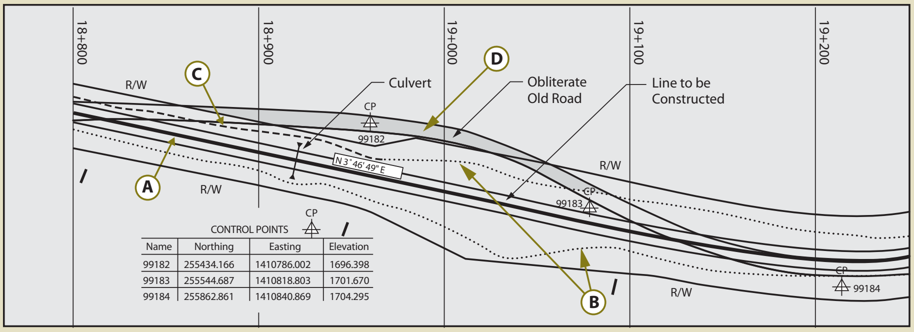
***Table 3.1** – Definitions of Views (Keller and Sherar 2003)*

Plan View	A drawing depicting a section of the road from a bird's eye view.
Profile View	A drawing depicting the vertical plane along the longitudinal centerline of the road, expressed in elevation or gradient.
Cross-section View	A drawing depicting a section of the road viewed vertically, as if cut across the width of the road.
Typical View	A drawing depicting features of a particular design, installation, construction or methodology.

3.2.1 Plan View

The plan view shows the existing and proposed road locations from a bird's eye view. The proposed road is usually designated with solid lines (Figure 3.1 A). The solid centerline (of the road to be constructed) is divided into 100 meter sections (large ticks), with 20 meter subdivisions also designated (small ticks – not shown). Each 20 meter division is called a station, representing a discrete, surveyed, and identifiable point within the road corridor. Each station is identified with a unique number that indicates its distance from the beginning of the project. For example, the station 19+000 indicates this point is 19,000 meters from the start of the project; 19+040 meters indicates this point is 19,040 meters from the start. This short-hand identifier is also used to indicate the placement of road-related infrastructure, such as culverts, the beginning and end of guard-rail construction, or the placement of a sign. In the field, stations are identifiable as vertically aligned numbers written on wooden stakes and driven into the ground, facing the roadway. Not only do the stations provide locations, they help to locate revegetation units. The plans also show the top of the cut slope (Figure 3.1 B, dotted

Figure 3.1 *– Example plan view.*



Name	Northing	Easting	Elevation
99182	255434.166	1410786.002	1696.398
99183	255544.687	1410818.803	1701.670
99184	255862.861	1410840.869	1704.295

line), bottom of the fill slopes (Figure 3.1 C, dashed lines), and the location of the original road (Figure 3.1 D, shaded area). In this example, the original road will be obliterated.

3.2.2 Profile View

The profile view is a trace of a vertical plane intersecting a particular surface of the proposed road construction (Figure 3.2 E). It corresponds to the longitudinal centerline of the road bed in the plans. Profile grade means either elevation or gradient of the trace, depending on the context. The trace of the existing road is shown as a dashed line (Figure 3.2 F) and a dotted line (Figure 3.2 G). A vertical scale provides useful information about the profile of construction grades throughout the project. This view shows where the proposed road will be lower than the existing road (Figure 3.2 H) and areas where it will be higher (Figure 3.2 I). Where the planned road is lower, material will usually be removed and used in areas needing fill. Additional information is often displayed adjacent to and locatable by the station numbers, such as volumes of excavation and embankment work, guard-rail placement, or wall placements.

3.2.3 Cross-Section View

Cross-sections are views of the slopes perpendicular to the direction of the road. They display a vertical section of the ground or structure at right angles to the centerline or baseline of the roadway. Depending on the length and topographic complexity of the road, there can be hundreds of cross-sections. Each cross-section is referenced back to a station. For example, the cross-section shown in Figure 3.3A depicts the slope at Station 18+940. It shows the proposed road (Figure 3.3 J), and the natural ground line as a dotted line (Figure 3.3 K). This section will have material brought in and placed as fill (Figure 3.3 L). The cross-section in Figure 3.3B shows a through cut at 19+000. Material will be removed from the natural ground line (Figure 3.3 K) to the proposed ground line – solid line (Figure 3.3 M).

Cross-section and plan views are used together to view the proposed road three-dimensionally. From these views, a more detailed revegetation plan can be developed. Each cross-section can be reviewed and a set of revegetation criteria can be developed for similar cross-sections throughout the project.

Figure 3.2 *– Example profile view.*

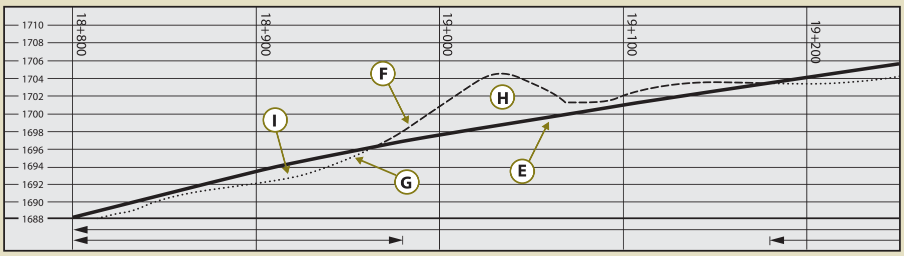


Figure 3.3A – *First example cross-section.*

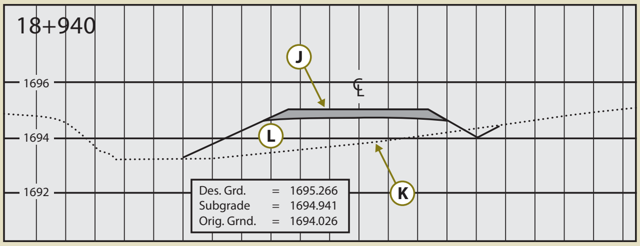
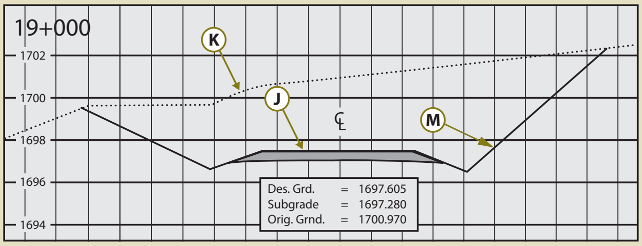


Figure 3.3B – *Second example cross-section.*



Cross-sections provide the revegetation specialist a means to determine slope steepness. Cross-sections show the proposed slope gradients for cut and fill slopes. Slope notation is expressed as vertical over horizontal (vertical:horizontal). When slopes are flatter than 1:1 (45° or 100%), the slope is expressed as the ratio of one unit vertical to the number of units horizontal. For slopes steeper than 1:1, the slope ratio is expressed as number of units vertical to one unit horizontal. To avoid confusion, it is wise to notate the ratio by indicating the vertical and horizontal, for example 1V:2H, and to think in terms of rise over run (See Section 5.6.6.1).

3.2.4 Typical Views

Typical views graphically illustrate the design or construction details of the structures or other components that will be encountered in the road project. They can cover such structures as retaining walls, road surfaces, guardrails, ditch lines, plant installation, etc. They may be shown in profile, cross-section, or plan views. Like special contract requirements (See Chapter 2), typical views are useful in helping communicate a new or modified approach to an existing methodology or construction technique. The two example typical views in Figure 3.4 are related to plant placement and installation.

3.2.5 Summary of Quantities Table

Tabulation of plan quantities list quantities, types of materials, and performance specifications. For example, when working on federal or state projects, standardized specifications for construction are invaluable. The FHWA handbook: *Standard Specifications for Construction of Roads and Bridges on Federal Highway Projects*, is cited as “FP-03,” indicating “Federal Project” Standard Specifications issued in 2003. The state departments of transportation have analogous manuals as well. Tabulation of plan quantities references not only the particular item specification number in the FP manual, but also the station number(s) of the planned work. Information of interest for the revegetation specialist includes the number of hectares of clearing and grubbing, hectares of obliterated roads listed by station, and the number of cubic meters of wood mulch to be produced. The summary of quantities table provides a single table summarizing all tabulation of plan quantity tables located throughout the plan. It generally does not include station numbers. Learn how to locate and read these tables.

Figure 3.4A – *Example typical view.*

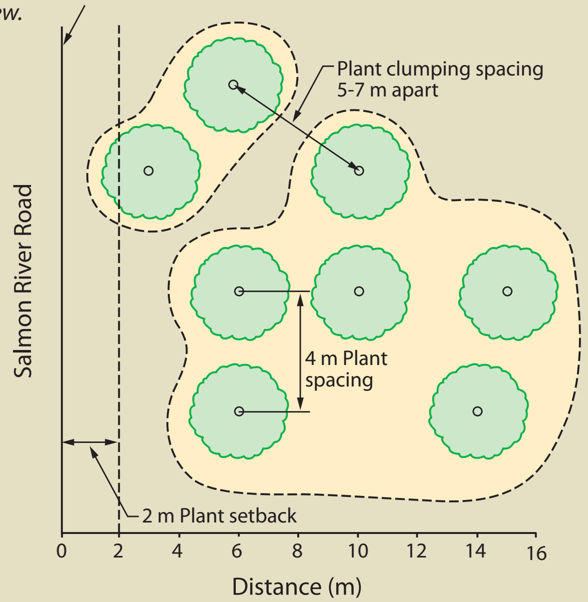
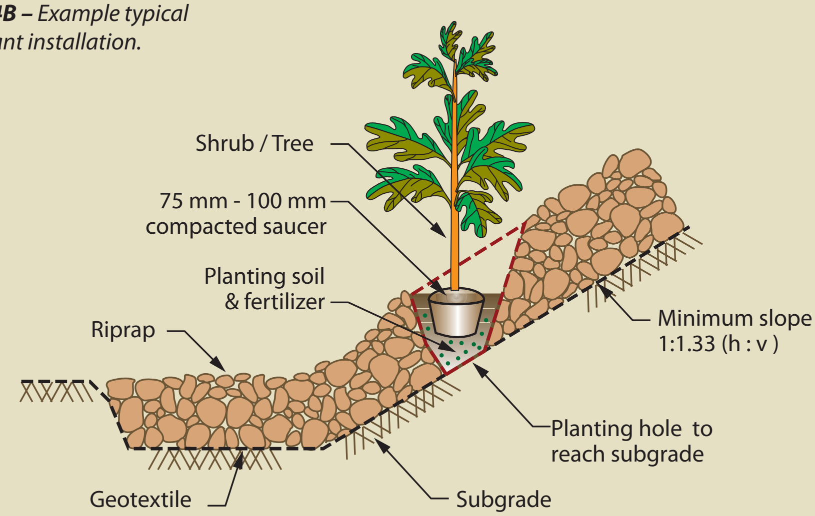


Figure 3.4B – *Example typical view of plant installation.*



3.3 INTERPRETING ENGINEERING VIEWS FOR REVEGETATION PLANNING

Road construction, management, and safety concerns result in distinct revegetation zones along roadsides. Properly interpreting plans helps define where these zones may be and what types of vegetation may be established. While the sizes and characteristics will vary, the zones which parallel the road can be grouped into four categories. Zone 1 begins immediately adjacent to the road surface (black top) and includes the road shoulder (compacted gravel, coarse subsoil, etc.), the bottom of the drainage ditch, and portions of cut and fill slopes. This first zone is generally considered to be up to 10 feet (3 meters) from the pavement edge and is often barren of vegetation due in part to herbicide application, road salts, frequent ditch cleaning, and/or mowing. Prior to revegetating Zone 1, determine how close local, state, and federal road managing agencies will allow vegetation to be established next to the road. Zone 2 begins at roughly 10 feet (3 meters) from the pavement edge and continues laterally to about 30 feet (10 meters). This zone may begin at the ditch bottom or at some point on a cut or fill slope, and may continue to the limit of the construction zone. Within Zone 2, grasses and forbs can thrive, but larger forbs, shrubs, and trees usually are not planted or encouraged due to safety, maintenance, and visibility issues. Beyond 30 to 50 feet (about 10 to 16 meters) from the pavement edge, Zone 3 begins in which larger forbs and shrubs can be planted. Past about 75 feet (25 meters) from the pavement edge, Zone 4 begins with largely unrestricted revegetation potential. Understanding these zones is necessary to coordinate revegetation with road management practices and safety considerations (Forman and others 2003).

To define the zones and begin to interpret engineering plans for revegetation work, information from plan sheets and quantity tabulations is applied to the plan map as shown in Figure 3.5A. Each area can be considered a revegetation unit or subunit. An estimate of the area in each of these units can be calculated and used in determining how many seedlings or pounds of seeds will be needed. These criteria can be graphically displayed on a typical cross-section (Figure 3.5B). On this cross-section, the criteria can be expressed as follows: from 7 to 19 m, grasses/forbs will be hydroseeded; from 19 to 31 m, shrubs will be planted; and on obliterated roads, trees will be planted. The slopes given in cross-sections can help define the types of revegetation methods available.

3.4 UNDERSTANDING TECHNICAL CONCEPTS AND TERMINOLOGY

The ability to understand and utilize the technical concepts and terminology that road engineers use is essential to revegetation planning. Not only is this invaluable in understanding what is happening on the project site, but it is necessary in order to describe where revegetation efforts will be carried out. The section below introduces key technical concepts and terminology.

3.5 NEXT STEPS

The ability to read and understand construction plans and utilize road-related terminology will be helpful in all aspects of roadside revegetation. This ability enables the revegetation specialist to contribute effectively to road design and construction processes, as well as to communicate revegetation needs and goals to others involved with the project. Following the initiation phase is the four-step planning phase to create a revegetation plan.

***Figure 3.5A** – Interpretation of plan view showing revegetation zones.*

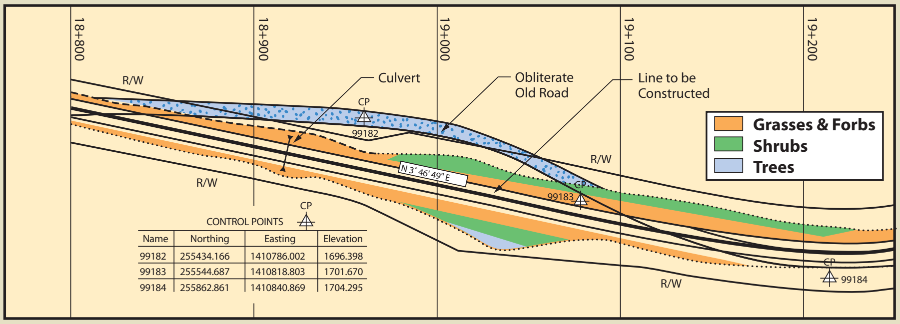
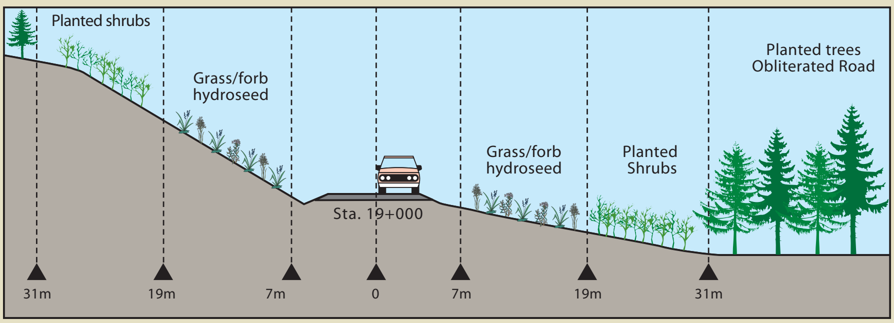


***Figure 3.5B** – Cross-section showing revegetation zones as interpreted from engineering plans.*



Road Concepts and Terminology

(Adapted from: Keller and Sherar 2003)

Road Components

***Figure 3.6** – Terms used to define roads.*

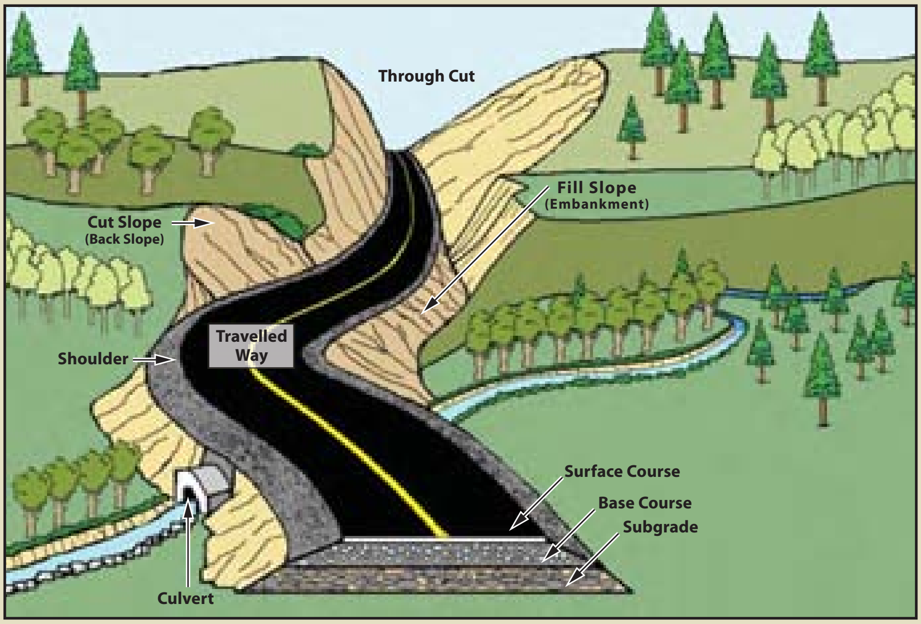
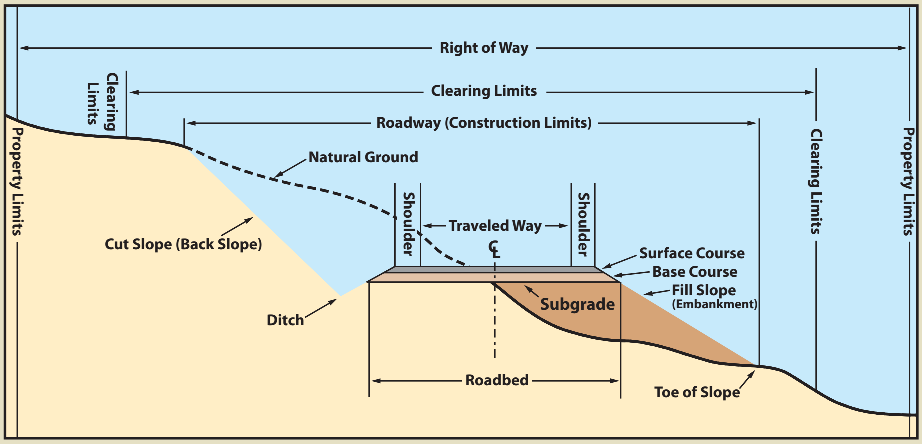


***Figure 3.7** – Terms used to define roads: cross-section.*



Berm – A ridge of rock, soil, or asphalt, typically along the outside edge of the road shoulder, used to control surface water. It directs surface runoff to specific locations where water can be removed from the road surface without causing erosion.

Buttress – A structure designed to resist lateral forces. It is typically constructed of large riprap rock, gabions, or well-drained soil to support the toe of a slope in an unstable area.

Cross-Section – A drawing depicting a section of the road sliced across the whole width of the road. Can also apply to a stream, slope, or slide.

Cut Slope (Back Slope or Cut Bank) – The artificial face or slope cut into soil or rock along the inside edge of the road.

Cut-and-fill – A method of road construction in which a road is built by cutting into the hillside and spreading the spoil materials in adjacent low spots and as compacted or side-cast fill slope material along the route. A "balanced cut-and-fill" utilizes all of the "cut" material to generate the "fill." In a balanced cut-and-fill design there is no excess waste material and there is no need for hauling additional fill material. Thus cost is minimized.

Ditch (Side Drain) – A channel or shallow canal along the road intended to collect water from the road and adjacent land for transport to a suitable point of disposal. It is commonly along the inside edge of the road. It also can be along the outside edge or along both sides of the road.

End Haul – The removal and transportation of excavated material off-site to a stable waste area (rather than placing the fill material near the location of excavation).

Fill Slope (Embankment Slope) – The inclined slope extending from the outside edge of the road shoulder to the toe (bottom) of the fill. This is the surface formed when excavated material is placed on a prepared ground surface to construct the road subgrade and roadbed template.

Grade (Gradient) – The slope of the road along its alignment. This slope is expressed as a percentage and is the ratio of elevation change compared to distance traveled. For example, a +4% grade indicates a gain of 4 units of measure in elevation for every 100 units of measure traveled.

Natural Ground (Original Ground Level) – The natural ground surface of the terrain that existed prior to disturbance and/or road construction.

Plan View (Map View) – View seen when looking from the sky towards the ground (bird's-eye view).

Reinforced Fill – A fill that has been provided with tensile reinforcement through frictional contact with the surrounding soil for the purpose of greater stability and load carrying capacity. Reinforced fills are comprised of soil or rock material placed in layers with reinforcing elements to form slopes, walls, embankments, dams, or other structures. The reinforcing elements range from simple vegetation to specialized products such as steel strips, steel grids, polymeric geogrids, and geotextiles.

Retaining Structure – A structure designed to resist the lateral displacement of soil, water, or any other type of material. It is commonly used to support a roadway or gain road width on steep terrain. They are often constructed of gabions, reinforced concrete, timber cribs, or mechanically-stabilized earth.

Right-of-Way (ROW) – The strip of land over which facilities such as roads, railroads, or power lines are built. Legally, it is an easement that grants the right to pass over the land of another.

Road Center Line – An imaginary line that runs longitudinally along the center of the road.

Roadbed – Width of the road used by vehicles, including the shoulders, measured at the top of subgrade.

Roadway (Construction Limits or Formation Width) – Total horizontal width of land affected by the construction of the road, from the top of cut slope to the toe of fill or graded area.

Side-Cast Fill – Excavated material pushed on a prepared or unprepared slope next to the excavation to construct the roadbed. The material is usually not compacted.

Shoulder – The paved or unpaved strip along the edge of the traveled way of the road. An inside shoulder is adjacent to the cut slope. An outside shoulder is adjacent to an embankment slope.

Traveled Way (Carriageway) – That portion of the road constructed for use by moving vehicles including traffic lanes and turnouts (excluding shoulders).

Through Cut – A road cut through a hill slope or, more commonly, a ridge, in which there is a cut slope on both sides of the road.

Through Fill – Opposite of a through cut, a through fill is a segment of road that is entirely composed of fill material, with fill slopes on both sides of the road.

Road Structural Section and Materials

Borrow Pit (Borrow Site) – An area where excavation takes place to produce materials for earthwork, such as a fill material for embankments. It is typically a small area used to mine sand, gravel, rock, or soil without further processing.

Quarry – A site where stone, riprap, aggregate, and other construction materials are extracted. The material often has to be excavated with ripping or blasting, and the material typically needs to be processed by crushing or screening to produce the desired gradation of aggregate.

Surface Drainage

Armor – Rocks or other material placed on headwalls, on soil, or in ditches to prevent water from eroding and undercutting or scouring the soil.

Drainage Structure – A structure installed to control, divert, or move water off or across a road, including but not limited to culverts, bridges, ditch drains, fords, and rolling dips.

French Drain (Underdrain) – A buried trench, filled with coarse aggregate, and typically placed in the ditch line along the road, which acts to drain subsurface water from a wet area and discharge it to a safe and stable location. French drains may use variable sizes of rock but do not have a drain pipe in the bottom of the trench.

Inslope – The inside cross-slope of a road subgrade or surface, typically expressed as a percentage. Inslope is used to facilitate the draining of water from a road surface to an inside ditch. An insloped road has the highest point on the outside edge of the road and slopes downward to the ditch at the toe of the cut slope, along the inside edge of road.

Outslope – The outside cross-slope of a road subgrade or surface, typically expressed as a percentage. Outslope is used to facilitate the draining of water from a road directly off the outside edge of the road. An outsloped road has the highest point on the uphill or inside of the road and slopes down to the outside edge of the road and the fill slope.

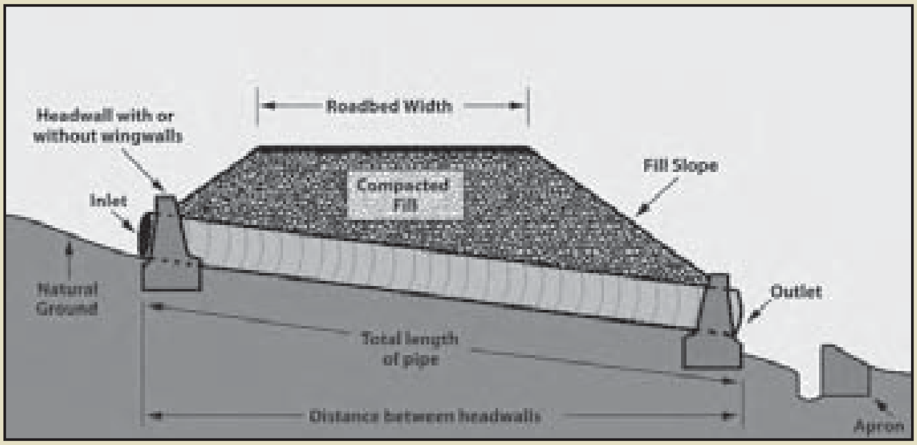
Riprap – Well-graded, durable, large rock, ideally with fractured surfaces, sized to resist scour or movement by water and installed to prevent erosion of native soil material.

Culverts and Drainage Crossings

Catch Basin – The excavated or constructed basin at the inlet of a culvert cross-drain pipe, used to store water and direct it into the culvert pipe.

Culvert – A drainage pipe, usually made of metal, concrete, or plastic, set beneath the road surface to move water from the inside of the road to the outside of the road, or under the road. Culverts are used to drain ditches, springs, and streams that cross the road. The invert is the floor or the bottom of the structure at its entrance.

Figure 3.8 – *Culvert components.*



Headwall – A concrete, gabion, masonry, or timber wall built around the inlet or outlet of a drainage pipe or structure to increase inlet flow capacity, reduce risk of debris damage, retain the fill material, and minimize scour around the structure.

Inlet – The opening in a drainage structure or pipe where the water first enters the structure.

Outlet – The opening in a drainage structure or pipe where the water leaves the structure. The outlet is usually lower than the inlet to ensure that water flows through the structure.

Miscellaneous Terms

Angle of Repose – The maximum slope or angle at which a granular material, such as loose rock or soil, will stand and remain stable.

Gabions – Baskets (usually made of wire) filled with rocks (or broken pieces of concrete) about 10-20 cm in size, used for building erosion control structures, weirs, bank protection, or retaining structures.

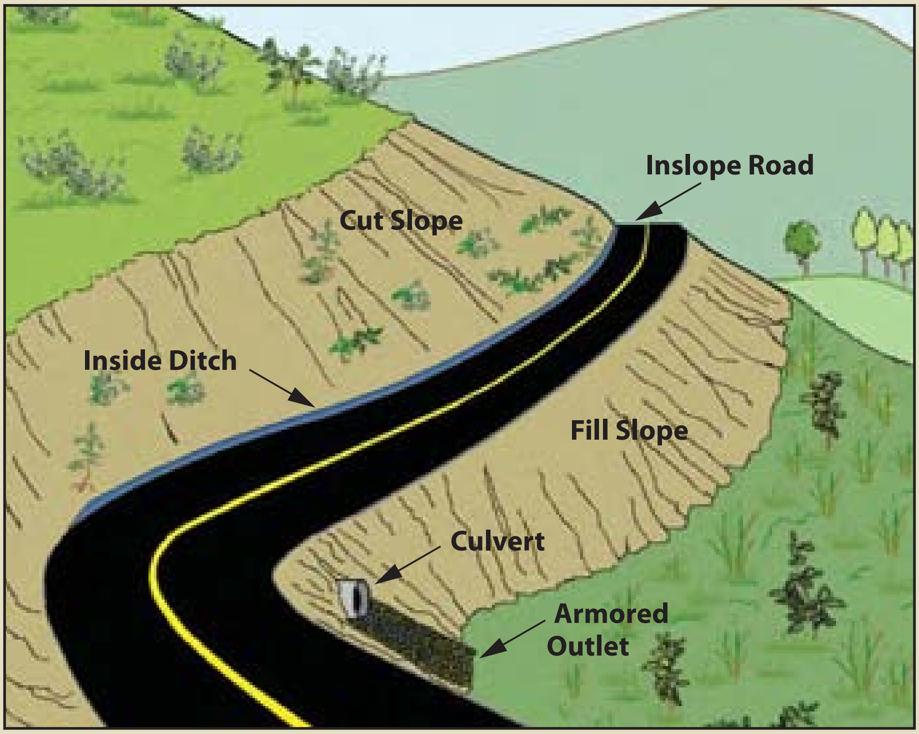
Road Decommissioning – Permanently closing a road through techniques that include blocking the entrance, scattering limbs and brush on the roadbed, replanting vegetation, adding waterbars, removing fills and culverts, or reestablishing natural drainage patterns. The basic road shape, or template, is still in place. The end result is to terminate the function of the road and mitigate the adverse environmental impacts of the road.

Road Obliteration – A form of road closure that refills cut areas, removes fills and drainage structures, restores natural contours, revegetates the area, and ultimately attempts to restore the natural ground shape and condition. Most adverse environmental impacts of the road are eliminated.

Silt Fence – A temporary barrier used to intercept sediment-laden runoff from slopes. It is typically made of porous geotextile material.

Streamside Management Zone (SMZ) – The land, together with the associated vegetation, immediately in contact with the stream and sufficiently close to have a major influence on the total ecological character and function of the stream. It is a buffer area along a stream where activities are limited or prohibited.

Figure 3.9 *– Terms used to describe road slopes.*



4 PLANNING PHASE ONE: ORIENT

4.1 INTRODUCTION

Careful planning is essential to the success of any roadside revegetation project. In this phase, the revegetation specialist will be oriented to the specifics of the project, and will perform the following tasks:

- Determine revegetation objectives,
- Define revegetation units,
- Select reference sites, and
- Define the desired future condition.

It is important to first define the overall project objectives and translate them into what this will mean for revegetating the site. The objectives of revegetation are usually to initiate and/or accelerate the process of natural succession along the roadside and establish native plant communities that can sustain themselves without intensive, ongoing human intervention (Brown and Amacher 1999; SER 2004). Revegetation objectives are usually stated in broad, general terms addressing revegetation, soil stabilization, beautification, and other goals.

Once overall project and revegetation objectives are defined, the second step is orientation to the project site. The site should be mapped and revegetation units delineated. Revegetation units are distinct areas within the project that will have different management strategies. A project consisting of sites with little variation in topography, soils, vegetation types, rainfall, and so on may comprise a single revegetation unit. Most project sites, however, contain different soils, climate, and vegetation types, requiring the delineation of a number of distinct revegetation units.

The third step is to identify reference sites for each of the revegetation units. Reference sites serve as models for revegetation planning, and later for monitoring and evaluating project success (SER 2004). Reference sites are natural or revegetated areas that demonstrate a desirable trajectory of recovery. For roadside revegetation purposes, suitable reference sites have undergone some disturbance, but have revegetated over time with functioning communities of native plants. Reference sites illustrate desirable developmental pathways for the revegetation units.

***Table 4.1** – Phase one of planning involves four steps.*

Activity	Definition
Step 1. Determine project objectives	Describe the general purpose and goals of the project as determined by societal, ecological, and transportation needs; environmental regulations; and other factors.
Step 2. Define and map revegetation units	Classify areas within the project site that are similar enough to be appropriate for similar strategies and treatments. Homogenous sites will have only a few units; sites with greater diversity (different soil types, microclimates, vegetation types, management needs, etc.) will have more revegetation units. Each unit should be distinct in terms of ecology, management requirements, or both.
Step 3. Select reference sites for each revegetation unit	Locate natural or revegetated areas that will serve as models for desirable recovery of native plant communities. One or more reference sites are identified for each revegetation unit in the project area.
Step 4. Specify desired future conditions for each revegetation unit	Create specific, measurable goals for each revegetation unit, usually defined in terms of the percentage of vegetative cover, ground cover, species composition, and so on.

The fourth and final step is to define the desired future conditions (DFCs) for each revegetation unit. Incorporating information from reference sites and other data, DFCs specify guidelines (percentage of vegetative cover, plant species, etc.) appropriate for each revegetation unit in the project area.

4.2 STEP ONE – DEFINE REVEGETATION OBJECTIVES

Overall project objectives drive the modification and construction of roads. As discussed in Chapter 2, the project objectives usually involve goals of improving safety and efficiency, as well as environmental health. Overall project objectives are translated into revegetation objectives. Revegetation objectives are the foundation of all revegetation efforts. It is important to develop a clear set of revegetation objectives early in the planning phase. When these objectives are understood and expectations are clear, the development and implementation of a revegetation plan is easier and more successful. Most roadside revegetation projects share the common objective of initiating and/or accelerating the process of natural succession near the roadside in order to establish self-sustaining native plant communities (Brown and Amacher 1999; Clewell and others 2005). This objective usually reflects larger project goals, stated in terms of protecting soil and water resources, enhancing beauty, and improving safety and function while protecting environmental health. Later in the planning process, these general objectives will be pursued through specific goals (stated as DFCs) that can be used to evaluate the revegetation project. Table 4.2 defines some terms commonly used in defining revegetation objectives. Clarifying whether the overall goal is reclamation or restoration, for example, is an essential distinction for defining revegetation objectives.

Table 4.3 illustrates some of the most common road-related revegetation objectives as they relate to societal goals. Most revegetation projects state several objectives to address both short-term and long-term outcomes. For example, short-term, immediate revegetation objectives on most projects include erosion control and water quality protection through mulch and vegetative cover. Long-term revegetation objectives might include exclusion of invasive weeds, visual enhancement, and establishment of healthy native plant communities through soil restoration. While short-term objectives might rely on quick-growing ground covers such as grasses and forbs, long-term objectives are often broadened to include such revegetation treatments as planting deep-rooted tree and shrub seedlings to stabilize roadsides, creating visual screens, and/or supporting sustained plant community development.

Revegetation objectives are often developed by the revegetation specialist and design team and are supported by, or integrated with, public documents such as Environmental Assessments or Environmental Impact Statements. The objectives sometimes originate from a state or federal agency, motivated by environmental concerns and regulations regarding water quality, erosion control, and vegetation establishment. At this stage, revegetation objectives will be broad and general. As the project evolves, objectives are translated into more precise and

***Table 4.2** – Terms Used in Defining Revegetation Objectives (adapted from Allen and others 1997).*

Revegetation	The goal is to reestablish vegetation on a disturbed site. This is a general term that may refer to restoration, reclamation, and rehabilitation.
Restoration	This is the recreation of the structure and function of the plant community identical to that which existed before disturbance. Restoration's goal is conservation, with the intention of maximizing biodiversity and functioning.
Reclamation	This is the recreation of a site that is designed to be habitable for the same or similar species that existed prior to disturbance. Reclamation differs from restoration in that species diversity is lower and projects do not recreate identical structure and function to that before disturbance. However, a goal of long term stability with minimum input is implied.
Rehabilitation	This process creates alternative ecosystems that have a different structure and function from the pre-disturbance community, such as a park, pasture, or silvicultural planting.

Table 4.3 – Common Road Revegetation Objectives.

Revegetation Objective	Function of Native Plants
Erosion Control	Controlling surface erosion and thereby protecting soil and water quality is a high priority on road construction projects. Native grasses, forbs, and other herbaceous plants can help meet this challenge, particularly when they are accompanied by appropriate mulching treatments. Deep-rooted native trees and shrubs can also enhance stability of cut and fill slopes.
Visual Enhancement	Vegetation is often used to enhance the aesthetic experience of the traveler. Wildflowers add beauty in spring; deciduous trees change color in fall; and evergreen species stay green all year. Vegetation can also be used to hide structures such as gabion walls or slopes covered by riprap.
Weed Control	Roadsides can be corridors for the transport and establishment of noxious or invasive weed species. Once established, weeds are hard to eradicate and become seed sources for further encroachment. Revegetating with desirable native species minimizes opportunities for problem species to establish.
Wildlife Protection	Many roads intercept animal corridors. Techniques to make roads more permeable to wildlife (often via under- or over-passes) are being developed. The revegetation specialist can help by minimizing dangerous interactions between vehicles and wildlife. The presence of birds and small animals can be enhanced when appropriate plant species are reestablished.
Cost Management	Advanced planning, an integrated approach, and the use of appropriate stocktypes and equipment all facilitate successful and cost-effective revegetation.

measurable goals (DFCs). After the installation is complete, DFCs and revegetation objectives will be utilized in monitoring, evaluating, and managing the project.

4.3 STEP TWO – DEFINE AND MAP REVEGETATION UNITS

The revegetation plan must include a map of the project area that displays the management areas, or revegetation units, where the various revegetation treatments will be applied. As the name implies, revegetation units are relatively homogenous areas that will receive similar treatments. Revegetation units are delineated management areas that represent the integration of similar site factors, such as soil, vegetation, and climate that will affect the revegetation potential of a site. Usually the revegetation units are based on site similarities. Projects containing different ecological zones or in complex geologic terrain might have many revegetation units, while projects on more homogeneous sites may have only one or two revegetation units. Revegetation units also represent areas of similar revegetation objectives. If, for example, there are distinctly different road objectives (beautification objectives on one area versus erosion control objectives on another), a revegetation unit might be split into two revegetation units. Although the two revegetation units are similar from a soils and climate standpoint, they must be treated differently due to management considerations.

Examples of Defining Revegetation Units

1) Example One (Rock type): The site survey combined with pre-field map research revealed that a planned road corridor crossed two very distinct soil types, one of soils formed from granite and another formed from sedimentary bedrock. Because plant growth will respond differently to these distinct soils, they represent two revegetation units.

2) Example Two (Climate): The road begins in a valley bottom, where the vegetation consists of moisture-loving species, and rises out of the valley to a side slope with species that thrive in hot, dry conditions. The vegetation change represents a significant change in microclimate; therefore, two different revegetation units were created.

3) Example Three (Aspect): The road cut creates a throughcut with steep south- and north-facing slopes. Because the vegetation capable of establishing on either aspect is quite different, they are delineated as separate revegetation units.

4) Example Four (Landform): A proposed road crosses a flat glacial bottom and then climbs the side of a steep glacial slope. Two revegetation units would be defined by the associated landform.

4.3.1 Mapping

The revegetation unit map is developed by first conducting a pre-field evaluation of soil and vegetation using available information, including:

- Road plans, including cross-sections and plan views for road construction;
- Vegetation maps, plant association guides, and literature about the area;
- Climate data and information; and
- Soils maps, such as USDA Natural Resources Conservation Service (NRCS) soil surveys and USDA Forest Service Soil Resource Inventory.

Pre-field research draws from existing site information and maps as much as possible. Print out all available maps that cover the road construction area. Soil and vegetation maps will delineate soil types and plant communities, and this information should be sketched or overlaid onto the road plans. Often the boundaries of soil types and plant communities will align, revealing distinct ecological areas within the project site. These mapping units form the preliminary designation of revegetation units.

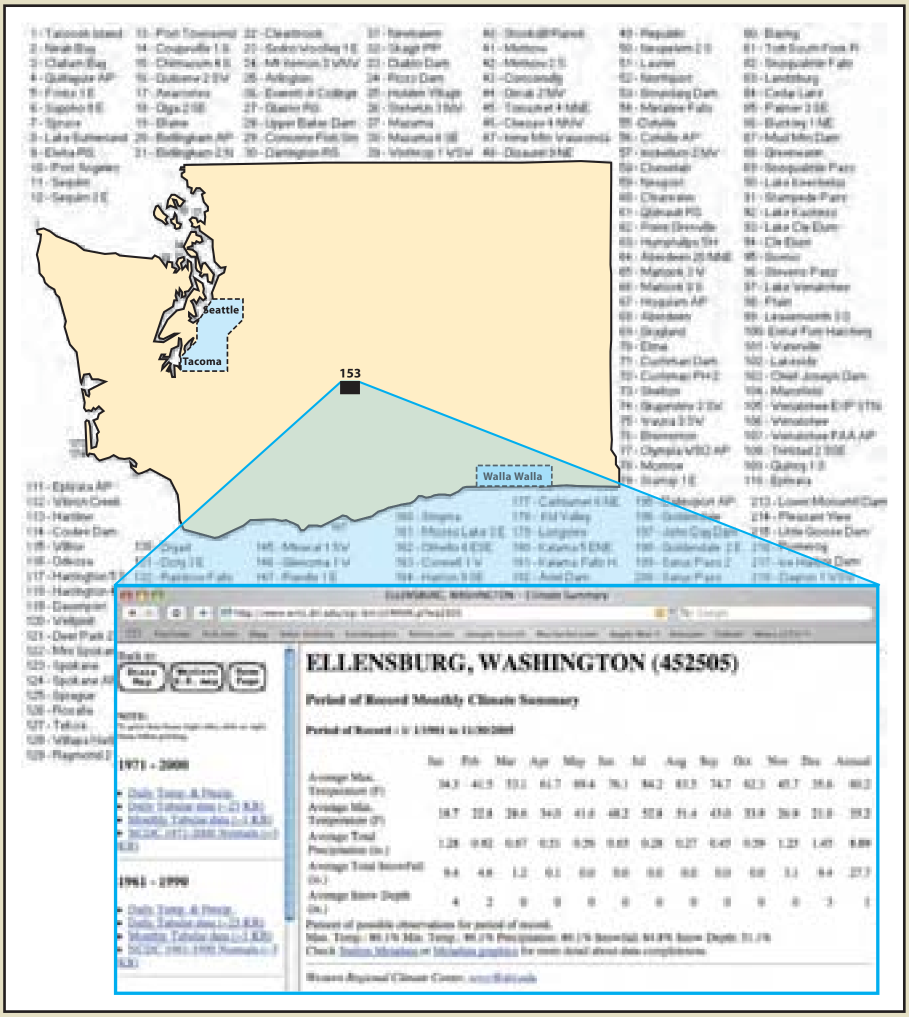
Maps and other descriptive information about the project site can be obtained from a number of state and federal agencies. For example, on USDA Forest Service lands, vegetation maps can usually be found within the Forest Service GIS system. Existing and potential vegetation are often available as layers, and can be provided by the district silviculturist. There may also be some broadscale plant classifications and mapping units that have been done by the ecology group within the agency. For some areas, a Terrestrial Ecological Unit Inventory (TEUI) may be available on the internet. TEUI is a land survey system administered by the Forest Service that provides baseline ecosystem information on soils and vegetation to revegetation specialists and other land use planners.

4.3.2 Climate Information

Climate plays a dominant role in the success or failure of the revegetation effort. Knowledge of climate factors can help delineate the appropriate revegetation units and develop achievable DFCs. In later phases of the planning process, climate data will be utilized to determine appropriate revegetation treatments.

Obtaining climate records from a variety of sources is the first step in conducting a climate assessment. Climate records for the western United States can be located at the Western Regional Climate Center website http://www.wrcc.dri.edu. This website contains the climate summaries for over 2800 climate stations (Figure 4.1). Clicking on the weather station will display data for each year the station has operated. Information can also be obtained from automated weather stations, called SNOTEL stations, that have been installed in remote areas to fill in weather information gaps. The records for these sites are located at the same website. While SNOTEL stations lack some of the reliability of staffed stations (remote stations can break

***Figure 4.1** – Average monthly temperatures and precipitation can be obtained from internet sources such as the Western Regional Climate Center http://www.wrcc.dri.edu. The data from these stations can be extrapolated to the project site.*



down in the winter and not be fixed until spring) and cover fewer years of data collection, the data is usually sufficient for understanding the local climate of the project site. For many construction projects, a local weather station will not exist. In these cases, data from the nearest weather stations can be extrapolated to the project site. A computer model for extrapolating weather station data to a project site is located on the Forest Service WEPP erosion model website http://forest.moscowfsl.wsu.edu/fswepp under the heading Rock: Clime. This model allows the user to modify a base weather station on known parameters of the project site, such as elevation and site location.

4.3.3 Soils

Many counties in the United States have soils maps either completed or in the process of completion. These maps have been developed by the NRCS, and are available at the website http://soils.usda.gov/. This website contains over 200 soil surveys covering large portions of the western United States. If a soil survey is available for the project site, all soils maps covering the road construction area should be printed. Most soil survey websites will have the option to place a topographic map or orthographic photo as a base to a soils map (Figure 4.2B). Soils maps are a composite of soil mapping units with a number or letter within each unit. These alphanumeric codes correspond to a mapping unit narrative that can be found in the text associated with the survey. Locate the narrative for each of the mapping units transected by the road project. The narratives describe a typical soil profile, list the native vegetation, define the land uses for the soil, and summarize soil characteristics, such as water-holding capacity, permeability rates, pH, and soil depth. Most lands administered by the USDA Forest Service will have separate soils reports in addition to, or in lieu of, the NRCS soils report. These reports are often referred to as a Soil Resource Inventory (SRI) report, and can be obtained at the Forest Service district office.

4.3.4 Site Survey

While information from published surveys, maps, or resource inventories is useful, it often does not provide the detail needed for defining and mapping revegetation units. A detailed survey of the project area will verify that preliminary revegetation unit mapping matches the realities in the field. A site survey is usually carried out after the preliminary road location has been staked on the ground. The road location stakes are useful points for collecting site information because they have been surveyed and located on a preliminary road plan, and can therefore be easily referenced throughout the life of the project.

Your site survey should locate, verify, and refine the boundaries of the revegetation units on the ground. Walking the site with maps in hand is key to accurately defining revegetation units. When several resource specialists are involved in collecting site information, they should integrate their survey information to delineate the revegetation units.

After completing your walk-through, it is important to sit down with the highway project maps, pre-field, and field information. As you examine the information collected on soils, climate, and vegetation, the boundaries of revegetation units will probably seem clear. Areas with similar soils, climate, microclimates, and plant communities will be one unit. Management considerations may require that ecologically homogenous units be divided into several units if there are different management goals. Revegetation units should now be sketched onto your project map.

Roadside ecological zones must also be considered when delineating revegetation units (See Chapter 3). Discussing long term objectives with those responsible for road maintenance and engaging in field surveys will help define these zones. Understanding the zones and their corresponding vegetation is necessary to define revegetation units and set appropriate DFCs aligned with road management practices. Otherwise, you may be attempting to establish species that have no chance to survive due to roadside management practices, or you may underinvest in potential plant communities further out from the road margin that are important for healthier roadside ecology.

4.4 STEP THREE – LOCATE AND DESCRIBE REFERENCE SITES

Reference sites provide a reference, or natural model, for possible vegetation outcomes and are important for defining DFCs, as well as later monitoring and evaluation of the project following implementation (SER 2004).

Each revegetation unit should have at least one corresponding reference site that models some aspect of the DFC. The reference site shows how a revegetation unit might recover from disturbances at different points in time after road construction. Reference sites can be considered as a snapshot, or series of snapshots, of possible future outcomes. They demonstrate a point in time along a desirable developmental trajectory of a plant community. Using reference sites to understand the possible vegetative outcomes after disturbances will help the revegetation specialist develop realistic expectations and provide a guide to the development of appropriate revegetation strategies. The revegetation specialist may sometimes choose to obtain baseline ecological data from several reference sites and then assemble DFCs from multiple references (SER 2004).

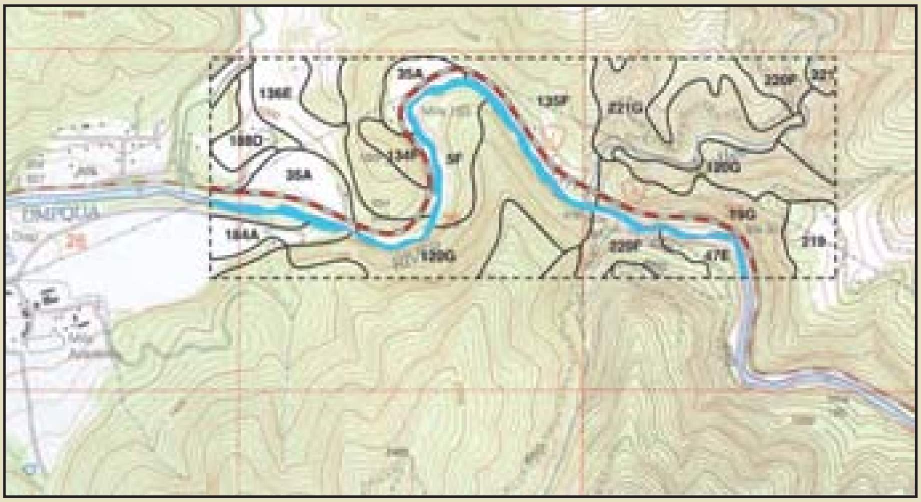
4.4.1 Disturbed and Undisturbed Reference Sites

Reference sites have similar site characteristics to the corresponding revegetation unit, but are in different stages of plant succession. There are two types of reference sites: disturbed and undisturbed. For most road projects, suitable reference sites will be areas that are ecologically similar to the revegetation unit and have recovered from disturbances similar to those planned in the road construction project. Undisturbed reference sites may also be utilized when ecological restoration is an objective, or when suitable recovered reference sites are not available.

***Figure 4.2** – Developing the Revegetation Map.*

***Figure 4.2A** – The initial step in developing a revegetation map is to obtain topographic maps of the project area. These maps will then be overlaid with maps for soil, vegetation, ownership, and other relevant information.*

***Figure 4.2B** – Soils maps are available for most project sites if a soil survey has been completed for the county. Soils maps can be obtained from sources such as the U.S. Department of Agriculture http://soils.usda.gov/, or from contacting a NRCS office. The codes are described in an accompanying soil survey report.*



Disturbed reference sites can be categorized several ways:

1) Type of disturbance;
2) Length of time after the disturbance; and
3) Desirability of the recovered vegetation.

Disturbed reference sites can be old road cuts and fills, abandoned roads, ground-based logging sites, waste areas, rock source sites, ski runs, or other areas that have recovered from past disturbances. Disturbed reference sites often show a range of possible vegetative outcomes years after disturbance. Some sites will show good recovery, including stable soil, visually pleasing, and populated by functioning communities of native plants. Others might show what can go wrong if revegetation is not carried out properly, including erosion, poor

Figure 4.2C – *In this example, a portion of an existing road will be reconstructed; a new road section will be constructed through a forested area; and the section of road that is not needed will be obliterated and revegetated.*

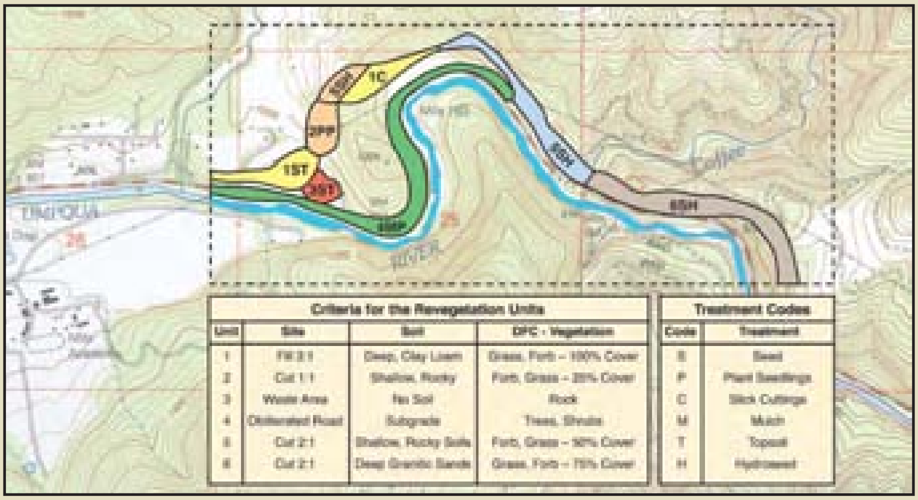
Figure 4.2D – *The proposed road location was surveyed on the ground by specialists in soils and botany. The survey identified old disturbances that had revegetated naturally over the last 50 years to a community of native grasses and forbs. Several disturbed reference sites (RR1, RR5 and RR6) were identified. Intensive soil and vegetation surveys were conducted at each site. For the new stretch of forest road, undisturbed reference sites (UR2 and UR4) were identified and surveyed.*

ground cover, weed infestation, and a lack of native vegetation. Understanding the conditions that lead to these vegetative outcomes can be a guide to avoiding this outcome in the future.

Disturbed reference sites are the best models to demonstrate what is possible on the site, what trajectories succession might take (with or possibly without human intervention), and ways to effectively intervene in order to facilitate desired outcomes. Disturbed reference sites are invaluable in developing realistic DFCs. Ideally, the type of disturbance on a disturbed site should match the type of road construction disturbance that will take place on the revegetation unit. For example, if the road cut after construction will be denuded of topsoil, then a disturbed reference site should be found that lacks topsoil.

The stage of recovery is also important. It is ideal to find several disturbed reference sites that represent different successional stages of site recovery. For instance, a revegetation unit

***Figure 4.2E –** Based on the soil and vegetation data collected during these surveys, six revegetation units were identified (colored areas). The criteria for differentiating these units and their treatments is described in the table below.*



Criteria for the Revegetation Units					Treatment Codes	
Unit	Site	Soil	DFC - Vegetation		Code	Treatment
1	Fill 2:1	Deep, Clay Loam	Grass, Forb – 100% Cover		S	Seed
2	Cut 1:1	Shallow, Rocky	Forb, Grass – 20% Cover		P	Plant Seedlings
3	Waste Area	No Soil	Rock		C	Stick Cuttings
4	Obliterated Road	Subgrade	Trees, Shrubs		M	Mulch
5	Cut 2:1	Shallow, Rocky Soils	Forb, Grass – 50% Cover		T	Topsoil
6	Cut 2:1	Deep Granitic Sands	Grass, Forb – 75% Cover		H	Hydroseed

would ideally be represented by a recently disturbed site (several years after disturbance), a recently recovered site (5 to 25 years after disturbance), and a fully recovered site (over 25 years since disturbance).

While there is no such thing as a "pristine" plant community, an "undisturbed" reference site is an area that has not been heavily impacted by ground-disturbing activities. Undisturbed reference sites indicate the highest potential of a revegetation unit, and are most often used as models when the goal is not merely revegetation, but ecological restoration. The description of soil, climate, and vegetation in an undisturbed reference area can become the framework for the DFC. It provides the revegetation specialist an understanding of those site characteristics or components necessary for healthy ecological functioning.

4.4.2 Locate Reference Sites

The process of selecting and describing reference sites is best accomplished in an interdisciplinary manner. Soils and vegetation specialists should work together to locate, select, and assess reference sites. The discussions that are generated during this process are generally far more thorough in knowledge and understanding of recovery processes than if surveys were conducted separately.

Prior to going to the field to locate reference sites, a list should be made of all reference sites (age, prior disturbance, and desirability) needed for the analysis. Then, using road, soils, and vegetation maps of the area, possible locations for reference sites can be determined. Based on these maps, a "windshield survey" can be conducted by driving adjacent or connecting roads where potential reference sites might be found. Frequently stopping to get out of the vehicle and examine the site will ensure the sites are similar to the general characteristics of the revegetation unit. A search should be done for different ages and plant communities on undisturbed and recovered reference sites. The reference site process will reveal the variation in the project area and will help you understand the best strategy for future surveys. Once reference sites are selected in the field, they are identified on a revegetation map to be surveyed.

***Table 4.4** – Reference Sites Should Assessed with a Series of Surveys of Increasing Complexity.*

What	Where	How	Why
Prefield survey	Office	Maps, contacts, literature	Begin to identify species, communities, and successional processes; determine scope of other surveys
"Windshield" Survey	Proposed Road Corridor, existing road and reference sites	Windshield/drive through	Get oriented; strategize field survey
Field Survey	Proposed road corridor, existing road and reference sites	Intuitive survey, observe, identify, list	Develop comprehensive species list, conduct soil survey, define plant communities and successional processes

4.4.3 Survey Reference Sites

Conducting a series of surveys (Table 4.4) will provide baseline ecological data and a vegetation inventory. The goal is to obtain sufficient information from reference sites to realistically define DFCs. During an initial survey, the appropriate survey intensity can be determined based on information needs and knowledge gaps. For example, if one of the revegetation objectives is to restore an abandoned road to a DFC similar to a neighboring forest, then a survey of vegetation and soils of an undisturbed and disturbed neighboring forest would be conducted to describe the site characteristics and species composition.

Prior to field surveying of reference sites, the data used to define revegetation units (See Section 4.3) should be reviewed. Information regarding land ownership, site history, resources, and past and current management is also valuable. Government specialists who might have knowledge of the soils, vegetation, climate, and hydrology, as well as locals who can provide insight on site history, should be contacted.

Your survey of reference sites should have 4 objectives:

1) Create a comprehensive species list,
2) Define the plant communities,
3) Determine possible successional trends in the plant communities, and
4) Survey soils.

***Table 4.5** – Ecological settings in forested sites of the Blue Mountains of northeastern Oregon (Powell and others 1998).*

	Wet	Very Moist	Moist	Dry
Cold	Cold, Wet	Cold, Very Moist	Cold, Moist	Cold, Dry
Cool	Cool, Wet	Cool, Very Moist	Cool, Moist	Cool, Dry
Warm	Warm, Wet	Warm, Very Moist	Warm, Moist	Warm, Dry
Hot	Hot, Wet	Hot, Very Moist	Hot, Moist	Hot, Dry

4.4.3.1 Create a Comprehensive Species List

A good method for compiling a comprehensive species list is to choose a representative cross-section of the major habitats and topographical features, with the goal of identifying as many species as possible. This is accomplished by surveying only in areas of maximum diversity. This is sometimes called an "intuitively controlled survey" (Riley 2006). The intuitively controlled survey is appropriate for reference site descriptions because the method maximizes an understanding of species diversity. It should be noted that if there are a few species that cannot be identified in the field, samples should be collected in a plant press and brought back to the office for identification. If more detailed data collection is desired, transects or grids may be run to conduct a vegetation survey.

All observations during or immediately following field surveys should be documented. Note if the species are native or introduced and keep track of species by general life form, including: trees, shrubs, annual grasses, perennial grasses, annual forbs, perennial forbs, sedges, and rushes. This information will be used later in Phase Three to develop a comprehensive species list for the project.

4.4.3.2 Describe Plant Communities

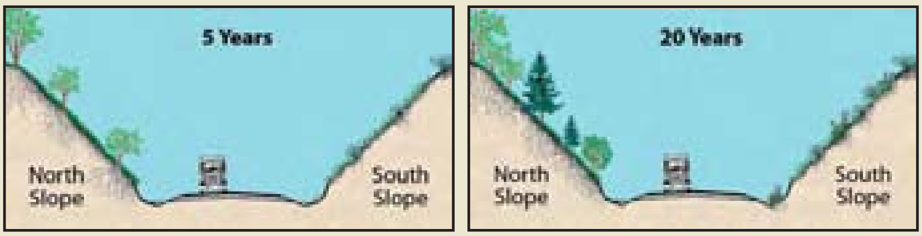
Species should be grouped by plant community and ecological setting. Ecological settings are based on characteristics of the site, which are usually a range of temperature/moisture conditions (Table 4.5).

Within each of these ecological settings, note each plant's amplitude, or how often the species occurs across different ecological settings. For example, a species that crosses eight ecological settings and is found in cold, wet through warm, dry environments would have a wide amplitude. Amplitude is usually quantified in terms of abundance (e.g., stems per square foot), density (ground or canopy cover percentages), or other measures within a given ecological setting. See Phase Three for a detailed description of this process.

Next, note groups of species that commonly occur together within or across ecological settings. The goal of most projects is to revegetate not just individual species, but to develop healthy, functional communities of plants. Gather information that shows how each species fits into an assemblage or association of plants. These assemblages may be referred to as "plant associations," "plant communities," or "guilds." In this manual, the term "plant community" will be used.

One method to define plant communities and successional processes is to refer to agency-created guides, such as a Plant Association Guide or equivalent. (A Plant Association Guide is available for each National Forest.) Based on species lists, density, canopy cover, and/or relative abundance, the Plant Association Guide allows you to key out the plant community in which you are working. The guide also supplies information on associated soil types, full species lists, climate ranges, and how each plant community might respond to different types of disturbances. (For some roadside environments, it may be difficult to identify plant communities because species close to the road can consist of many non-native species.) Patterns of plant communities, their species, and their ages should be noted on a map.

***Figure 4.3** – Successional processes and plant communities vary considerably based on site conditions. In this example, plant communities developed differently on north-facing and south-facing slopes.*



Visiting reference sites and adjacent areas of different seral stages following a disturbance is invaluable in understanding successional processes and guiding revegetation efforts. Characterizing the plant successional stages of the reference sites will be helpful. Categorize the plant communities into four categories: early, mid, and late seral, and climax. Figure 4.3 illustrates how plant communities develop differently over time, depending on site conditions and successional processes.

4.4.3.3 Survey Soils

Understanding the soil characteristics on reference sites is essential to effectively define DFCs. Although soils reports provide general information on soil characteristics, such as soil depth, pH, and water-holding capacity, intensive soil surveys should be conducted on all reference sites. Soil pits should be dug at each site and the following information collected for topsoil and subsoil:

- Soil texture (See Section 5.3),
- Rock fragments (See Section 5.3),
- Rooting depth (See Section 5.3),
- Topsoil depth (See Section 5.5),
- Nutrient levels (See Section 5.5),
- Soil structure (See Section 5.3),
- Litter and duff layers (See Section 5.4),
- Site organic matter (See Section 5.5), and
- Infiltration rates (See Section 5.2).

The process for collecting and interpreting this information is described in depth in Chapter 5 (Planning Phase Two).

4.4.4 Describe Revegetation Units Using Survey Information

The process of describing revegetation units in detail is interpretive and predictive, rather than purely descriptive. You are attempting to define the processes and species in a revegetation unit, using the snapshots obtained from the reference sites. Since each revegetation unit can have several reference sites, the data from these sites must be compiled, summarized, and interpreted. The following questions can help in understanding the ecological processes for revegetation of the site based on reference site information:

- What is the generalized site (soil, climate, vegetation) description of each revegetation unit?
- What are the ecological differences between revegetation units?
- How will each revegetation unit respond to different types of disturbances immediately after construction, in one year, three years, and ten years?
- What are the ecological trajectories for each unit and what are the dominating factors controlling them?
- What are the limiting factors (discussed in detail in the next chapter)?

The answers to these questions should be summarized as an ecological description for each revegetation unit.

4.5 STEP FOUR – DEFINE DESIRED FUTURE CONDITIONS (DFCS)

Once revegetation units and corresponding reference sites have been identified, mapped, and described, the desired future condition (DFC) can be defined for each unit. The DFC takes the overall revegetation objectives defined earlier and translates them into measurable goals tailored to each management unit. The DFC specifies the desired or expected composition of vegetation at a defined point in time after the completion of the revegetation work.

An example DFC would be, "2 years after seeding, vegetative ground cover will be 50%; of this cover, 75% will be composed of perennial native species." Stating expectations in this manner will:

- Clarify how the site will appear after treatments;
- Narrow down the appropriate revegetation treatments; and
- Define measurable criteria, or thresholds, that can be used for monitoring project success.

Commonly stated DFC criteria include:

- Vegetative ground cover (%),
- Bare soil (%),
- Native plant cover (%),
- Seedling survival (%),
- Seedling density (plants per area), and
- Tree growth (height per year).

Stating the DFC in measurable terms and with a timeline ensures that the project team, regulatory agencies, and the public have similar expectations of how the project will unfold. Quantifying the objectives also allows monitoring to determine how well project objectives were met. For example, if one of the objectives is erosion control, a quantifiable criteria for a desired future condition might be, "bare soil one year after road construction will be less than 20%." If another objective is the establishment of native plants, then a measurable threshold for success might be, "native perennial grasses and forbs will occupy over 40% of the site within three years of seeding." How to develop and implement monitoring and adaptive management is described in Chapters 11 and 12.

DFCs are stated within a time frame, which is commonly defined as the number of years after project disturbance. Defining DFCs usually takes into consideration how the revegetation units could look in both short-term (1-3 years) and long-term (5, 10, 15+ year) time frames. Asking a series of questions about the site's potential future condition is an important part of the thought process. What might happen with no intervention or management? What might happen with massive intervention and mitigation? Between these two extremes, what are the key leverage points that might provide for healthy succession of the local plant communities with minimal human intervention after the road is constructed? How could various interventions be timed, from the beginning of the project through infusions of energy and resources a few years after establishment? From an ecological standpoint, what is the optimal future condition for the site in short- and long-term time frames? Given constraints and limitations, what is possible and feasible on the site?

Another key aspect of defining DFCs is refining your understanding of limiting factors regarding the types of native vegetation that you hope to re-establish. In Phase Two, a comprehensive assessment of limiting factors for general revegetation will be carried out. In Phase Three, more information about the local native species and their requirements will be gathered. As species and site information are analyzed, some factors will emerge as more limiting to particular vegetation types than others. For example, water input might be limited on the site. However, if native drought-tolerant species are planted, water will be less of a limitation than if you were using species that require more water.

Revegetation strategies should be developed that will set the trajectory during establishment to arrive where you want the site to be in 10 years. Site parameters that might limit long-term, not just short term, plant establishment must also be considered. When developing DFCs, think in terms of the plant succession that is likely to occur on each revegetation unit. In some cases, planting early seral species at the outset may work. By year 3, when the early seral species begin to decline, the late seral species may be increasing. In other cases, you may need to intervene several years after the early establishment phase of the project in order to support healthy succession. For example, short-term revegetation planning might call for seeding grasses and forbs to stabilize the site. One year later, the site might be revisited to remove any invasive species before they produce seeds. Two years later, the site might be revisited to interplant conifers and shrubs to meet long-term objectives. These three intervention points (seeding, weeding, and planting trees) speed succession in order to establish a sustainable plant community on the site.

4.6 NEXT STEPS

With the revegetation units defined, reference sites described, and desired future conditions drafted, Phase One is complete and you are ready to move on to the next phases of the planning process. You will have more chances to reexamine and refine the DFCs in subsequent phases. For now, you can make an informed attempt at setting the DFCs for each revegetation unit, including specifying time and place. In Phase Two, the site attributes critical for plant establishment and long-term plant community development are described for each revegetation unit. The assessment of soils and climate made during the survey of reference sites should reveal if site characteristics are either obstacles to, or resources for, achieving DFCs. Based on the determination of limiting factors, a menu of the possible mitigating measures is developed. Once the limiting factors are understood, the vegetation is analyzed in greater depth in Phase Three. From the comprehensive list of species and plant communities present on the site, you will determine which species and groups are best adapted to the site and best suited to revegetation needs. Options for stocktypes and application methods are considered in order to achieve the best results. Finally, in Phase Four, all the elements are pulled together, selections are made, and recommendations are compiled into a comprehensive strategy and timeline for site treatments and revegetation strategies, or the Revegetation Plan.

5 PLANNING PHASE TWO: ASSESS SITE

5.1 INTRODUCTION

Phase Two identifies site factors that will limit revegetation establishment, defines the possible mitigating measures that can be employed to reduce the effects of limiting conditions on plant growth, and surveys those site attributes that can be used as resources to accomplish revegetation objectives. By the end of Phase Two, you should have:

- Identified limiting factors,
- Considered mitigating measures for limiting factors, and
- Assessed site resources.

***Figure 5.1** – Limiting factors to revegetation can be displayed as unequal boards of a barrel. Water can only be held to the level of most limiting factor.*

5.1.1 Limiting Factors

Site conditions that affect plant establishment and growth are referred to as limiting factors. Odum (1971) defines limiting factors as "any condition which approaches or exceeds the limits and tolerance (of a plant species)." He further states that "the chief value of the concept of limiting factors lies in the fact that it gives the ecologist an 'entering wedge' into the study of complex situations. Environmental relations of organisms are apt to be complex, so that it is fortunate that not all possible factors are of equal importance in a given situation or for a given organism." For the revegetation specialist, defining the limiting factors on any particular project or site is an essential process in developing a revegetation plan because it identifies from a multitude of site factors only those that are roadblocks to successful revegetation. Not only does this simplify a complex analysis, it requires the revegetation specialist to systematically consider all site factors, focussing on those of greatest concern. For example, typical revegetation treatments conventionally call for the blanket use of fertilizers without assessing if nutrients are really limiting to plant growth. In many cases, other limiting factors to revegetation, such as low rainfall, compacted soils, low organic matter, and poor rooting depth, are more limiting. Without a comprehensive assessment of limiting factors, the prescription for fertilizer is akin to a physician prescribing medicine before the patient has been properly diagnosed. While soil fertility is often important on many highly disturbed sites, it might not be the primary limiting factor to revegetation on the site.

This manual has grouped the site characteristics essential for plant growth into nine limiting factors to revegetation typically encountered in the western United States. These factors are further broken down into component parts, or parameters (Figure 5.2). In this chapter each limiting factor to revegetation and corresponding parameters are discussed in terms of why they are important to plant establishment and growth, how they are assessed, and what mitigating measures can be applied to make them less limiting.

The information used in defining limiting factors for each revegetation unit can be obtained from the surveys and reports conducted in Phase One. In this process, it is important that an assessment of every limiting factor and corresponding parameter be made for each revegetation unit based on the expected condition of the site after disturbance. For this assessment, the types of post-construction disturbance must be clearly understood.

Mitigating measures are the site treatments that will reduce or eliminate the site conditions limiting to revegetation. There are usually several ways to mitigate each limiting factor. In this phase, mitigating measures are identified and briefly described for each limiting plant factor and parameter. While some of the mitigating measures might seem impractical for a particular revegetation project, they nevertheless should be considered in this part of the assessment. A process for developing the most appropriate set of mitigating measures into an integrated revegetation strategy will be covered in Phase Four.

Introduction
Initiation
Planning
Phase II:
Assess Site
Implementation
Monitoring
& Management
Summary

Figure 5.2 – *This manual recognizes nine site characteristics that can limit plant growth. These factors are further broken down into component parts, or parameters.*

	Critical Plant Factors	Parameters
1	Water Input	Precipitation
		Interception
		Infiltration
		Road Drainage
2	Water Storage and Accessibility	Soil Texture
		Rock Fragments
		Soil Structure
		Rooting Depth
		Mycorrhizal Fungi
3	Water Loss	Wind
		Aspect
		Competing Vegetation
		Soil Cover
4	Nutrient Cycling	Topsoil
		Site Organic Matter
		Nitrogen and Carbon
		Nutrients
		pH and Salts
5	Surface Stability	Rainfall and Wind
		Freeze – Thaw
		Soil Cover
		Surface Strength
		Infiltration
		Slope Gradient
		Surface Roughness
		Slope Length
6	Slope Stability	Permeability
		Restrictive Layer
		Water Input
		Slope Length
		Slope Gradient
		Soil Strength
7	Weeds	Weed Sources
		Weed Growing Environment
8	Pests	Mammals
		Insects
9	Human Interface	Disease
		Road Maintenance
		Recreational Use

5.2 WATER INPUT

Water input refers to the moisture supplied to the soil through rainfall, snowmelt, and road drainage. This moisture recharges the soil and becomes the primary source of water for plant establishment and growth. Water input is influenced by obstacles that capture, or intercept, water before it can enter the soil, including standing live or dead vegetation and soil cover (litter, duff, and mulch). Surface infiltration rates also regulate entry of surface water. If infiltration rates are low, water that would normally enter the soil runs off the surface and is unavailable.

The primary site factors that affect water input are:

- Precipitation,
- Interception,
- Infiltration, and
- Road drainage.

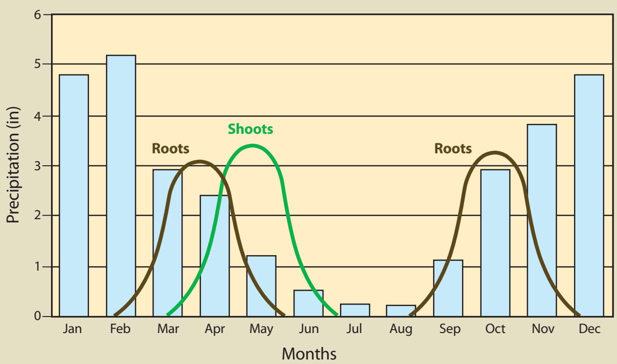
In the western United States, water input is at its lowest levels from late spring through early fall. This is also the period when plants require the most soil moisture for survival and growth. During the summer, when water input is low, the soil profile dries out as vegetation withdraws moisture. As soil moisture is depleted, plants cease growing; if soil moisture is not recharged, plants will go into dormancy or die. It is critical that any water from precipitation arriving during the dry season enters the soil and is stored for later plant use.

5.2.1 Precipitation

In wildlands revegetation, the only source of soil water comes through precipitation in the form of rainfall or snowmelt. In the western United States, this typically occurs from late fall through mid spring, during a period when plants are dormant and least able to utilize soil moisture for growth. Water that is not stored in the soil during these events is lost from the site either to ground water or runoff. The period when plants need soil moisture the most occurs during a five to six month period, from April through October. For most sites in the western United States, the amount of moisture that occurs in this period is less than a quarter of the total annual rainfall.

Vegetation native to the western United States has evolved to compensate for the limited supply of moisture during the growing season (Figure 5.3). During the spring, when soils are charged with moisture from the winter precipitation and soil temperatures increase, plants produce new roots, followed by new foliage. As the soil dries out and plants undergo mild moisture stresses, new root and foliage growth cease. During the summer months, soil continues to dry and plants respond to even greater moisture stress by shutting down their physiological functions and becoming dormant. By mid to late summer, when available soil moisture is depleted and evapotranspiration rates are high, plants will show stress symptoms (browning, loss of needles and leaves); under extreme circumstances, plants will die. By late summer and early fall, rain returns and the soil slowly moistens again, reducing plant moisture stress and signaling plants to grow new roots.

***Figure 5.3** – In the western United States, root and shoot growth occur when moisture is available in the spring. Growth ceases by early summer when there is very little rainfall. Root growth takes place again from late September through November when soils are recharged by fall rainstorms.*



The primary characteristic of precipitation for plant survival is the quantity of rainfall delivered in each storm event during the dry season. Storm events that deliver more than 0.25 inches of rainfall can wet the surface portion of the soil profile and reduce plant moisture stress. Precipitation events that deliver less than this amount will rarely supply enough water to enter the soil, especially if interception and runoff rates are high.

5.2.1.1 Precipitation – How to Assess

Average monthly rainfall can be estimated by extrapolating climate data from weather stations closest to the project site (See Section 4.3.2 for how to access weather information). For more site specific information, precipitation can be collected on-site using rain gauges that capture and record precipitation.

There are two types of precipitation gauges available – digital and non-digital. The advantages of digital gauges are that they record the amount of rainfall and time that it occurred; the downside is cost (although prices are coming down). There are many types of digital rain gauges available, ranging in price and quality. It is important to select a digital rain gauge that is rugged, self-maintaining, and can record for long periods of time.

Non-digital rain gauges are basically cylinders that collect and store precipitation while preventing evaporation. The gauges are monitored by simply measuring the water in the cylinder. The disadvantage of non-digital rain gauges is that they only report the rainfall that has occurred between site visits. They do not provide the dates when rainfall occurred and do not record rainfall intensities.

5.2.1.2 Mitigating for Low Precipitation

Making the most of rain and snowmelt is an important part of successful revegetation planning. In most cases, supplemental watering will not be feasible. However, if very little water input occurs during the summer months, supplemental water on a temporary basis might be considered during plant establishment. This can take an active form, such as irrigation, or a passive form, such as redirecting surface water to planted seedlings.

Irrigation **–** Irrigation can be expensive, and it is generally used only on projects with high visibility or when rapid establishment is necessary for slope stability. These are projects where revegetation objectives include minimizing the risk of seedling failure or enhancing vegetation growth.

There are several basic types of irrigation systems used in roadside revegetation. They are grouped into fixed systems, such as overhead sprinkler and drip irrigation, and manually applied systems. Fixed systems are discussed in Section 10.4.5.2, Drip Irrigation. Manual systems require water to be delivered directly to each plant, either from a hose or water container.

If only a few applications are necessary, the entire project can be done by hand. Personnel can water each seedling or seeded area using a water truck or hydroseeder (with water only), although care must be taken to avoid pulling hoses over establishing plants. Creating basins around seedlings will pond the surface-applied water and keep it concentrated in the seedling root zone. However, a better way to be certain that water will be delivered directly to the roots is to integrate the deep pot irrigation system into drip or manually applied irrigation methods (Bainbridge and others 2001). Pipes made from PVC or other materials are placed at depths of 1 to 2 feet beside the seedling at the time of planting. The pipes are then filled with water when the soils dry out in the summer. The advantage of deep pipe irrigation is that water is delivered directly to the root system and, because the water is placed deeper in the soil, roots are forced to extend further into the soil for moisture. Refer to Section 10.4.5.1, Deep Pot Irrigation, for how to install this system.

For any irrigation method, it is important to monitor the wetting pattern of each irrigation. This will assure that water is applied at the appropriate rates. Digging a hole where the water has been applied at least one hour after irrigation will show how far the water has moved into the soil profile. Duration of irrigations can be adjusted accordingly.

Water Harvesting **–** Water harvesting is the alteration of local topography to capture runoff water and concentrate it in areas where it can be used by plants. Water harvesting designs can be applied to roadside revegetation in several ways. They include, but are not limited to, contour bench terraces, runoff strips, and fill slope microcatchments. Contour bench terraces

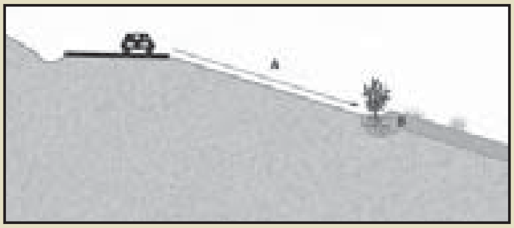


***Figure 5.4** – Fill slope microcatchments take advantage of the low infiltration rates of compacted fill slopes. Water moves off impervious road surfaces and compacted road shoulders during rainstorms (A), and is captured in berms or flattened areas below the road shoulder (B). If this area is ripped and amended with organic matter, it becomes a very good environment for establishing shrubs and trees. Berms and/or flattened areas are also catchments for sediments.*

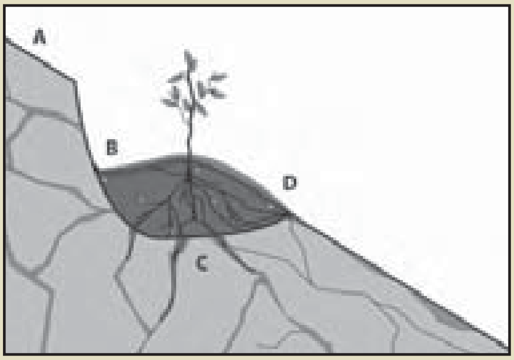


***Figure 5.5** – Planting pockets are designed to capture water from upslope runoff (A), that collects in a slight depression (B). Captured water wets up the soil after each rainstorm and drains into the fractured bedrock (C). Soil is protected from surface erosion on the downhill side of the pocket with mulch or erosion fabric (D).*

are structures carved out of cut and fill slopes that collect and store runoff water. When filled with topsoil or amended soil, they are referred to as planting pockets. Figure 5.4 shows how planting pockets collect water. Fill slope microcatchments take advantage of water that drains off road surfaces and shoulders during intense rainstorms by capturing runoff in berms or depressions created at the base of the road shoulder (Figure 5.5). Shrubs and trees planted in these catchment areas will receive greater soil moisture. Even very low rainfall events, which would normally be of insufficient quantity to moisten the soil surface, can recharge soil in planting pockets and fill slope microcatchments. Sediments will also be deposited on the benches and pockets during rainstorms, building the soil up over time and reducing soil erosion.

5.2.2 Rainfall Interception

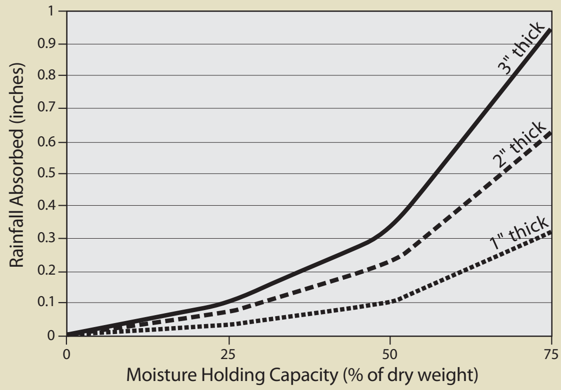
The amount of water entering the soil profile from a rainfall event can be significantly reduced by the interception of live or dead vegetation cover. Rainfall is captured through a series of layers, beginning with 1) the tree and shrub canopy, 2) ground cover, 3) litter, and 4) duff, and is returned to the atmosphere through evaporation. During the dry season, moisture from a low rainfall event might not reach to soil.

5.2.2.1 Rainfall Interception – How to Assess

Interception can be determined by the soil cover and vegetation that exist on the site after construction. In most cases, there will be very little vegetation and ground cover. It is therefore important to understand the effects of various types of ground cover used in revegetation on the rainfall interception. The depth and water-holding capacity of the material will determine the effect on water input.

Water-holding capacity of a material can be measured through testing labs specializing in composts. Alternatively, it can be measured by collecting the soil layer (duff, litter, mulch) and drying this material at 230 °F in an oven or crockpot with a meat thermometer stuck in the material. When the sample is dry (reaching 230 °F), it is placed in a 5-inch long by 3-inch round PVC pipe with the bottom secured with a flat piece of cardboard to prevent the material from falling out. The PVC pipe is weighed and recorded, then placed in a bucket. The bucket is filled with water to the top of the pipe. The sample is removed and tipped upside down on a stack of paper towels to allow the water to drain. Wet towels are exchanged with dry towels until

Figure 5.6 *– The amount of rainfall intercepted by soil cover (e.g., mulch or litter) is dependent on its water-holding capacity and thickness.*



towels are no longer wet. The pipe containing the material is reweighed. The material is then removed and the pipe plus bottom material is weighed. The moisture holding capacity of the material (by % dry weight) is: (wet weight - container) - (dry weight - container))/(dry weight - container)*100.

Figure 5.6 can be used to approximate how much rainfall is intercepted based on these parameters.

5.2.2.2 Mitigation for High Rainfall Interception

It is important to consider the water-holding capacities of the mulches to be used, especially on arid sites. Highly decomposed, fine textured composts have high water-holding capacities compared to coarser textured, less decomposed organic materials, such as bark, wood chips, and wood strands. Coarser materials allow more water to reach the soil.

5.2.3 Infiltration

Infiltration is the ability of the soil surface to absorb water from rainfall, snowmelt, irrigation, or road drainage. When infiltration rates are slower than the amount of water applied to the surface of the soil, runoff will occur and this water will not be available for plant uptake. In addition, runoff can detach and transport soil, causing soil erosion and water quality problems. See Section 5.6.5 for a discussion of infiltration rates on surface stability.

The size, abundance, and stability of soil aggregates in the surface soil determine the infiltration rates. Large stable pores created by worms, insects, and root channels will absorb water quickly and have high infiltration rates; soils that have been compacted, topsoil removed, or are low in organic matter will have poor infiltration rates.

Under undisturbed conditions, infiltration rates are typically high, especially where a litter and duff cover exists. When soil cover is removed, the impact from rainsplash can seal the soil surface, creating a crust that will significantly reduce infiltration rates. Infiltration rates are also reduced when the soil is compacted by heavy equipment or traffic.

5.2.3.1 Infiltration – How to Assess

The most accurate method to measure field infiltration rates is using the rainfall simulator (See Figure 5.48). This equipment is calibrated to simulate the appropriate drop size and impact velocity of many rainfall events (Grismer and Hogan 2004). The rainfall simulator is expensive to operate and is not routinely used by the revegetation specialist. The most common application for this technology is in comparing different mitigating measures, such as mulches and tillage methods, on infiltration capacity.

Without conducting rainfall simulation tests, infiltration rates must be inferred by measuring soil strength, using a soil penetrometer, bulk density measurements (See Section 5.3.3), and from site characteristics such as visual observation of compaction and the percentage of soil cover. For most construction activities that remove surface cover or disturb the topsoil, it can be assumed that infiltration rates will be reduced to levels that will create overland flow under most rainfall intensities.

5.2.3.2 Mitigating for Low Infiltration Rates

Minimize Compaction **–** Driving heavy equipment over soils causes compaction and reduces infiltration rates. After sites have been prepared for seeding or planting, heavy equipment must not be driven over soils. Such practices that are often recommended for erosion control, such as trackwalking, can actually decrease infiltration rates and adversely affect the establishment and cover of native plants. These practices may not be appropriate on all soil types and should be assessed on a site specific basis (Hogan and Grismer 2007).

Tillage **–** Infiltration rates can be increased through soil tillage, including subsoiling, ripping, and disking (See Section 10.1.2, Tillage). Tillage will, in most cases, reduce compaction and increase macro-pore space in the surface soil, as well as create surface roughness that further increases infiltration rates. Depending on the stability of the surface material and the level of organic matter, the effects of tillage on infiltration might only be effective for a short time. Concentrated water from road drainage has the potential to create deep gullies and must be avoided on tilled soils.

Organic Amendments **–** Incorporating organic amendments into the soil surface can create large, stable pores. However, unless the pores are interconnecting, they will not drain well (Claassen 2006). One method for creating continuous pores is to use long, slender organic material, like shredded bark or wood, composted yard waste, straw or hay (See Section 10.1.5, Organic Matter Amendments). Compared to short organic materials like wood chips, longer materials can increase infiltration rates. Incorporating higher quantities of organic matter in the soil will also increase porosity because of the potential of the organic material to overlap and interconnect.

Mulch and Tillage **–** Applying mulch by itself does not necessarily increase infiltration rates, although it can reduce sediment yields (Hogan and Grismer 2007). However, combined with surface tillage in the form of subsoiling or ripping, infiltration rates can be significantly increased. Mulch fills in the micro-basins left from the tillage operation (Figure 5.7).

Establish Vegetation **–** Ultimately, the best method to increase infiltration is to create conditions for a healthy vegetative cover. Good vegetative cover will produce soils with extensive root channels, aggregated soil particles, and good litter layers.

5.2.4 Road Drainage

Roads intercept surface and subsurface water and, depending on how the road is designed, either disperse or concentrate this water. Dispersed water is often seen on outslope roads, where water moves in sheets over the road surface during rainstorms. Concentrated water occurs where runoff from the road surface and cut slopes, as well as intercepted water from seeps and streams, is collected in ditchlines that flow into culverts or other road drainage structures. These structures, in turn, deliver the concentrated water to slopes below the fills. Concentrated water is not always directed into creeks or natural drainage landforms. Therefore, during rainfall events and snowmelt, concentrated water might be directed onto soils that were drier before construction. The greater water input to these sites increases soil moisture and may change the type of vegetation that can survive and grow.

***Figure 5.7** – Surface applied compost has greater surface area contact with the soil when it is applied to roughened surfaces (B), compared to smooth surfaces (A). Creating a rough surface prior to the application of composts creates better rooting, greater surface stability, and faster organic matter decomposition. Tilling the soil, through subsoiling and ripping, to depths of one to two feet (C) will break up compaction and create channels for compost to move into the soil, increasing soil contact and creating greater infiltration rates.*

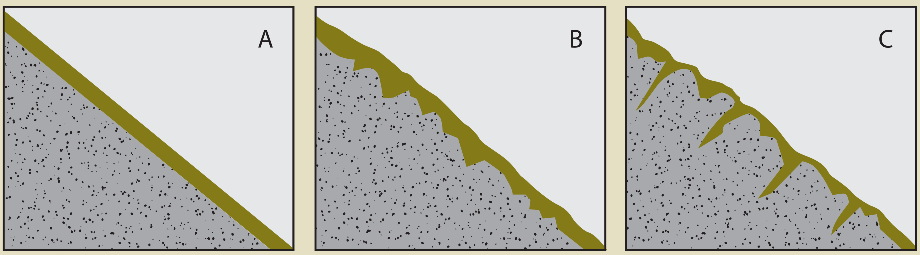
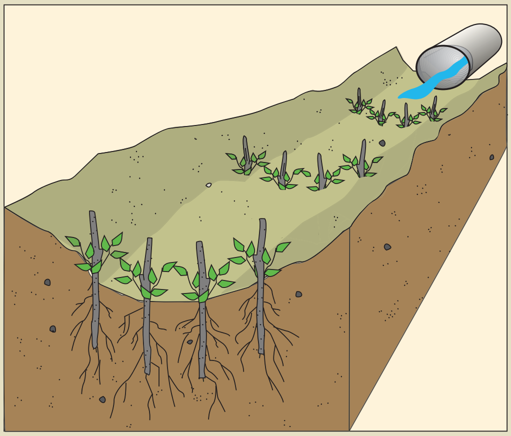


***Figure 5.8** – In gullies, draws, intermittent streams, or below culvert outlets, live willow stakes (See Section 10.3.3.2, Live Stakes) are placed in rows, creating what is referred to as a live silt fence, to slow water velocities and catch sediment and debris (Polster 1997). The stakes root and establish into plants over time.*



5.2.4.1 Road Drainage – How to Assess

Road drainage is assessed by identifying drainage structures on the road plans and visiting these sites in the field during both pre- and post-construction. The outlets of culverts are the areas most likely to have concentrated water that can be considered for mitigation. Outslope roads and long road shoulders will produce sheet water.

5.2.4.2 Mitigating for Road Drainage

Species Selection – In areas below culverts, soil moisture should be higher than surrounding areas after rainstorms or snow melt. These areas should be evaluated to determine if more moisture-loving plant species should be sown or planted to take advantage of the increased soil moisture. However, be aware that, in arid climates, these sites may be as dry as the surrounding areas during long periods of summer drought. Consider placing obstacles, such as berms or large wood, at the base of culverts and perpendicular to the slope to slow concentrated water and increase soil moisture in these areas.

Biotechnical Slope Protection – Gullies can form below culvert outlets, and, for this reason, these sites are often armored with rock. Moisture-loving vegetation, such as willows, sedges, and rushes, can be integrated into the hardened surfaces as shown in Figure 5.8 and as discussed in Section 10.3.3, Installing Cuttings.

Water Harvesting – Road surfaces, shoulders, and to a lesser extent, cut and fill slopes are impermeable surfaces that create runoff water during precipitation. Utilizing this water can be considered a form of water harvesting. Figure 5.4 shows a simple way of using water off road surface and shoulders.

5.3 AVAILABLE WATER STORAGE AND ACCESSIBILITY

The previous section discussed how water enters the soil surface. This section describes how water is stored in the soil, and how soil water is accessed by roots. The total available water-holding capacity (TAWHC) is the sum of all water stored in the soil profile that is available to plant roots. The amount of water that a soil can store is primarily a function of:

- Soil texture,
- Rock fragments,
- Soil structure,
- Rooting depth, and
- Mycorrhizae.

The amount of water a soil stores and how easily it is accessible by roots determines the types of species and the amount of vegetative cover a site can support.

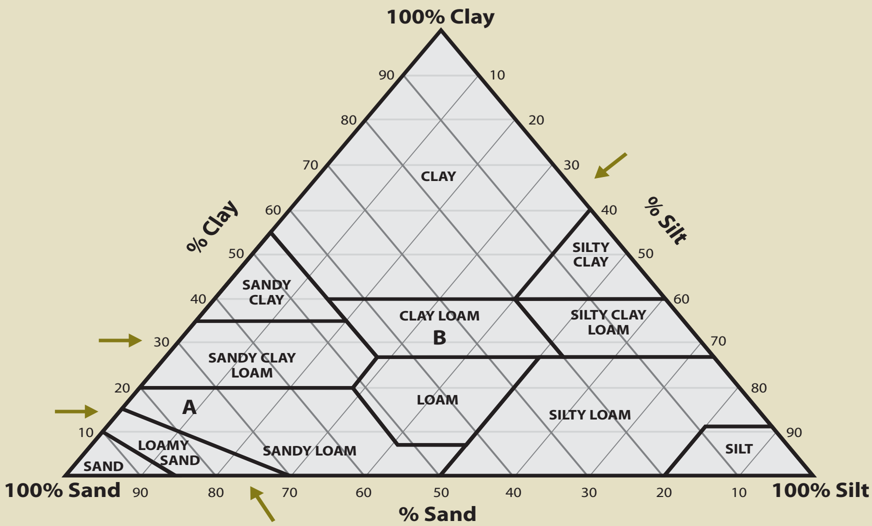
5.3.1 Soil Texture

Soils are composed of minerals of varying sizes, ranging from clay (the smallest) to stone (the largest). Each mineral particle in a soil sample can be grouped into six categories depending on its size: clay (<0.00008 in [0.002 mm]), silt (0.00008-0.002 in [0.002 to .05 mm]), sand (0.002-0.08 in [0.05 to 2.0 mm]), gravel (0.08-3.0 in [2 mm to 8 cm]), cobble (3-8 in [8 to 20 cm]) and stone (>8in [20 cm]). The fine soil fraction is composed of a combination of sand, silt, and clay size particles. The proportion of these size groups in a soil is called the soil texture.

Figure 5.9 shows 12 soil textural classes by their proportions of sand, silt, and clay as defined by the U.S. Department of Agriculture classification system (Soil Survey Staff 1975). There are two other soil classification systems, American Association of State Highway and Transportation Officials (AASHTO) and the Unified Soil Classification systems, which are used for geotechnical engineering. These two systems use different particle size ranges and include parameters such as liquid limit and plasticity in classifying soils. There is no accurate way of converting values from these systems to the USDA textural classes.

Soil texture is an important function of soil water storage because the unique arrangement of pores created in each texture class holds differing quantities of moisture. Clays are typically thin, wafer-like particles with highly charged surface areas that retain large amounts of water. Clay particles are often arranged to form small void spaces, or micropores, that also store water. Sands, on the other hand, are large, rounded particles that have a very low surface area and therefore do not hold as much water. The large pores (macropores) that are created when sand particles are adjacent to each other are good for air and water flow, but poor for storing water. Soils high in silts hold more water than sands because of the greater quantity of micropores. However, silt particles are not charged, therefore holding less water than clays.

Figure 5.9 *– The soil textural triangle defines 12 textural classes based on the percentage of sand, silt, and clay in a soil sample. The textural classes make it easy to describe soils without having to state percentage of sand, silt, and clay. To use the textural triangle, locate the percentage of sand on the bottom side of the triangle and trace the line up to the left hand side of the triangle. Do the same with either the silt or clay percentages on the other two sides of the triangle (follow silt diagonally down to the lower left and clay across from left to right). Where the two lines intersect is the textural class for that soil. For example, a soil with 75% sand and 15% clay would be a sandy loam (A). A soil with 30% clay and 35% silt would have a clay loam texture. Adapted from Colorado State University Extension Publication (GardenNotes #214 at http://www.ext.colostate.edu/mg/files/gardennotes/214-EstTexture.html).*

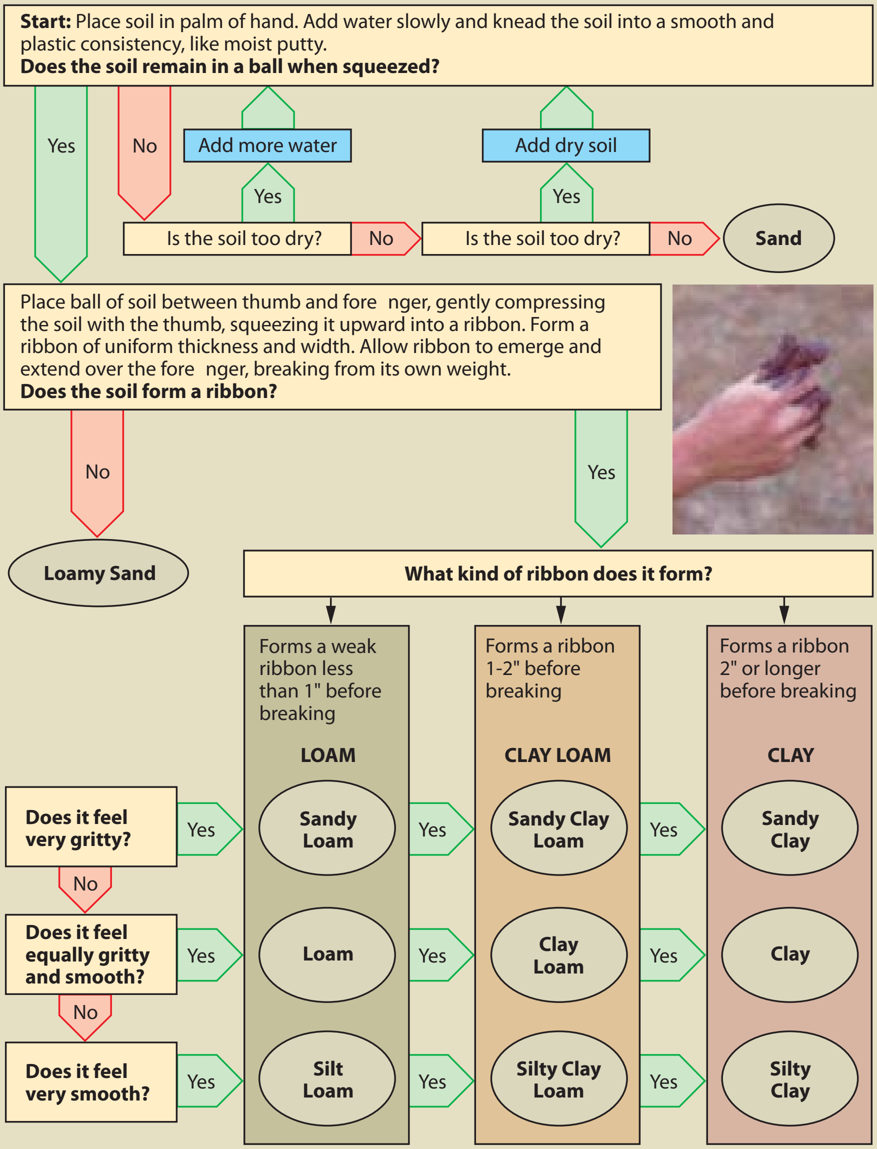


5.3.1.1 Soil Texture – How to Assess

Soil texture can be determined fairly accurately in the field using the "feel" test. This is done with the aid of a soil sieve (2 mm opening size) and a bottle of water. Obtain a fairly dry field sample and separate the fine fraction from the coarse fragments with the sieve (note the volume of gravel in the sample). Take a sample of the fine fraction in the palm of the hand and moisten it with water. The soil is rubbed between the fingers and thumb and classified using the decision tree in Figure 5.10.

For a more exact determination of soil texture, a sample of soil can be sent to a soils laboratory for a particle size distribution test. This test will report the percentage of sands, silts, and clays in the sample. Published soil surveys of the project area will also give a reliable classification of the soil texture.

***Figure 5.10** – Soil texture by feel method. Adapted from Colorado State University Extension Publication (GardenNotes #214 at http://www.ext.colostate.edu/mg/files/gardennotes/214-EstTexture.html).*



Knowing soil texture is essential for estimating the available water-holding capacity (AWHC) of a soil. Figure 5.11 shows some typical available water-holding capacities for various soil textures. The values in this figure are generalized, but are acceptable for making recommendations on most revegetation projects. For a more accurate assessment, samples can be sent to soils labs for moisture determination. This is a specialized test and not all labs offer this test; therefore it is important to contact the lab prior to collecting samples. You can also measure water-holding capacity by the methods outlined in Inset 5.1.

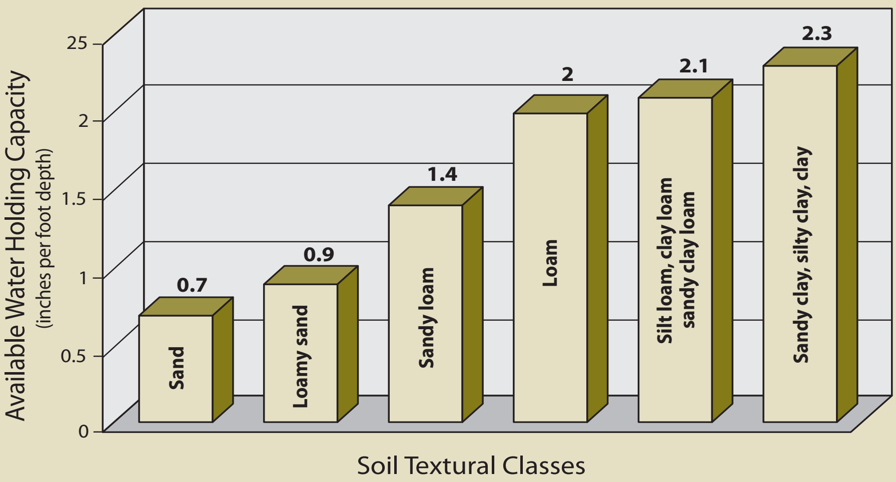
5.3.1.2 Mitigating for Textures with Low Water-Holding Capacities

Organic Amendments – Incorporation of organic amendments (e.g., compost) can increase the water-holding capacity of a soil. Because the water-holding capacity of each type of organic matter varies by composition and degree of weathering, the effect on soil water-holding capacity by any organic matter being considered must be assessed prior to application (See Section 10.1.5, Organic Matter Amendments for assessment methods). Sandy textured soils benefit most from organic matter additions, especially those with plant available water of 9% or less (Claassen 2006), which are typically sands, loamy sands, and sandy loam soils. Testing several different rates of incorporated organic matter on soil moisture-holding capacity should be done to prior to selecting the source and the amount of material to apply.

Clay – The water-holding capacity of sandy textured soils can be increased by incorporating clay loam, sandy clay loam, and silty clay loam textures in the soil. The addition of clays should be at rates that result in new soil textures similar to loams, silt loams, or sandy clay loams. Higher rates of clay addition are not recommended. It is always important to test the additions of any soil to another to understand what the effects on water-holding capacity and structure might be. Ideally this should be in the field in small plots.

Polyacrylamides – Polyacrylamides are hydrophilic polymers that absorb many times their weight in water. They have been used to increase the water-holding capacity of greenhouse growing media. The use of polyacrylamides as a measure to improve impoverished soils associated with road construction, however, has not been demonstrated. The uncertainties of using polyacrylamides range from which of the many products on the market to use, the method of application, the life span under field conditions of each product, the effects of salts and minerals on water-holding capacity, and the amount of material to use. If the rate of polyacrylamide application in the soil is too high, the polyacrylamide granules will swell into

Figure 5.11 *– General relationship between soil texture and available water-holding capacity. As clays increase in a soil, so does water-holding capacity. Typically, clay loam soils hold more than twice as much water as sandy textured soils (adapted after Ley and others 1994). The presence of humus in topsoil increases water-holding capacity of loams and sandy loams at a rate of 2.25% water to each percent rise in soil humus (Jenny 1980) which equates to approximately 0.75% increase in water for every 1% increase in organic matter.*



the macropores, displacing soil air and creating anaerobic soil conditions (Cook and Nelson 1986). If the rate of application of polyacrylamides is too low, there is a good chance that there will not be much benefit to the soil. Fertilizers and minerals can reduce the amount of water being held (Wang and Greg 1990). Any full scale use of polyacrylamides should be tested at different rates on the site being revegetated. The best candidates for testing these products would be sandy textured soils.

5.3.2 Rock Fragments

Mountainous soils and highly disturbed sites are typically high in rock fragments. The presence of rock fragments is important because the rock reduces the amount of water and nutrients a soil can hold. At high volumes in the soil, rock fragments will limit the composition of species and vegetative cover a site can support.

The rock classification system classifies rock fragments into five size ranges: fine gravels (.08 to 0.2 in), medium gravels (0.2 to 0.8 in), coarse gravels (0.8 to 3 in), cobble (3 to 10 in) and stone (>10 in).

Highly weathered rock can retain some soil moisture depending on the size of the rock fragments and degree of weathering (Flint 1983). For practical purposes, however, it is usually assumed that the presence of cobbles and stone rock fragments in the soil will reduce the available water-holding capacity of the soil proportionally. For example, a sandy loam soil without rock fragments has a water-holding capacity of 1.4 inches per foot of soil (Figure 5.11). When 30% large rock fragments are added to the soil profile, the available water-holding capacity is reduced to 70% or 0.98 inches of available water (1.4 * 0.7 = 0.98). Fine and medium gravels (0.08 to .8 inches in diameter), on the other hand, hold some moisture. A rule of thumb is that these fine and medium gravels reduce water-holding capacity by two-thirds of their volume. In the above example, if 30% of the soil were composed of medium and fine gravels, the available water in this soil would be 1.12 inches per foot (1.4 - (1.4 * 0.3 * 0.66)).

5.3.2.1 Rock Fragments – How to Assess

Rock fragment content is usually determined in the field during soil surveys or soil sampling for laboratory analysis. Large rock fragments, such as cobble and stones, are estimated in a variety of ways. The most common methods are surveying freshly exposed road cuts or observing soil excavation during road construction. Estimating the volume can be difficult, and often the amount of rock is over- or under-estimated. One method of estimating large rock in road cuts is to take a digital picture and lay a grid over the surface, as shown in Figure 5.12. Whenever rock is estimated from old road cuts, it must be discerned whether a portion of the rock is masked by soil that might have moved over the rock. This is why it is best to observe freshly exposed road cuts.

Inset 5.1 – Measuring Available Water-Holding Capacity in the Field
(modified after Wilde and others 1979)

Available water-holding capacity (AWHC) can be measured in the field by collecting soil samples from a reference site or disturbed site in mid to late summer when soils are presumably as dry as they can be. For determining AWHC for undisturbed soils, samples are collected in bulk density rings in the same manner as sampling for bulk density (See Section 5.3.3). After removing the rings from the soil, cardboard or plastic is secured at each end of the rings to keep the soil from falling out. Rings are placed in airtight plastic bags to ensure that the samples stay intact during transport. The samples are weighed and placed in a bucket and filled with water to just the top of the ring. The sample is allowed to saturate with water. After you see glistening at the surface (indicating the soil is fully saturated), the ring is removed and placed upside down on paper towels and allowed to dry (soil surface should be in direct contact with towels). When paper towels become saturated with water, they are removed and replaced with dry towels. After 24 hours paper towels should not be saturated with water when in contact with the soil. The ring is then weighed. Available water-holding capacity *(inches of available water per foot) = (wet weight – dry weight)/volume of cylinder * 12*. For disturbed soils, the sample can be collected in an airtight bag and placed in a cylinder of known volume (placed firmly in the cylinder). The test is conducted from this point on as described above.

Figure 5.12 – The amount of rock in a section of soil can be roughly estimated from road cuts. Large rock can be determined by laying a grid of 20 circles over a photograph of a road cut and recording the number of circles intercepting rock (in the center of the circle). This value is divided by the total number of circles in the grid to obtain the percentage of subsoil in rock fragments. In the picture below, subsoil contains approximately 25% large rock (5 intercepted rocks divided by 20 points).

Figure 5.13 – *The number 10 sieve (2mm opening) on the right separates soil particles (C) from rock particles (B and A). The 3/4 inch sieve on the left separates the fine and medium gravels (B) from the coarse gravels (A).*

Rock encountered while digging a soil pit will give a more accurate estimate of larger coarse fragments. Cobbles and stones, if they can be moved, are set apart from the soil when the pit is excavated. The volume of cobbles and stones is then visually compared to the volume of soil excavated from the soil pit to estimate the percentage of rock fragments.

Gravel content is determined from the excavated soil by sieving it through several soil sieves. Sieves are available through most engineering equipment companies (Figure 5.13). The 2 mm sieve (also referred to as a #10 sieve) is the most important sieve to use because it separates the gravels from the soil fraction. Another useful sieve is the 3/4 inch sieve because it separates the fine and medium gravels from the coarse gravels. This sieve can be used in the field to remove larger rock fragments from the soil sample to reduce the volume. Finer sieving can be done back at the laboratory with a 2 mm sieve. If the soils are dry, this can be done in the field. When soils are moist, they must be air dried first before they can be sieved. The gravel and soil fractions are weighed and the gravel weight is divided by the weight of gravel plus soil (multiplied by 100) to determine the percent gravel.

It is important to remember to include the volume of cobbles and stones estimated in the field with the gravels determined through sieving to calculate the total rock fragments in a soil:

% rock fragments in profile = (100 - % cobbles and stone) * % gravels in sample

For example, a soil is estimated to have 25% cobbles and stones from observing road cuts and from several soil pits. Sieving shows that 50% of the sieved soil is composed of gravels. The soil would be composed of 25% cobbles and stones, 37.5% gravels ((100 – 25) * .50), and 37% soil.

5.3.2.2 Mitigating for High Rock Content

***Rock Removal* –** Removing rock fragments from the soil will increase the available water-holding capacity of a soil. This can be done through screening and reapplication of the screened material. Screened subsoil should be kept separate from topsoil in this operation. The greatest benefit from screening would be with soils that are very high in cobble and stone, where the reduction in volume of rock in the soil would be significant. The "grizzly feeder" acts as a giant sieve to sort rock from soil. Rocky soil is dropped on the surface of the grizzly and fine soil falls through the screen while the rock fragments roll to the side through gravity or vibratory action, depending on the type of grizzly.

Incorporate Compost **–** Compost incorporated in the soil at high rates will increase the water-holding capacity of a rocky soil (See Section 10.1.5, Organic Matter Amendments). Depending on the size of the coarse fragments, incorporation can be difficult.

Surface Apply Compost **–** A more practical method to mitigate for rocky soils is to apply composts to the soil surface without mixing. When surface applied, composts can be good growing media for seeds of grasses and forbs (See Section 10.1.3, Mulches). At rates of greater than 3 inches applied to the surface, seeds can germinate well and establish into seedlings that can access moisture and nutrients not only from the compost, but also some moisture from the rocky soil below the compost.

Apply Topsoil **–** If topsoil is available, it can also be applied over a rocky soil (See Section 10.1.4). Topsoil depth will have to be placed deep enough to compensate for the quantity of rock in the soil being covered.

Planting Islands **–** On very rocky sites, mitigation of rocky soils can be accomplished by focusing mitigating measures into planting islands (See Section 10.1.8.4). Topsoil application, compost additions, or rock removal can occur in mounds, pockets, or benches strategically located throughout a revegetation unit and then planted with trees and shrubs.

5.3.3 Soil Structure

Just as soils are composed of many-sized mineral particle sizes, they are also composed of different size voids, or pores, whose influence is responsible for water movement, water storage, air flow, and root penetration. Small pores (micropores) strongly influence soil moisture-holding capacity, while large pores (macropores) are responsible for water movement, air flow, and root penetration. The arrangement of large pores is called soil structure. It is qualitatively observed as cracks, channels, aggregates, crumbs, and clods in the soil, and described by alternative terms such as friability and tilth. Water flow and root penetration depend on good soil structure. If soil structure is poor or compacted, roots are less able to penetrate the soil to access the water. Soil structure is important for other soil functions such as air flow, drainage, permeability, infiltration, and as essential habitat for soil life. Soils with good structure are typically very productive.

Soil structure is significantly reduced by heavy equipment on soils. The pressure applied by the equipment compacts the macropores (large pores), reducing soil volume and increasing soil density. This impact is called soil compaction (Figure 5.14). The effects of soil compaction on tree growth are well documented (Poff 1996). Trees growing on highly compacted soils have far less root, stem, and leaf production than those growing on non-compacted sites. Studies have shown a linear relationship between the increase in surface soil bulk density and decrease in height growth of young Douglas-fir and ponderosa pine trees (Froehlich and McNabb 1984).

Figure 5.14 – *Compacted soils are created by heavy equipment operating over soil. The large pore spaces are compressed and the soils often form a platy structure as shown in this photograph.*

Figure 5.15 *– Compacted soils drain very slowly, as the puddles on the surface of the obliterated road in this photograph indicate. During rainfall or snowmelt, soils can stay saturated for days and even weeks. Establishing seedlings during this period can be very difficult because roots cannot survive when soils are poorly drained. Seedlings shown in this photograph were dead within three months.*

Figure 5.16 *– A soil core is used to determine bulk density and available water-holding capacity.*

It should be assumed that soils will be highly compacted after construction due to the use of heavy equipment. In addition to reducing the potential of a construction site to grow vegetation, compaction increases runoff and sedimentation in rainstorm events. During the growing season, this means there will be less water entering the soil after rainstorms.

Compaction can occur several feet below the soil surface, depending on the type and weight of the equipment, soil texture, and soil moisture content. Very compacted strata can significantly reduce or eliminate root penetration. Where compacted strata occur, downward water movement is restricted and water may saturate the soil layers above the compacted layer. The resulting saturated soil conditions can be very restrictive to root growth because of the lack of oxygen and the propensity for higher incidence of disease (Steinfeld and Landis 1990) and ultimate mortality (Figure 5.15). Compacted layers will naturally recover to their original porosity through root penetration, animal activity, and freeze-thaw events, but recovery can take 20 to 70 years (Wert and Thomas 1981; Froehlich and others 1983).

5.3.3.1 Soil Structure – How to Assess

It is easy to differentiate good soil structure from compacted soil (Figure 5.14) by touch or sight, but measuring it quantitatively is difficult. There are several indirect field tests to quantify soil structure. These include bulk density and penetrometer tests. It is important to consider that exact soil measurements are less important than recognizing that after construction, most soils will be compacted. Nevertheless, these tests are good to perform when there is a question of degree of compaction, during reference site assessment, or when assessing the effects of revegetation treatments over time.

The bulk density test measures the dry weight of a standard volume of soil. If the soil has a high porosity, the bulk density values will be low; if the soil is compacted, the bulk density will be high. In this method, a cylindrical tube is driven into the soil with a portable bulk density sampler and a soil core is removed. The soil is shaved evenly on both ends so that the soil is exactly the shape and volume of the cylinder. The soil is then removed from the cylinder, oven-dried and weighed.

***Figure 5.17 –** A simple, qualitative method of determining compacted layers is to mark the face of a long shovel with a ruler. By pushing the shovel in the ground with the entire body weight and observing the distance the shovel penetrated can give a measure of the depth to a compacted layer.*

Bulk Density = weight of soil (g) / cylinder volume (cc)

Bulk density values of a disturbed site must be related back to the bulk density of an adjacent reference site to make the values meaningful. Remaining within a 15% increase in bulk density over reference site values is ideal. Unfortunately, the bulk density method is time consuming and cannot be conducted on soils with high rock fragments.

A less quantitative, but more practical, method of measuring soil porosity is with a soil penetrometer. This equipment measures soil strength instead of density. Compacted soils have greater strength, and greater resistance to penetration by a penetrometer, than non-compacted soils. There are several types of penetrometers that can be purchased for field work—penetrometers that measure the resistance as a continuous pressure is applied to the probe and penetrometers (impact penetrometers) that measure the number of blows of a hammer to drive the penetrometer into a specified depth. A monitoring protocol for assessing compaction using an impact penetrometer has been developed by the NRCS (Herrick and others 2005b). The most practical and economical field method for assessing compaction, however, is simply using a long shovel as shown in Figure 5.17. In this method, a site is traversed and, at predetermined intervals, a shovel is pushed into the ground to determine how loose the soil is. By applying the entire body weight to the shovel and observing the distance the shovel penetrates the soil, a qualitative measurement of soil compaction can be made. A rule of thumb is that a shovel penetrating over 12 inches deep indicates that a soil has a very high porosity; penetration below 3 inches deep indicates a very low porosity.

Whether a shovel is used or a soil penetrometer, the readings are affected by rock content and soil dryness. When soils are dry, they have more strength and higher resistance to penetration. This is why any comparative sampling using a penetrometer must be done at the same moisture levels. Encountering rock poses an obvious problem to the use of penetrometers. It can be overcome by moving the penetrometer around until a point is found where the penetrometer can be applied without hitting rock.

Penetrometer values for disturbed sites must be evaluated against those from reference sites for comparative analysis.

5.3.3.2 Mitigating for Poor Soil Structure

Tillage – Breaking up compacted layers can be done effectively when deep tillage equipment is operated correctly (See Section 10.1.2, Tillage).

Incorporate Organic Matter – The effectiveness of deep tillage can be enhanced if organic matter is incorporated into the soil prior to tillage (See Section 10.1.5, Organic Matter

Amendments). Organic matter can keep the soil from settling back to higher, pre-tillage densities. Application rates at which organic matter showed positive effects on soil structure was observed at a ratio of 25% incorporated organic matter to 75% soil by volume (Claassen 2006). Longer shreds of organic matter are preferred over smaller, chip sizes because the longer strands create interconnecting pathways for water, air, and roots while increasing soil strength (Claassen 2006). The additions of non-composted organic matter, however, will tie-up nitrogen for a period of time. While this might be problematic in the short term, the importance of developing soil structure for long-term site recovery might override the concerns about the lack of immediately available nitrogen.

Operate Equipment With Care **–** Soil compaction is greatest when soils are moist. When heavy equipment is being used on non-compacted soils, the moisture status of the soil must be considered. Under moist and wet conditions, soil structure may be severely damaged. If heavy equipment must be used, schedule it during times when the soil is dry. Compaction can be also be minimized by using smaller equipment (Amaranthus and Steinfeld 1997). Leaving slash or deep mulch on the soil surface can further reduce the amount of compaction because this material will provide some cushioning to the soil.

Avoid Last Minute Compaction **–** There is no avoiding soil compaction during construction, but compacting the soil after mitigating treatments have been implemented must be avoided. There are many cases where the benefits of mitigating treatments have been nullified by the lack of attention to heavy equipment operations after topsoil additions or tillage treatments have been made. For example, topsoil salvage and placement, as discussed repeatedly in this manual, benefit the site in many ways. But this expensive mitigating measure loses much of its value if the soils are compacted during or after soil placement. Once topsoil is deep-tilled, there must be no more passes by equipment over the soil.

5.3.4 Rooting Depth

Rooting depth is the distance from the surface of the soil to the lower reaches that roots can penetrate. It encompasses any strata that can be accessed by plant roots (topsoil, subsoil, and parent material). The deeper the rooting depth of a disturbed site, the greater the total available water storage and the higher the productivity of the site.

Rooting depth is affected by restrictive layers that block root penetration to lower strata (See Section 5.7.2, Restrictive Layer). For example, the rooting depth of a post construction site is estimated at 6 feet deep. However, further investigation finds that there is a highly compacted layer at 12 inches, which would limit most, if not all, root penetration below that point. The rooting depth under these conditions has been reduced to only one foot of soil instead of six feet. Restrictive layers also include soils with very high or low pH, toxic materials, or a high water table.

Rooting depths vary by plant species and age of the vegetation. Most mature tree species have deep root systems that access subsoil and parent material; roots of grasses and forbs are predominantly limited to the surface soils. Annual grasses and forbs require less rooting depth than perennial grasses and forbs, with the roots of these species growing in the upper surfaces of the soil. The age of the vegetation also determines the abundance and location of roots. Newly established seedlings have shallow roots but, as the plants mature, root systems expand to access moisture deeper in the soil.

Rooting patterns and root morphology play a role in how plants access soil water. Some species have finer textured root systems that access tightly held soil moisture; other species have aggressive root systems that can penetrate deeply into cracks between rock fragments. Grasses, for instance, have shallower root systems than trees and shrubs, but their small size and high density in the surface soil gives them an advantage in shallow soils.

5.3.4.1 Rooting Depth – How to Assess

Rooting depth should be estimated from reference sites during planning and post-construction, but is not always an easy parameter to measure. Observing road cuts is often the best means to determine rooting depth below the topsoil and subsoil. Rock type (e.g., granite, sandstone, schist), fracturing patterns, rock weathering, and the degree of rock fracturing will give an indication of rooting depth. Observing the amount and type of roots in the fractures of existing road cuts will give a good idea of rooting depth.

Fracturing and weathering of rock can also be determined from geotechnical analysis. If the bedrock has been drilled, the drill log report can give an indication of degree and depth of rock fracturing and weathering. One way that rock quality is assessed is through a classification called the Rock Quality Designation Index (RQD). This system rates the bedrock by how much fracturing is observed in the cores. It is calculated by measuring the pieces of rock in the core sample that are longer than 10 cm, summing the length of these pieces, and dividing by the total length of the core (Deere and Deere 1988). A small RQD means that the bedrock is highly fractured whereas a high RQD means the bedrock is massive. A RQD may be poor from an engineering standpoint because of the high fractures, but favorable from a revegetation standpoint because cracks will hold some moisture and allow root penetration. A RQD rated as "very poor," "poor," and even "fair" should be somewhat favorable to root penetration.

Rooting depth is also affected by the presence of a restrictive layer caused either naturally or by compaction. How to determine the presence of these layers is addressed in Section 5.3.3.1 and Section 5.7.2.1.

There are many references in the literature defining the depth of soil needed to support different plant communities. For example, 18 inches of soil has been shown to support simple grassland ecosystems, but more diverse native grassland communities are reported to require up to 4 feet or more (Munshower 1994). These figures can be misleading if they are not put in the context of site climate and soil type. In many respects, it is more useful to state the total available water-holding capacity (TAWHC) of a site rather than the rooting depth.

Figure 5.18 shows how the TAWHC is calculated. Using the same format and equations, a similar spreadsheet can be created for your use by copying the equations into the "Results" column. In this example, there is 1 foot of topsoil and 2 feet of subsoil over a highly fractured basalt. The topsoil has a loam texture and available water-holding capacity of 2.0 inches (estimated from Figure 5.11 or obtained from lab results) but, because of the rock fragments, it is reduced by approximately 0.4 inches. The subsoil has a high water-holding capacity because of high clay content, but the available water-holding capacity is reduced by half due to rock. Highly fractured basalt is encountered at a depth of 2 feet, and it is estimated from the road cut that approximately 30% is actually fractured. Within these weathered fractures is a gravelly clay loam textured material storing approximately 0.5 inches of water. The TAWHC for this site would be the sum of all sections of soil (approximately 3.2 inches).

The TAWHC can be used for relative comparisons between revegetation units and reference sites. For example, the TAWHC for a post construction soil is 3.6 inches compared to an adjacent reference site, which is 6 inches. If the desired future condition of the post construction soil is to be similar to the adjacent reference site, then the TAWHC of 3.6 inches must be increased upward toward 6 inches for the site to be capable of supporting the vegetative community occurring on the reference site.

5.3.4.2 Mitigating for Poor Rooting Depth

Increase Available Water-Holding Capacity – Improving the water-holding capacity of the existing soil will increase TAWHC. Mitigating measures discussed in Section 5.3.1, Soil Texture and Section 5.3.2, Rock Fragments can be used to increase soil moisture.

Tillage – If restrictive layers due to compaction are encountered, deep tillage should be considered. Section 10.1.2 provides guidelines for deep tillage.

Apply Topsoil – Increasing rooting depth and TAWHC can be accomplished by applying topsoil (See Section 10.1.4).

Planting Islands – Mitigating measures, such as applying topsoil, organic matter incorporation, deep tillage, and other measures that increase water-holding capacity, can be focused in strategic locations, such as planting islands. This will conserve on materials and reduce costs (See Section 10.1.8.4).

Blasting – Strategic blasting to shatter the parent material has been suggested (Claassen 2006) as a possible means of increasing rooting depth.

__Figure 5.18 –__ The total available water-holding capacity (TAWHC) is the total amount of moisture that a soil can store for plant growth when fully charged with water. TAWHC values for each revegetation unit are helpful for determining which species will perform well, and in developing the mitigating measures necessary to increase water-holding capacity or rooting depth. TAWHC is calculated by determining the texture, rock fragment content, and depth of each soil layer, and calculating how much water each layer will optimally store. The water-holding capacity of each soil layer is added together to obtain the TAWHC for the soil profile. The analysis requires determination of rooting depth to ensure that deep moisture is taken into account.

Soil Strata	Soil Characteristics	Data		Results		Equations
0 to 1'	AWHC of texture (inches / foot):	2	(A)	2		From Figure 5.11 or lab results
	Small Rock (%):	20	(B)	0.264		= A * (B / 100) * 0.66
	Large Rock (%):	5	(C)	0.1		= A * (C / 100)
	Thickness (ft):	1	(D)	1		(the thickness of soil section)
	Available water by section:			1.6	**(E)**	= (A - B - C) * D
1 to 2'	AWHC of texture (inches / foot):	2.2	(F)	2.2		From Figure 5.11 or lab results
	Small Rock (%)	35	(G)	0.5082		= F * (G / 100) * 0.66
	Large Rock (%):	25	(H)	0.55		= F * (H / 100)
	Thickness (ft):	1	(I)	1		(the thickness of soil section)
	Available water by section:			1.1	**(J)**	= (F - G - H) * I
2 to 5'	AWHC of texture (inches / foot):	2.2	(K)	2.2		From Figure 5.11 or lab results
	Small Rock (%)	35	(L)	0.5082		= K * (L / 100) * 0.66
	Large Rock (%):	70	(M)	1.54		= K * (M / 100)
	Thickness (ft):	3	(N)	3		(the thickness of soil section)
	Available water by section:			0.5	**(O)**	= (K - L - M) * N
Total Available Water Holding Capacity (inches): 3.2						= Sum of (E, J, O)

5.3.5 Mycorrhizal Fungi

The discussion to this point has addressed the primary factors responsible for soil water storage (soil texture, rock, and rooting depth) and the accessibility of roots to grow to this water (soil structure). In this section, the discussion turns to how plants increase the efficiency of accessing water through mycorrhizae. While mycorrhizae provide many other benefits to the site besides water enhancement, they are covered in depth in this section because of the importance of water to establishing vegetation on highly disturbed sites in the western United States.

Mycorrhiza is the unique symbiotic relationship between fungi (called mycorrhizal fungi) and host plants. To the naked eye, many mycorrhizal fungi appear as a fine web or netting that seems to connect the root system to the surrounding soil (Figure 5.19), and in essence, this is exactly what is occurring. The extremely small hyphae of the mycorrhizal fungi are actually taking on the form and function of an extended root system of the plant. Because mycorrhizal hyphae are up to five times smaller than plant roots, they are able to access spaces in the soil not easily accessible by the larger plant roots. Mycorrhizal hyphae not only provide the plant with a greater access to soil moisture and nutrients, they also surround and protect roots from soil pathogens. In return, the host plant supplies carbohydrates to keep the mycorrhizal fungi alive.

Mycorrhizae play a critical role in site restoration by building soil structure. Hyphae and water stable organic "glues," like glomalin, are excreted by the mycorrhizal fungi and bind soil particles together into aggregates. These aggregates stabilize the soil, improving soil structure (See Section 5.3.3, Soil Structure) important for good air exchange and water permeability. This basic soil building process, or repair, facilitates the creation of nutrient reserves and nutrient cycling essential for restoring ecosystems (Miller and Jastrow 1992). Mycorrhizal fungi can also improve survival of tree and grass seedlings (Steinfeld and others 2003; Amaranthus and Steinfeld 2005). A healthy population of mycorrhizal fungi has also been shown to increase plant biomass and cover (Wilson and others 1991; Brejda and others 1993; Sobek and others 2000), and increase the diversity of native species (Smith and others 1998; Charvat and others 2000).

***Figure 5.19** – Mycorrhizal fungi can greatly increase the surface area of the root system. The ectomycorrhizal fungi attached to the pine root system (A) comprise most of the absorptive surface shown in this photograph. The mycorrhizae include brown branched structures (B) and white hyphae or filaments (C). (Photo courtesy of Mike Amaranthus, Mycorrhizal Applications).*

Ninety percent of all terrestrial plants form symbiotic relationships with mycorrhizal fungi. Of the thousands of known species, most generally fall into two categories – ectomycorrhizal fungi and arbuscular mycorrhiza fungi.

Arbuscular mycorrhizal fungi (AMF), formerly called endomycorrhizae, are the most commonly occurring mycorrhizal fungi, forming on 75% to 85% of plant species. These include legumes, composites, grasses, bulbs, most shrubs, and ferns. In addition, AMF occur on many tree species, including redwoods and some cedars, and many types of tropical trees. AMF grow inside the roots of the host plant and extend hyphae out into the soil. These fungi are more general in their association with plant species, meaning that one mycorrhizal species can form an association with a broad spectrum of plant species. AMF reproduce in two ways: 1) by forming single spores outside of the root, and 2) from fungal structures (vesicles and hyphae) present inside a colonized root system. Arbuscular mycorrhizal fungi do not disperse their spores in the wind, but instead are dispersed from root to root or by animals. For this reason, recolonization of drastically disturbed sites by arbuscular mycorrhizal fungi can be slow, especially if there are limited sources of healthy, undisturbed soils nearby to repopulate the site.

Unlike arbuscular mycorrhiza fungi, ectomycorrhizal fungi, as the name implies, coat the outside of the roots with hyphae that extend out into the soil. Ectomycorrhizal fungi form on 5% to 10% of plant species, the majority of which are forest trees in the western United States. Species include Douglas-fir, western larch, true firs, spruce, hemlock, oak, manzanita, willows, and cottonwood. These fungi form a netting of fine hyphae around the root system of the tree that is often observable on nursery produced seedlings inoculated with mycorrhizal spores. Unlike AMF, the relationship between ectomycorrhizal fungi and host species is very specific. Many ectomycorrhizal fungi species have evolved to associate with only one plant species. Ectomycorrhizal fungi produce fruiting bodies, such as mushrooms, puffballs, and truffles, that yield reproductive spores for wind or animal dispersal.

AMF and ectomycorrhizae do not associate with all plant species found in the western United States. Manzanita and madrone, for instance, form arbutoid mycorrhizae, while huckleberry form ericoid mycorrhizae. The remaining 10 % of plant species do not form mycorrhizae at all. Many of these plant species have evolved root systems that function similarly to mycorrhizae and therefore can outcompete mycorrhizal species during early establishment on highly disturbed sites. While host plants might be present during early establishment of these sites, they nevertheless languish because of the lack of mycorrhizal fungi, giving non-mycorrhizal species a distinct advantage. This advantage is why many plant species that are considered weeds are non-mycorrhizal species.

5.3.5.1 Mycorrhizal Fungi – How to Assess

Where soils have been drastically disturbed, it can be assumed that the mycorrhizal fungal propagules that colonize plant roots are drastically reduced or absent from the site. The size and severity of the disturbance determines the colonization rates of mycorrhizal fungi. As the level of disturbance increases, the density of viable fungi propagules typically decreases. Small disturbances surrounded by native forests or rangelands often reestablish quickly; in larger disturbances, where topsoil has been removed, recolonization by mycorrhizal fungi may take years.

Some laboratories offer testing for mycorrhiza fungi, but these are expensive tests. Since it is unlikely that mycorrhizal fungi will be found in recently disturbed sites lacking topsoil, conducting these tests for most projects are unnecessary.

5.3.5.2 Mitigating for Lack of Mycorrhizal Fungi

For most construction projects, the management of mycorrhizae should be considered in the early stages of project planning. Several strategies are available to enhance mycorrhizal colonization.

Minimize Soil Disturbance **–** Operations that maintain topsoil will often preserve mycorrhizal inoculum and maintain soil nutrition. Partially disturbed topsoil is often adequate for reestablishing mycorrhizal plant species. Partial disturbances include clearing and grubbing of road right-of-way vegetation, ground-based logging, and light to moderate intensity burns. Colonized root systems left behind in these operations are sources of inoculum for endomycorrhizae.

Leave Undisturbed Areas **–** The colonization of AMF into highly disturbed sites is slow. Spores are transported by soil erosion and animal movement, but not by air. By leaving small areas of native vegetation and undisturbed soils within the larger disturbance, travel distance for the spread of fungi is reduced, facilitating a quicker repopulation of AMF. This practice is especially important where the size of the disturbance is large.

Salvage Topsoil **–** Reapplying topsoil to drastically disturbed sites is commonly done when quality native topsoil is available (See Section 10.1.4, Topsoil). If topsoil is obtained from non-forested sites, such as meadows, rangelands, and unforested clearcuts, AMF is often abundant because the host plants are grasses and forbs. It should not be assumed, however, that there will be ectomycorrhizal spores present to colonize the roots of tree seedlings.

Figure 5.20 **–** *The response to the addition of mycorrhizae spores to non-inoculated seedlings can sometimes be dramatic. Both sets of sticky currant (Ribes viscosissimum) seedlings shown in this photograph were stunted for months after seed germination. AMF spores were applied to the surface of each seedling container on the left with immediate growth response, while those on the right remained stressed (photo taken 50 days after inoculation).*

Apply Topsoil to Planting Holes **–** If topsoil is very limiting, placing healthy topsoil into holes prior to planting seedlings is an effective method of introducing an inoculum to a disturbed site. Collecting soils as inoculum from young, actively growing forests has been shown to be suitable inoculum for young tree seedlings (Amaranthus and Perry 1987).

Apply Commercially Available Mycorrhizal Fungi Inoculums **–** Applying commercially available mycorrhizal fungi inoculum is another method used to repopulate highly disturbed sites (See Section 10.1.7, Beneficial Soil Microorganisms). Commercially available sources of mycorrhizal inoculums are available for ectomycorrhizal and AMF plant species. These inoculums can be applied in hydroseeding slurries, as seed coats and root dips, through irrigation systems, or incorporated into the soil by broadcasting or banding. When purchasing live plants from a nursery, rooting media can be inoculated with mycorrhizal fungi during nursery culture (Figure 5.20). Fine grades of mycorrhizal inoculum can be applied to the surface of the soil and will move into the soil surface with rainfall. Coarser textured commercial inoculums must be incorporated in the soil to make them effective.

Reduce Fertilizer Use **–** While the application of fertilizer can increase plant biomass in the short term, it can also suppress mycorrhizal infection (Jaspers and others 1979; Claassen and Zasoski 1994). However, low rates of fertilizer have been shown to help establish plant cover and improve mycorrhizal colonization (Claassen and Zasoski 1994).

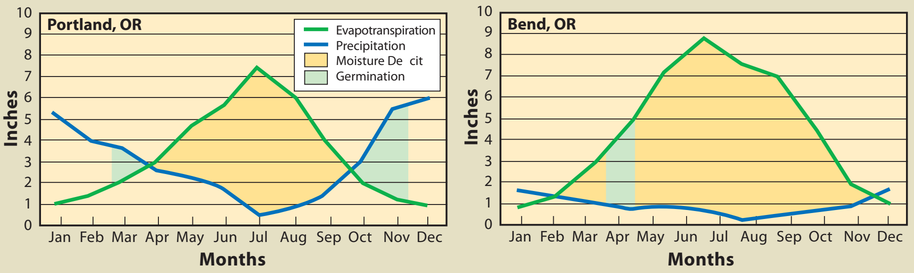
5.4 WATER LOSS

Water loss is the depletion of soil moisture during the year through transpiration (loss of water through leaves/needles) and evaporation of soil moisture from the soil surface. The rate at which evaporation and transpiration draw moisture from the soil profile is the evapotranspiration (ET) rate. ET rates can change daily, weekly, and seasonally: 1) daily changes occur as the sun hits vegetation, temperatures and wind speeds rise, and ET rates increase; 2) weekly changes occur when ET rates rise and fall as weather systems change from hot and dry to cool and wet; and 3) seasonal changes occur as air temperatures rise in spring, reaching maximum temperatures and minimum humidities in the middle of the summer, then decline in the fall (Figure 5.21).

Water loss due to ET can be influenced by a number of abiotic and biotic factors, primarily:

- Wind,
- Site aspect,
- Competing vegetation, and
- Soil cover.

Figure 5.21 **–** *Evapotranspiration (ET) rates can be found for many climate stations at http://www.wrcc.dri.edu. Plotting monthly evapotranspiration rates with precipitation rates (also found at this website) gives a good indication of the climate during plant establishment and growth phases. The following graphs show that the climate in Portland, OR has a very favorable environment (low ET and high precipitation) for seed germination in March; plant establishment should be adequate without the need for extra mitigating measures. The weather in the fall is also conducive to germination and plant establishment. The climate at Bend, OR during April and May, when seeds in that area germinate, has very high ET rates and very low rainfall; mitigating measures such as applying mulch over the seeds at sowing might be critical for success.*



On both disturbed and undisturbed sites, the effects of wind patterns and aspect on ET rates influence the types of species that can survive and grow. Competing vegetation that colonize a site following disturbances can have a large influence on the amount of soil moisture stored and the availability to desirable plants.

Evaporation of moisture from the soil surface is not generally a major factor on undisturbed soils because they are often protected by a surface mulch of litter and duff. These soil covers allow rainfall or snowmelt into the soil, but create a barrier to surface evaporation. Surface evaporation becomes a factor when these protective covers are removed or destroyed during construction.

Consider the plant as the "middleperson" between the atmosphere, which demands water from the plant, and the soil, which acts as a bank of moisture from which the plant is able to draw. When the atmosphere is demanding very little water (low ET rate), the plant easily pulls water from the soil to the leaves. Over time, as soil moisture becomes depleted, the plant comes under greater stress. Not only is the atmosphere demanding greater moisture from the plant, but less moisture is available. Consequently, the plant comes under very high moisture stress. The amount of stress that a plant is under is referred to as plant moisture stress or PMS (Figure 5.23). PMS is at its highest from middle through late summer in the western United States, when the ET rates are at their highest and soil moisture levels at their lowest.

5.4.1 Wind

Wind is often overlooked as a factor in the success or failure of reestablishing native vegetation, but it can play a major role, especially on sites where summers are hot and dry and soil moisture

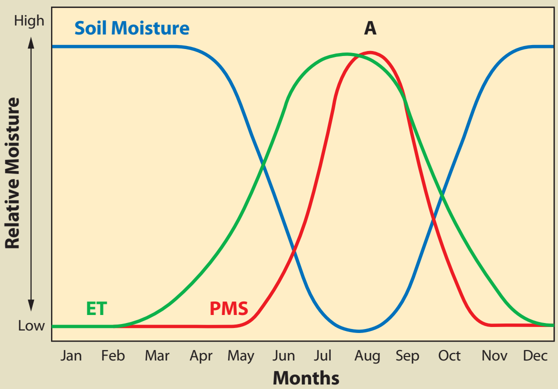
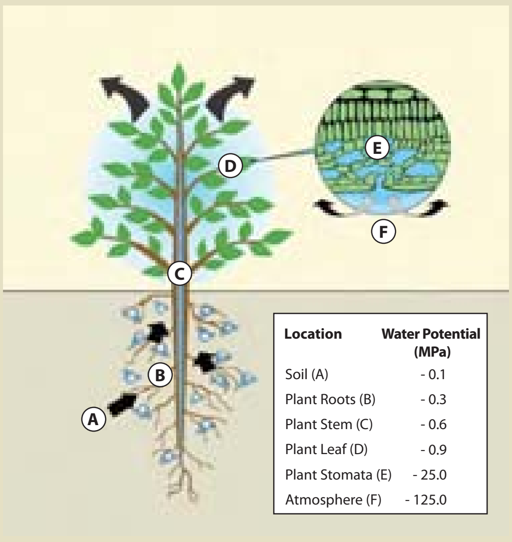


***Figure 5.22** – Conceptual relationship between evapotranspiration (ET), soil moisture, and plant moisture stress (PMS). PMS lags behind ET in late spring because soil moisture is still moderate to high from the winter rains. By mid summer (A), plant moisture stress has increased to its greatest level in the year because soil moisture is at its lowest. Newly planted seedlings undergo extreme stress during this period. Unless their root systems have grown deeper into the soil, accessing a greater soil moisture, or ET rates are reduced by cooler weather, seedlings will die. In late summer and early fall, cooler weather returns and rains wet the soil, driving ET and PMS rates down again.*



Location	Water Potential (MPa)
Soil (A)	- 0.1
Plant Roots (B)	- 0.3
Plant Stem (C)	- 0.6
Plant Leaf (D)	- 0.9
Plant Stomata (E)	- 25.0
Atmosphere (F)	- 125.0

***Figure 5.23** – Plant moisture stress (PMS) is a measure of the tension or pull of moisture through a vascular plant. Much like a straw, when the demand for moisture at the surface of leaves is high, moisture is drawn from the stomata. This creates a pull of water through the leaves, stem, and down to the roots, which draws water from the soil.*

levels are low. Until seedlings become established, high winds can severely limit growth and can ultimately lead to mortality.

5.4.1.1 Wind – How to Assess

Wind speed equipment is available, but most likely too costly for most revegetation specialists. Site visits during different times of the year can give some indication whether wind is a problem. Other site characteristics, such as position on the slope (e.g., ridgelines are more prone than valley floor), or proximity to forested environments – as forests often reduce wind speeds, – can be used to infer wind strengths and directions. In many environments, prevailing winds often come from one, or sometimes two, directions. Existing vegetation can sometimes give clues to prevailing wind directions (e.g., trees bent away from the prevailing wind). County and state department of transportation employees are often resources for local weather information. Recognize that road construction itself may change wind patterns (e.g., creating a wind tunnel by constructing a throughcut or removing a swath of existing vegetation). Some visual indicators of wind erosion are wind scour (See Figure 5.40 in Section 5.6), exposed roots, and deposition areas.

5.4.1.2 Mitigating for High Wind

Road Design **–** Designing islands of undisturbed vegetation to help break up wind patterns can aid vegetation establishment. The taller the plants left undisturbed, the greater the wind protection. Established trees, particularly those with low-growing branches, give the greatest protection from wind.

Wind Barriers **–** Obstacles that block wind at the soil surface can be effective for early seedling survival. These obstacles can include stabilized logs, large rocks, berms, and stumps. In using these structures, seedlings should be planted on the windward side.

Tree Shelters **–** Tree shelters completely surround seedlings and block them from the wind (See Section 10.4.4, Tree Shelters). They are an effective means of reducing ET rates created by high winds during early establishment. Once the vegetation has emerged from the top of the tube, however, tree shelters no longer protect the emerging foliage from the wind.

Shade Cards **–** Shade cards are sometimes used to block wind, but they are less effective than the fully enclosed tree shelter (See Section 10.4.3, Shade Cards). When used to block wind, shade cards must be placed on the windward side of the seedling, which is not necessarily the same location that cards would be placed if protection from sun is the objective. Often two shade cards are placed around the seedling for added protection against the wind. Placement of the shade cards at the height of the foliage affords greater protection to the seedling.

Appropriate Species Selection **–** The drying and damaging effects of wind are important considerations in appropriate species selection. A simple assessment of soil type and rainfall may not account for the effects of wind. Choosing hardier, wind-tolerant, and more drought-tolerant species may be necessary to establish vegetation on windswept sites. Find reference sites in windy locations to indicate which species are adapted to wind.

Leave Surface Roughened **–** A roughened soil surface can create a micro-basin or relief that protects young germinants from the drying effects of wind during the establishment phase (See Section 10.1.2, Tillage).

5.4.2 Aspect

Aspect is the direction a slope is facing, and is one of the predominant site characteristics affecting evapotranspiration. South and west aspects receive more solar radiation during the day and have higher ET rates than north and east slopes, and are therefore warmer and drier. Soils on these sites dry out faster than north and east slopes. In spring, during seed germination, south and west aspects can dry very quickly between rainstorms, reducing the rates of germinating seeds. As seedlings emerge and grow through spring and early summer, temperatures on the south and west slopes continue to rise to very high levels, creating very unfavorable conditions for seedling establishment. Even with planted seedlings, high surface temperatures can damage stems near the ground line, severely affecting seedling survival and establishment (Helgerson and others 1992).

In moist, cool climates, where moisture is not the limiting factor, south and west slopes are often very productive and have greater cover. Warmer soil and air temperatures create a longer growing season, offsetting the effects of moisture stress on plant growth.

On high elevation sites, north and east aspects are cold compared to the south and west aspects. The growing season is much shorter, resulting in very different composition of species between aspects. At high elevations, soil temperatures on south and west slopes stay higher longer in the fall, providing the opportunity to plant in the late summer and early fall months (Figure 5.24). During the spring at all elevations, south and west slopes warm up much sooner than north slopes. The differences in soil temperatures between north and south aspects is a consideration for determining when to plant.

5.4.2.1 Aspect – How to Assess

Aspect is measured in the field by facing the fall line of the slope (the imaginary line a ball would roll) and taking a compass bearing downslope. A "northeast slope," "northeast aspect," "northeast exposure," or "northeast-facing slope" all refer to an aspect with a compass bearing facing northeast.

Aspect can also be measured from topographic maps by drawing an arrow perpendicular to the contour lines and pointing the tip of the arrow downslope. Aspect is often a factor for delineating one revegetation unit from another due to the strong influence on growth and survival of seeds, seedlings, and cuttings. It can be useful to differentiate revegetation units using aspect by highlighting all areas on the road plan map with south to west slopes.

Soil and air temperatures differ greatly between aspects; taking temperature measurements can be important for assessing the effects of aspect on revegetation. There are many types of recording devices available on the market, but only equipment that can download data to spreadsheets for analysis and graphing should be considered. Some equipment has become so inexpensive that more than one unit can be purchased (Figure 5.25).

5.4.2.2 Mitigating for South and West Aspects

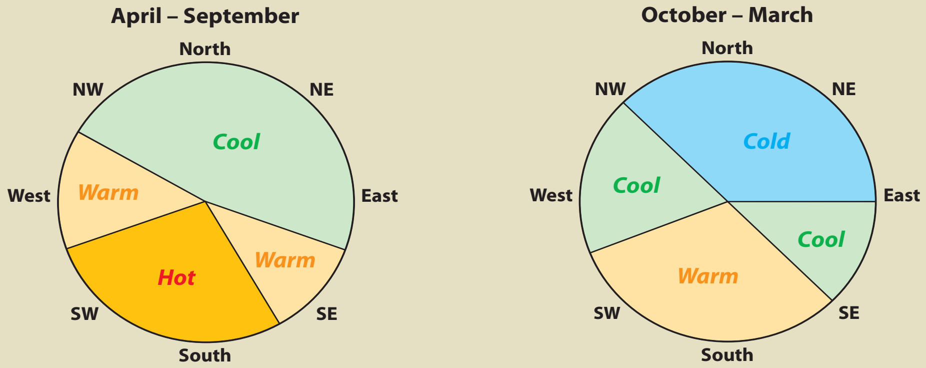
For most sites, any treatment that will shade vegetation on the south and west slopes from intense solar radiation should increase survival and growth of establishing plants.

Overstory Vegetation – Keeping overstory trees at a minimum density of one tree per tenth acre is a rule of thumb for reducing soil temperatures below lethal levels on south aspects (Helgerson and others 1992).

Shade Cards – Shade cards can significantly increase seedling survival on south aspects (Hobbs 1982; Flint and Childs 1984) (See Section 10.4.3, Shade Cards). They must be placed close to planted seedlings so that the stem and lower portion of the seedlings are shaded from the afternoon sun (Helgerson and others 1992).

Obstacles – Large obstacles that cast significant amounts of shade on young seedlings will create a more favorable environment for seedling establishment and increase seedling survival

Figure 5.24 – *Site climate changes throughout the year depending on aspect.*



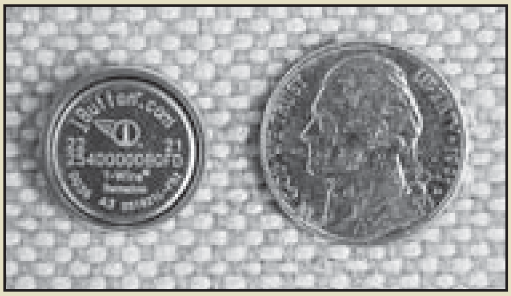


Figure 5.25 – *Temperature recording technology has become smaller and very inexpensive. The iButton® shown next to the nickel can record more than a year of temperature data.*

(Minore 1971). These include stabilized logs, large rocks, berms, and stumps. Seedlings should be planted on the north and east side of these features to be shaded from the afternoon sun.

***Mulch* –** On south exposures, the use of mulches as a moisture barrier should be considered for seedlings, seeds, and cuttings (See Section 10.1.3, Mulches).

***Species Mix* –** The composition of species will probably be different for north and south aspects. Species adapted to hotter and drier environments are used for revegetating south exposures; those adapted to cool, moist environments are used on north aspects. Elevation can offset the effects of aspect. For example, species that grow on low elevation, north aspects often occur several thousand feet higher on south aspects because of the difference in temperatures. Reference site vegetation surveys will guide the revegetation specialists in the selection of appropriate species for each exposure.

***Plant Material Rates* –** South aspects often require a higher density of seedlings, cuttings, and seeds than north aspects due to the expected higher mortality rates. Adjusting for increased mortality rates is made when calculating plant materials rate for seeds (See Section 10.3.1), cuttings (See Section 10.2.2.5), and plants (See Section 10.2.5).

***Planting and Sowing Windows* –** Take advantage of warmer spring and fall soil temperatures on the south exposures by sowing and planting earlier on these sites (See Chapter 6).

5.4.3 Competing Vegetation

Controlling competing vegetation, whether native or non-native, around planted seedlings reduces the rate at which water is withdrawn from the root zone and increases the potential for survival and growth. A major factor affecting seedling survival and growth is the timing and the extent to which roots of competing vegetation encroach into the soil around the roots of the planted seedling. Annual grasses and forbs generally germinate early in the season as soil temperatures warm, often before native species. The early establishment of annual grasses and forbs deplete surface soil moisture, making it harder for perennial species to become established. Cheatgrass is an example of an annual species that establishes quickly in the early spring and depletes the soil moisture in the spring as perennial species are just beginning to germinate.

The rate at which water is depleted is a function of the type of competing species. Grass species, for instance, have very fibrous root systems in the surface soils which allow them to withdraw moisture very quickly and efficiently during dry weather. Unless grasses are controlled, it is very difficult to achieve good survival of planted seedlings in areas with high densities of grass. Perennial forbs are generally less competitive than grasses because their root systems are deeper and less concentrated in the surface where the seedlings are withdrawing moisture.

5.4.3.1 Competing Vegetation – How to Assess

Predicting the potential for vegetative competition at the time of planting on highly disturbed sites is difficult at best. If disturbed sites have been included as reference areas, some predictions of competing vegetation can be made. If competing vegetation becomes established, methods described in Chapter 12 for measuring ground cover can be used for assessment.

5.4.3.2 Mitigating for Competing Vegetation

Do Not Wait to Revegetate – Competing vegetation increases over time. The first year after construction is the optimum period to establish vegetation from seeds, seedlings, or cuttings. By the second or third years, competing vegetation is likely to dominate the site if no revegetation treatments have been applied. If competing vegetation dominates the site before native plants have become established, the measures to control the competing vegetation become far more expensive and less effective.

Scalping – Removal of competing vegetation by manually scraping or scalping the soil surface to remove weeds is ineffective in increasing seedling survival on dry sites when the area scalped is small (<2 foot radius); scalping becomes effective when the clearing is very large (2 foot radius or greater). Some of the problems associated with scalping are: 1) topsoil is removed; 2) surface soil evaporation is high; 3) weeds can invade on the bare soil; 4) infiltration rates are low; and 5) soils are prone to erosion. Scalping becomes more effective when the treated soils are immediately covered with a mulch or weed barrier cloth.

Mulches – Mulches have been shown to increase survival and growth of newly planted seedlings by reducing the amount of moisture loss through evaporation and plant competition (DeByle 1969; Lowenstein and Ptikin 1970; Davies 1988a, 1988b; Helgerson and others 1992). There is an array of mulches that can be used around seedlings (See Section 10.1.3, Mulches).

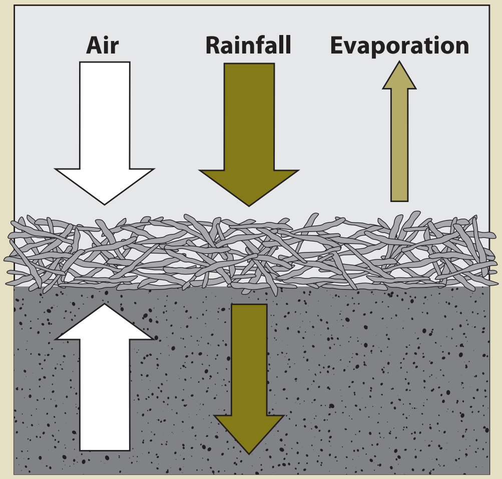
Herbicides – The use of herbicides for controlling competing vegetation around seedlings has been shown to be effective in increasing survival (Childs and Flint 1987). Not only is soil moisture increased in the rooting area of the planted seedling due to reduced transpiration, but dead foliage acts as a mulch or shade, further protecting the soil from moisture loss. There is a risk in using herbicides around shrub or tree seedlings because most herbicides are toxic to these species. The result of using herbicides may range from lower growth rates in subsequent years to increased mortality in the desirable species. This risk can be reduced by 1) using soil-active herbicides, 2) using extreme care when applying herbicides, 3) utilizing herbicides low in toxicity to the planted species, and 4) applying them during periods when the seedlings are less susceptible to damage (Helgerson and others 1992). If the road is on public lands, the land managing agencies should be contacted to discuss policies regarding the use of herbicides. Herbicides must only be applied by a trained professional following manufacturer and government guidelines and regulations for safe application and use.

5.4.4 Soil Cover

The thickness and composition of material that covers the soil surface influences many important soil properties covered in this manual, such as infiltration rates, interception losses, soil temperatures, surface erosion, runoff, and soil moisture loss. The following discussion will focus on soil cover as it affects soil moisture loss through evaporation.

Under undisturbed conditions, soil cover is predominantly composed of duff, litter, and stems of plants. Duff and litter layers form ideal surface mulches because they allow rainfall or snowmelt

Figure 5.26 – *An effective mulch for seed cover is one that is stable and allows good airflow and rainfall entry, while reducing evaporation from the soil surface.*



Introduction
Initiation
Planning
Phase II:
Assess Site
Implementation
Monitoring
& Management
Summary

into the soil while blocking the escape of soil moisture through evaporation. They are also unfavorable seedbeds for weed seeds because duff and litter dry out quickly (Figure 5.26). Disturbed soils, on the other hand, are mostly composed of bare soil. Evaporation from the surface of bare soil can be high, extending to at least 6 inches below the soil surface, affecting seed germination and seedling establishment rates. Until roots of establishing seedlings have extended further into the soil profile, surface drying will negatively affect seedling establishment, especially on sites where water input and storage are already limiting.

5.4.4.1 Soil Cover – How to Assess

Soil cover can be measured on undisturbed and disturbed reference sites or post-construction sites through ground cover monitoring protocols outlined in Section 12.2. In this protocol, the percentage of area in litter, duff, rock, vegetation, and bare soil is recorded and periodic measurements of litter and duff thickness are made. Transects can be conducted after disturbances. However, it is likely that where excavation has occurred, there will be no litter, duff, or vegetation cover present.

5.4.4.2 Mitigating for Low Soil Cover

Mulches for Seedlings and Cuttings **–** Mulches create a more favorable environment for establishing seedlings and cuttings not only by reducing surface evaporation, but also decreasing the amount of competing vegetation. There are two types of mulches for seedlings and cuttings – organic aggregate and sheet mulches. The organic aggregates are thickly applied ground wood or bark, while the sheet mulches are made from non-permeable or slightly permeable plastic, newspaper, or geotextile. Both types are placed around the base of the seedling and cover at least a radius of 1.5 feet from the base of the seedling.

Mulches for Sown Seeds **–** Selecting and applying mulches over sown seeds differs from those selected for planted seedlings and cuttings. Mulch application for seedlings and cuttings is typically too thick for seeds to germinate and grow through. An ideal seedbed mulch is one that is applied at the highest rates without affecting seedling emergence. Long-fibered mulches, such as straw, hay, or wood strands, create the greatest loft or thickness but, at lower rates, still allow light to penetrate and space for seedlings to emerge. Short-fibered mulches, such as wood fiber and paper found in hydromulch products, are more compact and create less loft. While these products reduce erosion rates, they are not necessarily good as seed covers.

5.5 NUTRIENT CYCLING

Nutrient cycling is the process by which sites store and release essential nutrients for plant survival and growth. There are 13 elements, or mineral nutrients. Each fills a specific role or function in plant development and each possesses individual characteristics of movement and storage in the soil. This manual will not attempt to explain the role and function of each mineral nutrient (there are many good textbooks on this subject). It will instead focus on how nutrients cycle through vegetation and soils; how they are captured, stored and released; and what site components are essential to support these processes. In contrast to an agricultural system of managing optimum growth in crops through fertilization, the goal in wildlands revegetation is to create an environment that will support a self-sustaining native plant community that can develop through successional processes. This includes facilitating the establishment of nutrient cycles in a way that conserves, cycles, and builds nutrients in the system.

Mineral nutrients are stored in: 1) soil, 2) live or dead vegetation, and 3) rock. They are slowly released over time at varying rates. The rates at which nutrients are released from each source will determine their availability for plant uptake. Rock and fallen trees, for example, both hold essential nutrients, but release them to the soil at significantly differing rates. The fallen tree can take up to 100 years to decompose and release its nutrients; the weathering of rock might take over 100,000 years. Soil, on the other hand, can release nutrients in the order of weeks and months. Once released, these nutrients are stored, taken up by plants, lost through leaching or erosion, or reabsorbed in the soil.

On undisturbed sites, there is a dynamic exchange of nutrients throughout the year. Plants absorb nutrients from the soil through the root system and assimilate them into vegetative biomass. As plants, or portions of plants, die, they drop leaves, branches, and stems to the ground where they eventually decompose and return nutrients to the soil. The nutrients are stored in the soil and once again available for plant uptake. This natural process of nutrients moving from soil to vegetation and back again is referred to as nutrient cycling. The factors important in nutrient cycling are:

- Topsoil,
- Site organic matter,
- Soil carbon and nitrogen,
- Nutrients, and
- Soil pH and salinity.

In a healthy plant community, nutrients are constantly recycled with a minimum amount of nutrients lost from the site. On drastically disturbed sites, however, nutrient cycling functions poorly, if at all. The topsoil, which holds the greatest concentrations of available nutrients and supports the primary microbial activity on the site, is missing or mixed with the subsoil. Organic matter, which is a primary source of long-term nutrient supply and energy source, has also been removed. Soil nitrogen, the most critical nutrient for plant growth and site revegetation, is lacking. Soil nitrogen governs how quickly vegetation will return to a disturbed site and how much biomass it will ultimately support (Bloomfield and others 1982). Its availability is closely regulated by the amount of carbon present in the soil, which is also in flux on highly disturbed sites.

For many sites that lack topsoil, the subsoil in its place may have pH values that are higher or lower than the pH of the original topsoil. pH values at extreme ranges affect nutrient cycling by making many nutrients insoluble and unavailable for plant uptake. In addition, increased soil salinity, which can be caused by soil disturbance and amendments, can disrupt nutrient availability and provide unfavorable conditions for plant establishment.

5.5.1 Topsoil

The topsoil is the horizon directly below the litter layer that is characterized by high organic matter, abundant roots, healthy microbial activity, good infiltration rates, high porosity, high nutrient content, and high water-holding capacity (Jackson and others 1988; Claassen and Zasoski 1998). Most nutrient cycling takes place in the topsoil where the greatest biological activity occurs. Decomposing microorganisms flourish, feasting on dead vegetation and roots and releasing stored nutrients back to the soil. Most life forms occur in forest and range topsoils, including mammals, reptiles, amphibians, snails, earthworms, insects, nematodes, algae, fungi, viruses, bacteria, actinomycetes, and protozoa (Trappe and Bollen 1981). The top 6 inches of an acre of forest topsoil can contain as much as a ton of fungi and a half of a ton of bacteria and actinomycetes apiece (Bollen 1974). Topsoil depth is highly correlated with the nutritional status of the soil and, in Northwest forests, has been found to be highly correlated to site productivity (Steinbrenner 1981). Topsoils possess humus, which is what gives topsoils their dark color. Humus is a stable end product of decomposition, important for nutrient storage, soil structure, and water-holding capacity.

Sites lacking topsoil have significantly reduced productivity, and obtaining even minimal revegetation can be very difficult. Planted seedlings often fail or growth is significantly reduced, resulting in inadequate plant cover to protect the soils from erosion. Growth of planted trees can be reduced by one third to one half when planted in subsoil instead of topsoil (Youngberg 1981). Restoring these sites to functioning plant communities is unlikely without mitigating measures.

***Figure 5.27** – Topsoil is generally darker, more friable, and has more roots than subsoil.*

5.5.1.1 Topsoil – How to Assess

It does not take a soil scientist to determine the basic characteristics of topsoil and topsoil depth. It is simply a matter of digging holes

Figure 5.28 – *Most of the nutrients found in a young Douglas-fir stand reside in the litter, duff, and branches (adapted from Cole and Johnson 1981).*

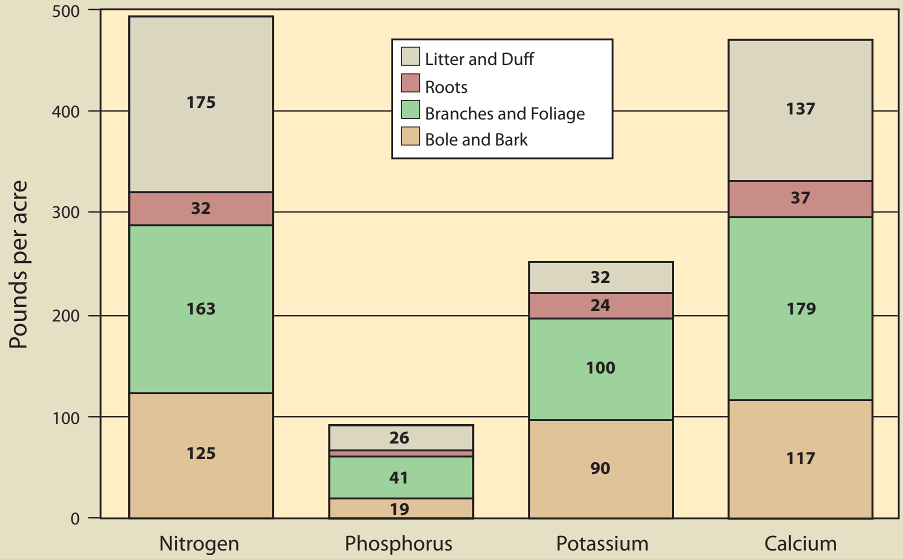
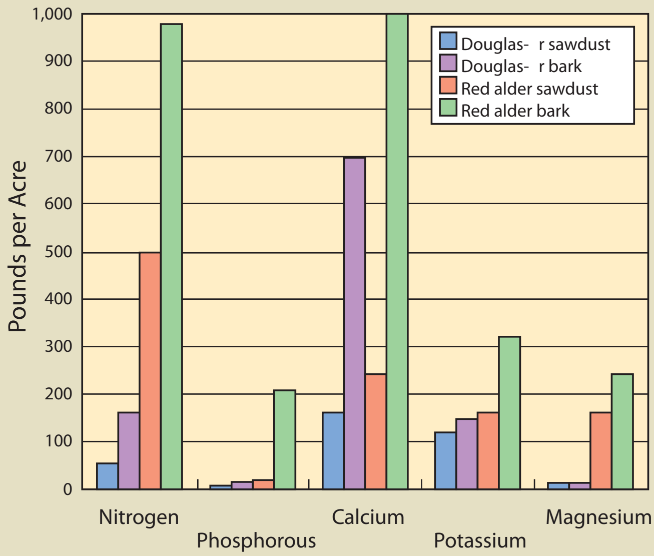


***Figure 5.29 –** Comparison of pounds per acre of nutrients resulting from bark or wood from Douglas-fir and alder trees, based on 2 inches of applied organic matter (Rose and others 1995).*



and observing some of the basic topsoil characteristics. Usually topsoil can be differentiated from subsoil by simple observations. On undisturbed sites, for example, topsoil is visually differentiated from the underlying subsoil by having darker colors, less clay, better soil structure, and higher abundance of fine roots. In forest soils, topsoil depths can be more difficult to differentiate from subsoils because the color changes are not always distinct. Other attributes, such as the abundance of roots, lack of clays, increased soil structure, and lower bulk density, can be used instead. Section 5.11.1, Survey Topsoil, gives a general approach to surveying a site for topsoil.

5.5.1.2 Mitigating for Lack of Topsoil

***Minimize Soil Disturbance* –** Where soils are especially fragile and reconstructing topsoil conditions is difficult, it is especially important to keep the "disturbance footprint" to a minimum (Claassen and others 1995). Sites with fragile soils include decomposed granitic soils, serpentine soils, and thin, high elevation soils.

Salvage and Reapply Topsoil **–** An effective practice in revegetating highly disturbed sites is salvaging and reapplying topsoils (See Section 10.1.4, Topsoil). This practice has been found to greatly increase plant growth and ground cover (Claassen and Zasoski 1994). Topsoil salvage and application requires good planning and implementation oversight. In the planning phase, a topsoil survey of the planned road corridor will identify the depth for topsoil removal; soil testing of the topsoil to be salvaged will indicate the nutrient status (See Section 5.11.1, Survey Topsoil). After topsoil is removed and stored, it is reapplied to the disturbed site, ideally at depths similar to pre-disturbance reference site topsoils.

Create Manufactured Topsoil **–** When topsoil is not available, "manufactured topsoil" can be created in situ or produced offsite and imported (See Section 10.1.4.5, Manufactured Topsoil). Manufactured topsoil will lack the native seed bank and some of the biological components of topsoil, but it can recreate a rooting zone high in nutrients and organic matter, with good water-holding capacity, porosity, and infiltration.

Create Planting Islands **–** If sources of manufactured or natural topsoil are scarce or too costly for broad scale applications, placing available topsoil in strategic locations, such as planting islands, can create a mosaic of productive growing sites.

5.5.2 Site Organic Matter

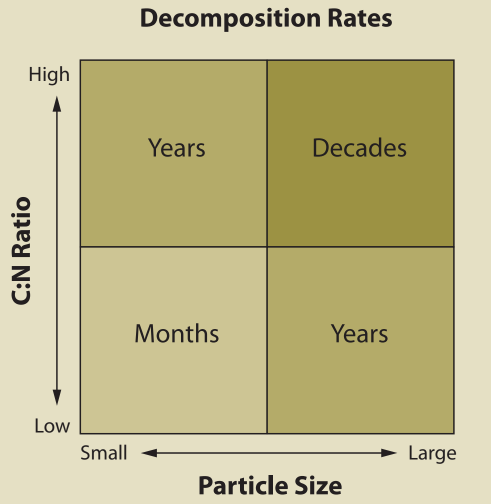
Site organic matter (OM) consists of plant materials in all stages of decomposition, including wood, bark, roots, branches, needles, leaves, duff, litter, and soil organisms. From a nutrient cycling standpoint, site organic matter assimilates nutrients drawn from the soil into live vegetation. Depending on the type of vegetation and the productivity of the site, the amount of nutrients held in organic matter can be significant. Figure 5.28 shows the quantities of four major nutrients held in the organic matter of a young Douglas-fir stand and Figure 5.29 shows the quantity of major nutrients found in the application of two inches of material derived from Douglas-fir and alder. These two examples show the possible nutrient reserves that organic matter can contribute to a disturbed site if they are used.

While plants are essential in nutrient cycling, equally important are the decomposing organisms that release nutrients to the soil. Decomposers consist of thousands of specialized species of animals, insects, fungi, bacteria, and actinomycetes that survive on organic matter. Decomposing organisms not only release nutrients, but are also essential to the development of soil structure (See Section 5.3.3, Soil Structure).

On an undisturbed site, organic matter is in all stages of decomposition, from recently dead trees to soil humus, the end product of hundreds of years of decomposition. This understanding is important for restoring a site to a functioning plant community, since it is a reminder that nutrients are released throughout the life cycle of a plant community, not just at the beginning of the revegetation project. A site that has a range of organic matter in all stages of decomposition not only conserves nutrients but slowly meters them out over time.

The rate at which organic matter decomposes and releases nutrients is a function of: 1) soil to OM contact, 2) OM particle size, 3) carbon-to-nitrogen ratio (C:N), 4) temperature, and 5) moisture. Decomposition rates of organic matter are highest in soil because the greatest microbial activity occurs when soil is in direct contact with OM (Slick and Curtis 1985; Rose and others 1995). Organic matter placed on the surface of the soil as a mulch will decompose at a

Figure 5.30 ***–*** *Relative rates are a function of decomposition by Carbon to Nitrogen ratio and particle size.*



much slower rate than organic matter incorporated into the soil because there is less contact with the soil.

Organic matter particle size plays an important role in the rate of decomposition. Within the soil profile, the smaller-sized OM fractions decompose faster than the larger fractions due to greater surface area in contact with soil. Roots, leaves, needles, and very finely ground sawdust or bark often decompose at a much faster rate than larger materials, such as buried logs or large diameter branches. Materials with high carbon to nitrogen ratios (C:N), such as wood or bark, decompose at a much slower rate than materials with low C:N, such as green leaves and grass cuttings. As Figure 5.30 illustrates, high C:N organic matter will take much longer to decompose than low C:N material, but both will decompose faster when they are reduced in size.

Moisture and temperature also control decomposition rates; cold and dry environments have very slow rates compared to warm, moist sites.

5.5.2.1 Site Organic Matter – How to Assess

Duff and litter in reference, pre-, and post-disturbance sites can be measured through transects or plots (See Chapter 12). Estimating forest biomass of down, woody materials in different size classes can be done using photo series guides (Maxwell and Ward 1976a, 1976b, 1979). Fire specialists are experienced in estimating the amount of biomass in forested environments.

5.5.2.2 Mitigating for Lack of Site Organic Matter

Salvage and Reapply Litter and Duff **–** Duff and litter can store a significant amount of nutrients, especially on sites where layers are deep. It can be salvaged separately (See Section 10.1.3.11, Litter and Duff) or mixed together when topsoils are salvaged (See Section 10.1.4, Topsoil).

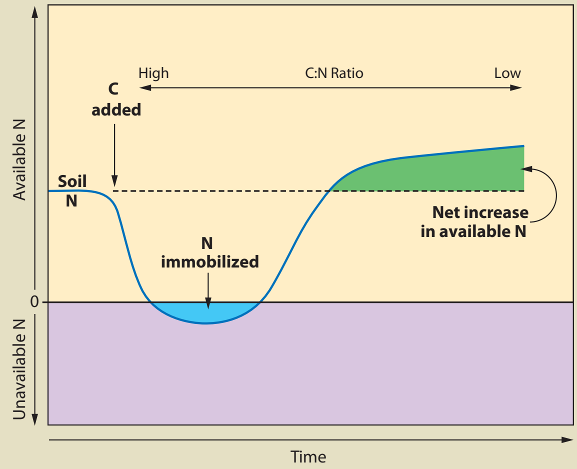
Chip and Apply Organic Matter **–** Road projects constructed through forested sites can generate high amounts of biomass that must be disposed, usually through burning. These materials can be a good source for slow-release nutrients. Methods of chipping and reapplication are discussed in Section 10.1.3. Chipped organic matter can be applied directly to the soil surface or mixed into the soil. High C:N organic materials, such as sawdust and bark, can be placed on the soil surface to prevent long-term nitrogen tieup in the soil, or they can be composted for several years to lower the C:N before adding as an amendment. Lower C:N materials, such as leaves, needles, and branches, can be placed in the soil with some addition of slow-release nitrogen to reduce the effects of nitrogen tie-up.

Apply Composts to Soil Surface **–** Compost functions as a soil cover to protect the soil from surface erosion while slowly decomposing and adding nutrients as the plant community develops. Decomposition rates of surface-applied compost are slower than mulch incorporated into the soil because there is very little soil contact. Nutrients are released at a slower rate and are available to the site longer. Leaving the soil surface very rough prior to the application of compost creates more soil-to-compost contact, which can increase the rate of decomposition of the compost.

Salvage and Place Large Wood **–** Large wood can be salvaged and placed in areas such as abandoned roads for microsite amelioration for revegetation. When placed in contact with the

Figure 5.31 **–** *Placement of large wood adds long-term organic matter while creating microsites for planting seedlings. Large wood can also slow runoff and detain sediments from surface soil erosion.*

__Figure 5.32__ – Available nitrogen (N) levels change as organic matter carbon (C) is added to the soil. High ratios move to low ratios during decomposition. Nitrogen is tied up in microorganisms during the immobilization phase (blue shaded area) and unavailable to plants. With time, nitrogen becomes available again and, at some point, exceeds the original level (green shaded area). Nitrogen is then released at a constant rate (modified after Havlin and others 1999).



soil, large wood helps stabilize the surface of the soil from sheet and wind erosion, and can be used as buttresses to stabilize slopes. Seedlings planted on the north side of the logs can be protected from wind and sun during establishment. Large and small wood can be placed at the outlets of culverts as obstacles to capture and store sediments, reducing the amount of sediment reaching live streams (Burroughs and King 1989; Ketcheson and Megahan 1996).

5.5.3 Soil Nitrogen and Carbon

Nitrogen (N) is discussed separately from the other mineral nutrients because of its critical importance to plant growth and long-term development of plant communities. Carbon (C) is included in this discussion because of its unique relationship to nitrogen availability. Carbon governs the amount of available nitrogen in the soil while nitrogen regulates the rate at which carbon is broken down. Both factors play a critical role in microbiological activity and the development of soil properties.

Carbon to Nitrogen Ratio (C:N): Carbon is the energy source for soil microorganisms, and practically all site nitrogen eventually passes through these microorganisms (Woodmansee 1978). The rate at which carbon (or organic matter) decomposes is directly related to the amount of available nitrogen and the type of dominant microbes present in the soil. The greater the nitrogen, the greater the decomposition rates. If decomposing organisms do not find sufficient nitrogen in the organic matter, they will withdraw it from the soil, leaving little or no nitrogen for plant growth. This is usually a temporary condition, lasting several years. The tieup of nitrogen can greatly affect the establishment of vegetation if organic amendments, such as composts, wood chips, or straw, are incorporated into the soil without supplemental nitrogen.

With time, nitrogen is eventually released from the organic matter by microbial activity. This nitrogen, plus nitrogen released from dead and decomposing micro-organisms, becomes available for plant growth. As organic matter breaks down further, there becomes a net increase in available nitrogen. In the last stage of decomposition, microorganisms move to a steady rate of decomposition, releasing a constant nitrogen supply. This process can take several years or more depending on site factors and organic matter levels. C:N is an indicator of whether nitrogen will be limiting or in surplus. A C:N of 30:1 or greater indicates that decomposing organisms have consumed the available nitrogen in the soil, leaving little if any available nitrogen for plant growth. Plants respond by turning yellow and becoming stunted. A C:N below 18:1 is an indication that the decomposing organisms are releasing available nitrogen from the breakdown of organic matter at rates that exceed their need, thereby increasing nitrogen for plant uptake (Claassen 2006). For example, undisturbed topsoils typically have ratios of 10:1 to 12:1, which is sufficiently available for plant growth (Tisdale and Nelson 1975). Dry hay, on the other hand, has a C:N around 40:1, indicating nitrogen will probably be limiting if the hay is incorporated into the soil.

The use of high C:N materials is often discouraged because of concerns about tying up nitrogen. However, there are strategies where the use of high C:N ratio materials can aid the revegetation specialist in achieving project goals. One use of high C:N ratio materials can be incorporation into the top several inches of soil or application to the surface to intentionally tie up nitrogen. The applications would lower the availability of N to annual weedy species, which thrive on available nitrogen (See Section 5.8.1.2, Reducing or Eliminating Weed Growing Environments).

Soil Nitrogen Capital: Soil nitrogen capital can be categorized into three nitrogen pools, or reserves, based on its availability in the soil:

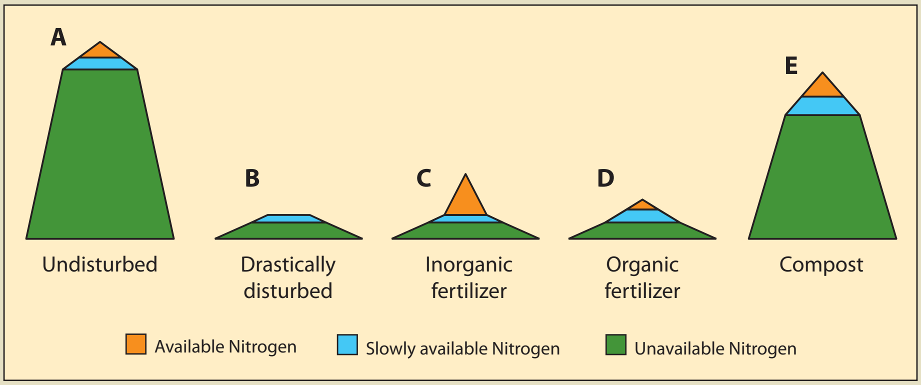
- Available nitrogen (referred to as "extractable nitrogen"),
- Slowly-available nitrogen (referred to as "mineralizable nitrogen"), and
- Unavailable nitrogen ("humified organic" or "fresh" forms).

Nitrogen capital can be viewed much like our banking system. Cash received from the bank teller is comparable to available nitrogen. When the money runs low, the teller replenishes it with money from the bank vault (similar to slowly-available nitrogen). Banks are backed up by money held in an extremely large banking reserve system, or unavailable nitrogen. While this money is not accessible, it is very important for the long-term stability of the banking system. Unavailable nitrogen is like the banking reserve system in that it backs up the nitrogen system and ultimately releases nitrogen to the plant community.

Like the banking reserve system, having high reserves of both slowly-available and unavailable nitrogen assures that available nitrogen levels will be released at constant rates over time, which is necessary for the development of a plant community. Figure 5.33 shows the relationship of different revegetation treatments on nitrogen capital.

On highly disturbed sites, all nitrogen reserves are low. The course of action in typical revegetation projects is to apply inorganic fertilizers during the seeding operation. While this immediately makes nitrogen available, it does little for increasing long-term nitrogen reserves. Within a year of application, most soils will need more available nitrogen to sustain plant growth. Organic fertilizers, on the other hand, provide a combination of available and slowly-available nitrogen. These fertilizers release nitrogen over several years, but are typically applied at rates not great enough to bring the nitrogen reserves up to levels for long-term plant community establishment (Claassen and Hogan 1998). Applying topsoil, composts, or low C:N organic matter into the soil are mitigation treatments that create the reserves of unavailable and slowly-available nitrogen important for a constant supply of available nitrogen over time.

***Figure 5.33** – Managing Nitrogen Capital. Undisturbed sites (A) have very high total nitrogen levels, with over 95% tied up in organic matter and not available (green). Slowly-available nitrogen (blue) makes up 1% to 3% of the total nitrogen; available nitrogen for plant uptake (orange) is less than 2% of the total nitrogen. Nitrogen capital is essentially removed on drastically disturbed sites (B). The addition of inorganic fertilizer (C) dramatically increases available nitrogen, but does little to build nitrogen capital. The application of organic fertilizers (D) raises the available and the slowly-available nitrogen, but does not add to the long-term reserves. Adding compost to the soil can increase available, slowly-available, and total nitrogen reserves (E) to levels comparable to undisturbed soils (A).*



Minimum Soil Nitrogen Levels: Total soil nitrogen is the sum of available, slowly-available, and unavailable nitrogen reserves. The level of total soil nitrogen varies by plant community and ecoregion. It can range from 20,000 lb/ac in deep forest soils of the Washington and Oregon coast (Heilman 1981) to as low as 800 lb/ac in desert grasslands of Southern New Mexico (Reeder and Sabey 1987). Shortgrass prairies in the Northeastern Colorado and shrub-steppe prairies of the Great Basin have a range of total nitrogen from 4,000 to 5,000 lb/ac (Reeder and Sabey 1987). Sites that are drastically disturbed often have nitrogen rates below 700 lb/ac. These sites cannot fully support vegetative cover. A minimum, or threshold, level of total soil nitrogen required for a self-sustaining ecosystem has been suggested at 625 lb/ac (Bradshaw and others 1982) to 670 lb/ac (Dancer and others 1977) for drastically disturbed sites. But Claassen and Hogan (1998) suggest much higher rates might be necessary. In their research on granitic soils in the Lake Tahoe area, they found a good relationship between total soil nitrogen and the percentage of plant cover. Sites with greater than 40% ground cover contained at least 1,100 lb/ac total soil nitrogen in the surface foot of soil. This implies that to maintain a minimum of 40% plant cover, sites like these must contain at least 1,100 lb/ac of nitrogen, with higher nitrogen levels necessary for higher plant cover (See Figure 5.34).

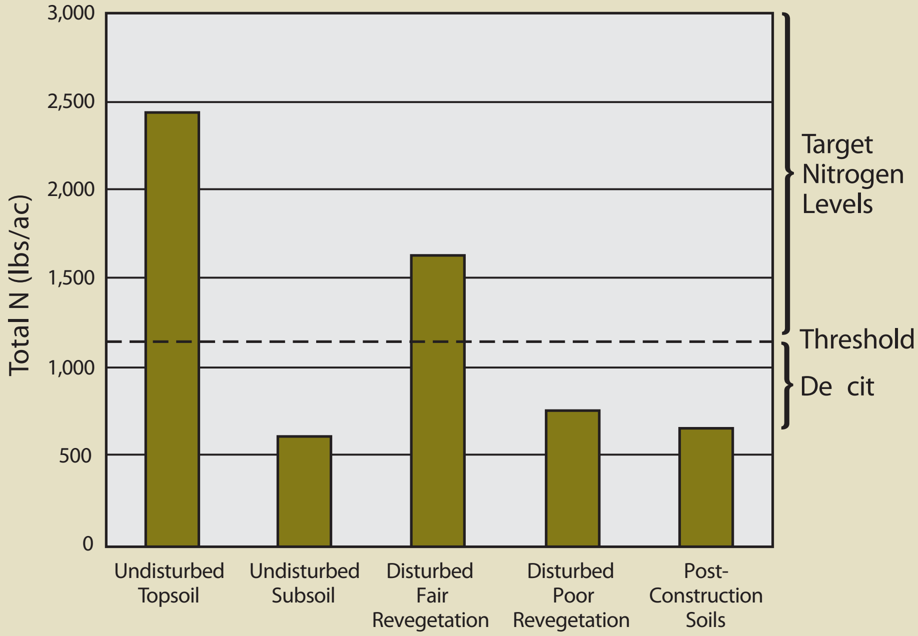
Target levels for available nitrogen released annually from nitrogen sources for plant growth range from below 27 to 50 lb/ac (Munshower 1994). These are nitrogen levels that should be considered when calculating fertilizer rates (See Section 10.1.1.6, Determine Fertilizer Application Rates).

5.5.3.1 Soil Nitrogen and Carbon – How to Assess

Nitrogen Testing – Soil testing for nitrogen should be conducted for: 1) topsoils that will be salvaged; 2) reference sites; and 3) post-construction soil materials. Procedures for collecting soil samples are presented in Inset 5.2, Soil Testing. The following nitrogen tests are available:

- *Total nitrogen:* Total nitrogen is an important test to request; the results will be used to determine nitrogen thresholds and nitrogen amendment needs. The common total nitrogen tests are Leco and Kjeldahl. Total nitrogen has been found to correlate well with plant cover (Claassen and Hogan 1998).

***Figure 5.34 –** Threshold values are determined from reference sites. In this example, the threshold was established at 1,100 lb/ac, which was between the total N of a disturbed reference site with "poor" revegetation and one with "fair" revegetation. Total N in post-construction soils was 650 lb/ac, making these soils deficient by 450 lb/ac. The undisturbed topsoils of reference sites showed a total N of 2,430 lb/ac, which set the target levels of nitrogen between 1,100 and 2,430 lb/ac.*



- *Mineralizable nitrogen:* This test requires the soil samples to be incubated for a period of time and then tested for available nitrogen. The results indicate the amount of slowly-available nitrogen present in the sample. It is a very good test to perform because the results correlate well with expected plant cover (Claassen and Hogan 1998). There are several types of incubation tests, so it is good to confer with the soil laboratory as to which tests would be most appropriate.
- *Extractable nitrogen:* This test is less meaningful, since it only indicates available nitrogen, not what is in reserve. This test is often included in a soil testing package. Extractable N pool has the lowest correlation to the amount of plant cover growing on a site (Claassen and Hogan 2002). The most common test for extractable nitrogen is 2N KCl extract.

Nitrogen testing for composts and organic matter should be done by laboratories specializing in these tests. These laboratories should follow the testing procedures outlined in the Test Methods of the Examination of Compost and Composting (TMECC) explained in Section 10.1.3, Mulches and Section 10.1.5, Organic Matter Amendments.

Nitrogen Analysis – Soils laboratories report nitrogen in a variety of units, such as gr/l, ppm, mg/kg, ug/g, and percent. Unless these values are converted to pounds per acre, it is difficult to determine rates of fertilizer, compost, or topsoil necessary to restore site nitrogen. Use Figure 5.35 to convert lab values to total pounds per acre of nitrogen. These calculations account for soil bulk density, soil thickness, and coarse fragment content, which affect the total nitrogen levels of a site.

Nitrogen Thresholds and Deficits – Each plant community has a total nitrogen requirement that must be met in order to develop into functioning and self-sustaining systems. For successful revegetation efforts, a practical goal is to meet the minimum target, or threshold level, for total nitrogen. Threshold values, however, are not found in textbooks and must be developed from soil tests of disturbed and undisturbed reference sites. Conducting nitrogen tests on disturbed reference sites where revegetation efforts have succeeded, as well as reference sites where revegetation efforts have failed, can lead to determining a threshold value (Figure 5.34). Conducting soil tests on undisturbed reference sites, on the other hand, will define the optimum nitrogen levels and also bracket target nitrogen levels. Converting soil test results into total nitrogen per acre is shown in Figure 5.35, line E.

Post construction soils are typically deficient in nitrogen. In order to develop a strategy for bringing soil nitrogen above threshold levels, it is important to determine the approximate nitrogen deficit. Figure 5.35 shows how this can be calculated by subtracting the total nitrogen value of post-construction soils (Line E) from the threshold nitrogen value (Line F).

Carbon Analysis – Carbon is determined directly using the combustion method (Leco instrument) or indirectly with the Walkley-Black and/or loss-on-ignition methods. The Walkley-Black and loss-on-ignition methods measure the percentage of organic matter that can be converted to the percentage of carbon by multiplying by a lab factor. Since carbon makes up between 50% to 58% of the organic matter (Tisdale and Nelson 1975), most labs will

Figure 5.35 – *Calculating the nitrogen deficit of a site – an example.*

A.	Total soil nitrogen (N)	0.025	%	From soil test of post construction soils - gr/l, ppm, mg/kg, ug/g divide by 10,000 for %
B.	Thickness of soil layer	0.5	feet	The thickness of soil represented in (A).
C.	Soil bulk density	1.4	gr/cc	Unless known, use 1.5 for compacted subsoils, 1.3 for undisturbed soils, 0.9 for light soils such as pumice
D.	Fine soil fraction	70	%	100% minus the rock fragment content - from estimates made from sieved soil prior to sending to lab
E.	N in soil layer: A * B * C * D * 270 =	331	lbs/ac	Calculated amount of total nitrogen in soil layer. To convert to kg/ha: E * 1.12
F.	Minimum or threshold N levels	1,100	lbs/ac	Determined from reference sites or literature
G.	N deficit: F - E =	769	lbs/ac	Minimum amount of N to apply to bring up to threshold

use a conversion factor within this range. For all tests, it is important to remember that soil labs sieve out any materials greater than 2 mm. Prior to sending the sample to the lab, sieve out the rock fraction but leave any organic matter in the sample. Request that the lab not sieve the sample so that the results report out all carbon and nitrogen.

C:N **–** C:N is calculated by dividing % carbon by % nitrogen from the laboratory results obtained for nitrogen and carbon tests.

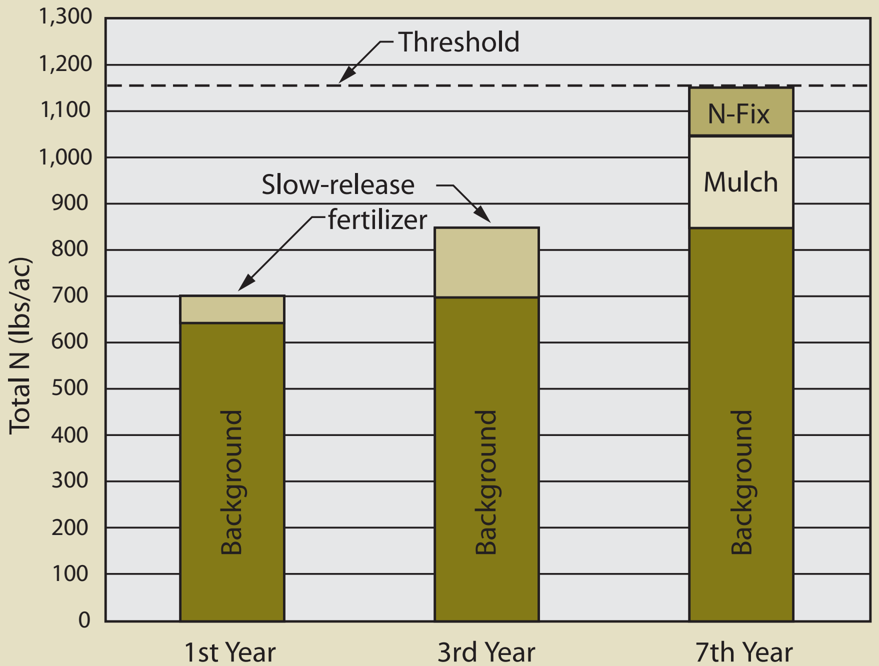
5.5.3.2 Mitigating for Low Soil Nitrogen

Develop a Strategy **–** It is important to develop a strategy for increasing nitrogen over time. It is not enough to just add fertilizer at seeding and call it good. On sites that are deficient in nitrogen, a strategy must be developed that considers the accumulation of nitrogen over time by all available sources – topsoil, mulch, compost, fertilizers, and nitrogen-fixing plants. Figure 5.36 shows an example of a strategy for increasing total soil nitrogen to a threshold level.

Topsoil **–** Salvaging and reapplying topsoil is an excellent way to increase total soil nitrogen on drastically disturbed sites. The depth to apply topsoil should be similar to the soil depth found in undisturbed reference sites or pre-construction soils. If topsoil material is limited, then using the calculations shown in Figure 5.35 can help determine the minimum depths to apply topsoil. Section 10.1.4, Topsoil discusses methods to salvage and apply topsoil. To determine if there is, or could be, a tieup or surplus of nitrogen in the salvaged topsoil, soil tests should be conducted and evaluated for C:N. C:N greater than 25:1 could benefit from the addition of nitrogen, while a ratio less than 8:1 will have available nitrogen for plant growth.

Composts **–** Applied on the soil surface and incorporated, composts can supply sufficient soil nitrogen for long-term site needs. Application rates for composts can be calculated using methods shown in Figure 5.35. Testing and application methods for compost are discussed in Section 10.1.3, Mulches and Section 10.1.5, Organic Matter Amendments.

Figure 5.36 **–** *Raising nitrogen levels on nitrogen deficient sites to threshold levels requires developing a long-term strategy. In this example, the site began with a background N of 650 lb/ac. After application of a slow-release fertilizer at 1,000 lb/ac during the first year, the site accumulated 50 lb N, assuming it was captured by plants or soil microorganisms and not leached from the soil. In the third year, another 3,000 lb slow-release fertilizer was applied, which increased total N to 850 lb/ac. By the 7th year, woody mulch that was applied during sowing had decomposed, releasing approximately 200 lb N. Nitrogen-fixing plants were well established by then and contributed approximately 100 lb N.*



Nitrogen-Fixing Plants **–** Significant quantities of nitrogen can be supplied by nitrogen-fixing plants (See Section 10.1.7, Beneficial Soil Microorganisms). Establishing nitrogen-fixing plants is a means of meeting short-term goals without having to amend with nitrogen fertilizers, and long-term goals by increasing the total nitrogen on the site.

Fertilizers **–** Applying nitrogen-based fertilizers to drastically disturbed soils is another means of increasing nitrogen levels, but it requires an understanding of fertilizers (composition and release), how the soils will capture and store nutrients, and how plants will respond to increased levels of available nitrogen. As the calculations in Figure 5.35 demonstrate, nitrogen based fertilizers cannot deliver enough nitrogen in one application for long-term site recovery of drastically disturbed sites. However, applied judiciously within an overall nitrogen strategy using topsoil, composts, and nitrogen-fixing plants, nitrogen-based fertilizers can be an effective tool in site recovery.

Not all sites or conditions require fertilizers. It might not be necessary to fertilize soils that have low C:N with nitrogen levels exceeding a minimum threshold level. In fact, applying fast release fertilizers may be a disadvantage on some sites by favoring weedy annuals over perennial species. A discussion on selecting fertilizers, calculating application rates, and determining methods of application are discussed in Section 10.1.1, Fertilizers.

Biosolids **–** Biosolids are rich in nitrogen and, if sources are available nearby, are a good means of raising soil nitrogen.

5.5.4 Nutrients

This section will broadly discuss the remaining mineral nutrients essential for plant growth (Figure 5.37). There are many references devoted to the role of nutrients in plant nutrition and the reader is directed to these sources for a more detailed discussion of each nutrient (Tisdale and Nelson 1975; Thorup 1984; van den Driessche 1990; Munshower 1994; Havlin and others 1999; Claassen 2006). The majority of research in soil fertility and mineral nutrients was conducted with the agricultural objective of optimizing crop yields through annual inputs of fertilizers, soil amendments, and irrigation. The primary objective of wildland restoration, however, is to restore or re-create self-sustaining plant communities that, once established, require very little input of resources. Unlike agriculture, revegetation of highly disturbed sites is not approached with the objective of optimizing the site for a single, high-yielding crop, but to develop a system of interrelated species that have evolved and adapted to site conditions. In wildland restoration, it is more important to re-create the components of the local soils than to change nutrient status based on agricultural models. For example, from an agricultural perspective, a serpentine soil has an imbalance of calcium and magnesium. Unless fertilizers containing a “correct” ratio of calcium and magnesium are applied to adjust this imbalance, the soils will be unsuitable for crop species. In wildland restoration, the approach is guided by the nutrient needs of the species endemic to the site, not to a generic agricultural crop. Since serpentine plant species have evolved on soils with these nutrient ratios, their nutrient requirements are vastly different than those of agricultural crops, or even native vegetation growing on adjacent, non-serpentine soils. In this example, the calcium to magnesium ratio would not be seen as an imbalance for native serpentine plant establishment, but as perhaps a “requirement” for certain endemic species to recolonize the site. This requires the revegetation specialist to compare post-construction mineral nutrient status to that of undisturbed or recovered reference sites to determine if there are deficiencies. Amendments can then be applied to bring nutrients and other soil factors to pre-disturbance levels or to levels that meet project revegetation objectives.

Success in wildland restoration is determined by its species richness, not biomass production, and being self-sustaining and resilient, not a system that requires constant energy inputs. By these standards, applying the basic agricultural model to wildland revegetation is limited.

5.5.4.1 Nutrients – How to Assess

The objective of nutrient analysis is to compare nutrient levels of post-construction, disturbed soils with those of pre-disturbance, or reference site, soils. Where there are large discrepancies, a strategy can be developed to bring low post-construction levels up to minimum nutrient levels. Since this is a comparative analysis, it is essential that the sampling, collection, and testing methods are identical.

Inset 5.2 – Soil Testing

Soil testing is a means of describing those soil characteristics that cannot be observed or accurately measured in the field. The tests include analysis of chemical properties including pH, soluble salts, macronutrients, micronutrients, and organic matter, and physical properties such as density, water-holding capacity, and texture. Soil testing is costly and if not sampled, analyzed and interpreted properly can lead to unneeded and expensive soil amendments and application practices. In many respects, it is better not to test soils than to test them or interpret the results incorrectly.

Soil testing is performed with site survey, topsoil recovery, and reference site surveys (discussed in other sections) to 1) identify soil physical and chemical factors that will limit plant growth, 2) develop site-specific soil quality targets and 3) develop a set of revegetation treatments that will increase short and long term soil productivity targets. There are three components of soil testing – 1) soil sampling, 2) lab analysis, and 3) interpretation of lab results. Adhering to an established protocol for each component of soil testing is critical for developing appropriate revegetation treatments.

Sampling soil **–** Soil sampling is the field collection of soils in a manner that best represents the soils of an area. The number of soil samples taken within a project area is usually kept to a minimum because of the expense of collecting and handling the samples and the cost of laboratory analysis. Taking a small amount of samples to describe a project site can be misleading, especially if the soils are extremely variable. This leaves the revegetation specialist with the challenge of determining the best approach to collecting soil samples in a way that most accurately represents the sites being described.

The following guidelines are useful in developing a sampling strategy for soil testing:

Determine the area to be sampled **–** The areas to be sampled are called sampling areas and they are typically revegetation units, topsoil stockpiles or topsoil salvage areas, or reference sites. For most projects, sampling areas will have no more than one sample collected from each, therefore the selection of the site to collect soils samples (the collection site) must be representative of the sampling area. The sampling area and collection site are not always one and the same. Only for small sampling areas, such as topsoil stockpiles or reference sites, will the collection site be the same as the sampling area. For larger sampling areas, such as revegetation units or topsoil salvage areas, the collection site will be a smaller, representative areas within the sampling area.

Collect multiple subsamples **–** Once a collection site has been identified, a set of subsamples are collected. Collecting soil from one point is never enough! The number of subsamples to collect within a collection site should be based on the site's variability. Small collection sites generally require fewer subsamples than larger areas because there should be less variability. Undisturbed sites are typically more homogenous than disturbed sites and therefore require fewer subsamples. Guidelines for the numbers of subsamples to collect range from 6 for very homogenous sites to 35 for large, heterogenous sites.

Randomly collect subsamples **–** Subsamples should be collected randomly within the collection site. For small areas like reference sites or stockpiled soil, the samples can be collected on a grid system. For very large areas, samples can be collected in a zigzag or "W" pattern at predetermined intervals.

Determine sampling depth **–** Review the objectives for soil sampling and determine the sampling depth. If the objective is to characterize the soil for topsoil recovery, then the soil samples must be collected only in the topsoil horizon, in which case the depth of the topsoil would have to be determined prior to sampling. If it is known that the surface soil including duff and litter will be removed to 15" during topsoil salvage, then collection depth would be a sample 15" deep that included the duff and litter layers. If soil sampling objectives are to determine the nutrient and mycorrhizal status of a topsoil pile, the entire pile is the sampling zone and the subsamples must be collected from various depths within the piles as well as around the pile to obtain a representative sample. (If the surveyor felt that the interior of the pile was significantly different in nutrient status or mycorrhizae, then the pile could be stratified into collection sites – the exterior of the pile and the interior – and sampled separately.) Sampling of the subsoil is important because this will give an indication during planning of how the disturbed site will appear after construction and before mitigation.

Collect a representative slice of soil – It is important to evenly sample the predetermined depth of soil. For example if the sampling depth is 0 to 15 inches deep, then the entire section of soil must be equally sampled for each subsample.

Mix subsamples – Place subsamples in a clean bucket and mix thoroughly. From the composite subsamples, remove the required amount of soil to send to the lab for analysis.

Determine coarse fragment content – If the soils are high in coarse fragments, the samples can be sieved in the field using a 2mm sieve. This will reduce the amount of sample weight to haul out of the survey area and give an estimate of the coarse fragment content; otherwise, sieve back at the office prior to sending to the lab. If the samples are wet or moist, they will need to be air dried prior to sieving. Record the percent coarse fragment content for the sampling area which includes large and small coarse fragments. This information will be used later to modify the lab results.

Selecting a lab – The criteria for selecting a soil lab is typically based on costs, turnaround time, analytical tests and consulting services. Most labs offer a general test package for under $50 per sample (2004 prices) and deliver the results within two weeks of receiving the soil samples. For an added fee, laboratories will interpret the results of the analysis. While these are important reasons for selecting a lab, the primary criteria for selecting a lab should be based on the quality of the testing facilities.

A common assumption is that all labs are of similar quality in their analytical testing, and that if a group of labs were sent the same soil sample they would report similar results for most tests. This is not typically the case, as several university reviews of laboratories have shown (Neufeld and Davison 2000; Rose 2004). In one comparison, eight reputable laboratories reported widely differing results for all soil nutrients when sent identical soil samples (Rose 2004). One reason for the variation in results is that there are usually several testing procedures that can be used to quantify a soil parameter. Some methods have greater accuracy and precision than others. The soil testing industry at this time has not settled on an agreed upon set of analytical methods to use. Even when the same tests are performed, labs often report different levels of accuracy (Rose 2004).

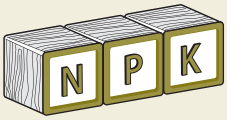
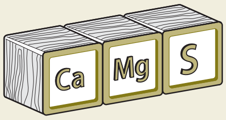
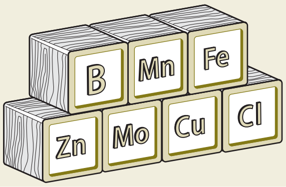
Soil laboratories can voluntarily participate in a testing program called the North American Proficiency Testing (NAPT) program that will assess the quality of their analytical procedures. In this program, NAPT periodically sends all participating labs identical soil samples. Each lab analyzes the samples for mineral nutrients using established analytical procedures, then sends the results back to NAPT. The results from all labs are compiled and analyzed statistically and each lab is sent a report on how their results compared to the other participating labs. NAPT suggest that the accuracy be less than 10% of industry values and precision no greater than 15% of industry values (Neufeld and Davison 2000). These reports are not available to the public but laboratories might share them if asked. NAPT is not a certification program but is often a basis for a soil lab quality control program.

The following is a checklist for selecting a high-quality lab (modified from Neufeld and Davison 2000):

- ✓ Does the lab have a quality control program? If they do, ask them to explain it.
- ✓ Does it participate in a proficiency testing program (like NAPT)?
- ✓ Will they share the results of proficiency testing program with you?
- ✓ Does the lab use established analytical methods (the most appropriate for soils in the geographic area being tested)?

If you receive no for the answers to any of these questions, another soil testing facility should be considered. If the selection is down to a couple of labs, consider sending duplicate soil samples with known properties ("checks") to each lab and compare the results using the NAPT suggested standards for accuracy and precision. Soil "checks" can be purchased through a proficiency testing program. Once a lab is selected, continue to ask for quality control reports. If the budget allows, periodically send duplicate "check" soil samples with your regular soil samples to assess accuracy and precision.

Figure 5.37 – *The 13 essential mineral nutrients.*

Mineral Nutrient Group	Elements & Symbols	Application to Restoration of Distributed Soils
Macronutrients 	Nitrogen – N	Major fertilizer component that is most commonly limiting in disturbed soils. Legumes and other plants fix atmospheric nitrogen in natural plant communities.
	Phosphorus – P	Major fertilizer component that is frequently unavailable in disturbed soils. Mycorrhizal fungi improve uptake in natural plant communities.
	Potassium – K	Major fertilizer component that is easily leached from soils.
Secondary Macronutrients 	Calcium – Ca	Besides being plant nutrients, calcium and magnesium can be applied as dolomitic limestone to raise soil pH.
	Magnesium – Mg	
	Sulfur – S	Besides being a plant nutrient, sulfur can be applied to lower soil pH.
Micronutrients 	Boron – B Manganese – Mn Iron – Fe Zinc – Zn Molybdenum – Mo Copper – Cu Chloride – Cl	More important for subsequent plant growth than for establishment. Micronutrients are frequently unavailable in disturbed soils, but special formulated and balanced micronutrient fertilizers must be used.

Nutrient testing should be performed on: 1) salvaged topsoils, 2) reference sites, 3) post-construction soil materials, and 4) amended soils. A guide to sampling soils for nutrient analysis is presented in Inset 5.2. Nutrient testing should evaluate total soil nutrient levels (long-term nutrient availability) as well as available levels (immediately available nutrients). Table 5.1 lists soil tests common to the western United States.

With soil laboratory results from reference sites and post-construction sites, determine which nutrients, if any, are deficient using a process outlined in Section 10.1.1.2, Develop Nutrient Thresholds and Determine Deficits. If a nutrient is found deficient, fertilizers, composts, topsoils, or other organic amendments can be applied to the soil to bring the nutrient above threshold levels. A process for determining fertilizer type, application rates, and application methods is presented in Section 10.1.1, Fertilizers.

5.5.4.2 Mitigating for Low Nutrients

Topsoil – Salvaging and reapplying topsoil is important for restoring nutrients to pre-construction levels, especially on sensitive soils (e.g., serpentine and granitic soils). The depth to apply topsoil should be at levels found in undisturbed reference sites or pre-construction soils, or can be calculated by methods described in Figure 10.25 in Section 10.1.4, Topsoil.

Compost – Incorporating composts is a good method for increasing nutrients to pre-disturbance levels. Determining which type of compost to select and how much to apply is discussed in Section 10.1.5, Organic Matter Amendments.

***Table 5.1** – Common soil testing methods for the western United States (Horneck and others 1989; Munshower 1994; Teidemann and Lopez 2004). Note: Composts use a different set of tests due to the high organic matter (See Section 10.1.4, Topsoil and Section 10.1.5, Organic Matter Ammendments).*

Tests	Type	Test Method	Notes
Boron	Available	Hot-Water	
Boron	Available	Aqueous extract of a soil paste	
Calcium, Magnesium	Available	Ammonium Acetate	
Calcium, Magnesium	Available	Aqueous extract of a soil paste	In semi arid to arid soils
Molybdenum	Available	Ammonium oxalate-oxi acid extraction	
Nitrate	Available	Aqueous extract of a soil paste (Saturated paste)	Accepted extrant for western soils
Nitrate	Available	CaO extract & Cd reduction	
Nitrogen (ammonium and nitrate)	Available	KCL Extraction	
Nitrogen (Mineralizable)	Slowly - Available	Anaerobic Incubation	
Nitrogen (Total)	Total	Kjeldahl N	
Nitrogen (Total)	Total	Combustion (Leco Instrument)	
Organic Matter	Total	Loss - Ignition	Best used for soil high in organic matter
Organic Matter	Total	Walkley-Black Method	
Organic Matter	Total	Combustion (Leco Instrument)	Reports out in Total C
pH		Aqueous extract of a soil paste (saturated paste)	
Phosphorus	Available	Olsen Sodium Bicarbonate	For arid and semi-arid soils
Phosphorus	Available	Dilute Acid-Flouride (Bray-P1)	For mesic sites
Phosphorus	Available	AB-DIPA	Reports out at half the rates of Olsen method
Potassium	Available	Sodium Acetate	
Potassium	Available	Olsen Sodium Bicarbonate	For arid and semi-arid soils
Potassium	Available	Ammonium Acetate	
Sodium	Available	Ammonium Acetate Displacement	
Sodium	Available	CTPA	
Sulfate Sulfur	Available	Aqueous extract of a soil paste (saturated paste)	
Sulfate Sulfer	Available	$CaHPO_4$ & ICP	
Zinc, Copper, Manganese, Iron	Available	CTPA	Iron is not performed in Oregon because not found deficient

Figure 5.38 – *Most portable pH meters will also measure salts (electrical conductivity). Some probes can be directly inserted into the saturated media and a reading taken. The sample is prepared by adding distilled water just to the point when the surface glistens and allowed to come to equilibrium after 15 minutes.*

Fertilizers – As discussed in Section 5.5.3, Soil Nitrogen and Carbon, fertilizers should be used within an overall nutrient strategy. See Section 10.1.1, Fertilizers, for a discussion on application methods, fertilizer types, timing, and other important aspects of fertilization.

Biosolids – Biosolids are rich in nutrients. If sources are available and transportation economical, this is a good way to add nutrients to disturbed sites.

5.5.5 pH and Salts

pH is the measurement of soil acidity or alkalinity, based on a logarithmic scale of 0 to 14. Soils with pH values below 7 are acidic, and those above 7 are basic. Basic soils have high amounts of bases (positively charged ions), such as calcium, magnesium, potassium, sodium, and phosphates. Basic soils have developed under arid and semi-arid climates and are found east of the Cascades and Sierra Mountains, throughout the Basin and Range province. Acidic soils have formed in wetter climates, where the continued movement of water through the soil profile has leached the bases from the soil. Acidic soils are found west of the Cascades and Sierra Mountains, and are most prevalent in the coastal ranges. Topsoils are typically more neutral when compared to underlying subsoil, whether the soils are acidic or basic. In some cases, the topsoil buffers the plant root systems from the underlying, inhospitable subsoil conditions. When topsoils are removed during construction, subsoils become the growing environment and, unless mitigating measures are taken, the results are disastrous for plant establishment.

Soil acidity or alkalinity, as measured by pH, affect mineral nutrient availability, mineral toxicity (Palmer 1990), and nitrogen fixation (Thorup 1984). In acid soils, the ability of plants to utilize many nutrients decreases, especially for calcium, and magnesium. As soil pH becomes more acid (less than 4.5), aluminum becomes more soluble and more toxic to plant growth. Low pH soils also hinder the establishment of nitrogen-fixing plants, such as legumes (Bloomfield and others 1982). Significant loss of rhizobia viability has been documented at pH levels less than 6 (Brown and others 1982).

Basic soils with pH values of 8.0 or greater indicate the presence of calcium carbonate (Thomas 1967). Calcium and magnesium are at such high levels that they can interfere with the uptake of other nutrients, notably phosphorus, iron, boron, copper, zinc (Campbell 1980). High pH soils typically have high salt levels, which can also restrict the growth of many plants. For example, as soil pH approaches 9, sodium concentrations become toxic to plants (Tisdale and Nelson 1975).

Soil salinity is the measure of the total amount of soluble salts in a soil. The term soluble salts refers to the inorganic soil constituents, or ions, that are dissolved in the soil water. The principal soluble salts in a soil contain the cations sodium, calcium, and magnesium, and the anions chloride, sulfate, and bicarbonate (Landis and Steinfeld 1990).

Almost all plants are susceptible to salt injury under certain conditions, with germinants and young seedlings being particularly susceptible to high salt levels (Figure 5.39). Soluble salts can injure plants in several ways:

1) Reduced soil moisture. Salts can lower the free energy of water molecules, causing an osmotic effect and thereby reducing the moisture availability to plants.
2) Reduced soil permeability. High salt concentrations (specifically sodium salts) can change the soil structure by reducing the attraction of soil particles, causing them to disperse. Pore space is lost and air and water movement within the soil profile are restricted.
3) Direct toxicity. High levels of certain ions, including sodium, chloride, and boron, can injure plant tissue directly.
4) Altering nutrient availability. Certain nutrients as salts can change the availability and utilization of other plant nutrients (Landis 1981; Landis and Steinfeld 1990).

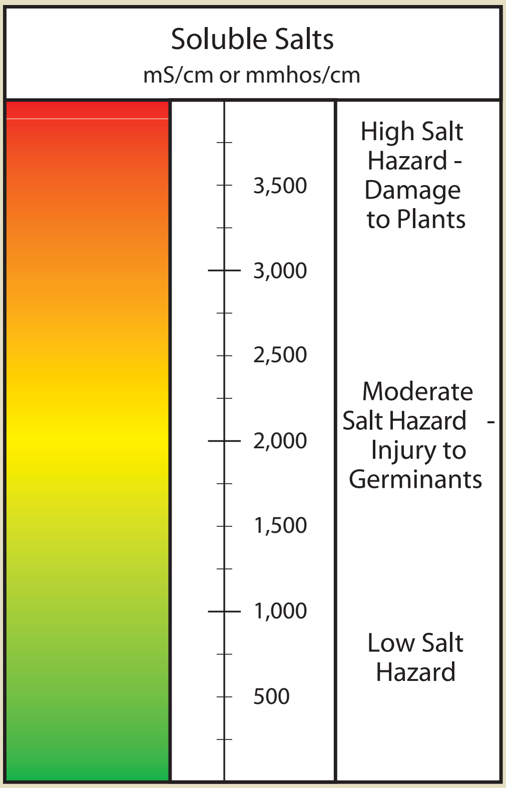
High salt levels can be found in arid climates where there is inadequate rainfall to leach salts out of the plant root zone. Topsoils tend to be lower in salts than subsoils, so during construction when topsoil is removed, the resulting soils can be very high in salts and pH. In addition, high salt concentrations can be created by poor soil drainage resulting from compaction; when excessive amounts of fertilizer, manure, or compost are applied; or when de-icing chemicals applied to roads run off and enter the soil (Parent and Koenig 2003).

5.5.5.1 pH and Salts – How to Assess

The pH and soluble salts tests are standard analytical measurements that should be run for all soil samples sent for nutrient analysis. pH tests should also be run on soil organic matter amendments considered for mulch or incorporation into the soil. These tests are accurate, with pH results differing between laboratories by 0.1 to 0.2 points (Thomas 1967). pH and soluble salts can also be tested by the revegetation specialist on site or back at the office using reasonably priced equipment. When considering purchasing a portable pH meter, be sure that it will also measure soluble salts and that it has a tip that can be submerged easily in a soil slurry.

The most accurate method of assessing pH and salinity is through lab analysis. However, quick, reliable estimates can be made with a hand-held pH/electrical conductivity meter using the Saturated Media Extract (SME) method for preparing samples (Figure 5.38). This method

***Figure 5.39 –** Soluble salts will injure germinants and, at high concentrations, can damage established plants. (Values are based on the SME method of conductivity measurement.)*



requires a small amount of soil (50 cc) be placed in a jar. Just enough distilled water is stirred into the soil to make the surface "glisten" but not readily flow. The mixture is allowed to stand for approximately 15 minutes. If the probe can be inserted into the soil so that the sensors are completely covered, then a pH and conductivity reading can be directly made. If the probe can not be submerged in the slurry, then a larger sample of soil or a gravity or vacuum filtration system solution should be used to extract enough water to test.

5.5.5.2 Mitigating for Low pH Soils

Apply Liming Materials – Raising the pH through the application of liming materials is a common agricultural practice that can be applied to revegetating road sites (See Section 10.1.6, Lime Amendments).

Apply Appropriate Fertilizers – Some commercial fertilizers, especially ammonium-based fertilizers such as ammonium nitrate, ammonium sulfate, and ammonium phosphate, will reduce pH (Havlin and others 1999) and should be limited on acidic soils. Fertilizers that have calcium, magnesium, or potassium in the formula are more appropriate for low pH soils. Examples of these fertilizers are calcium nitrate, potassium nitrate, magnesium sulfate.

Apply Lime With Organic Matter – Incorporation of lime will lower pH. On acid soils, application of lime with organic matter will raise the pH of the soil (See Section 10.1.6, Lime Amendments).

Apply Topsoil – Where topsoils have been removed leaving very basic or very acidic subsoils, reapplying topsoil or manufactured topsoil can moderate pH levels.

5.5.5.3 Mitigating for High pH Soils

Apply Sulfur – Agricultural soils can be treated with sulfur to lower pH, but high quantities of sulfur and irrigation must be applied to lower the pH just slightly (Havlin 1999). The use of sulfur in wildland revegetation therefore is not a widely practiced method.

Irrigation – Applying irrigation water is another method of reducing soil pH by leaching out bases. However, the amount of water needed to lower pH levels can be very high; in most cases, using irrigation is not a viable mitigating measure. It is also difficult to find irrigation water in arid environments that is low in bases and salts. Applying irrigation water high in bases will raise pH and salt levels in the soil, compounding the problem.

Apply Organic Matter – Incorporated composts or other types of organic matter can lower soil pH as the organic matter decomposes (Havlin and others 1999). For arid sites, however, the pH and conductivity of the organic matter must be tested prior to purchase to avoid the possibility of introducing organic matter high in salts.

Add Nutrients – To compensate for the tie-up of certain nutrients, the addition of nutrients through fertilization might be considered. The benefits of using fertilizers on arid soil must be offset by the possibility of creating fertilizer salt problems.

5.5.5.4 Mitigating for Salts

Since high levels of soluble salts are usually caused by poor soil management, the key to mitigating high salinity is to avoid creating the conditions that could potentially cause those levels. In soils where internal drainage is poor, prevention may be the only feasible approach for reducing salt problems.

Avoid Mulch or Soil Amendments With High Salinity – Testing all materials to be applied to the site will aid in the prevention of increased salt levels in the soil. Amendment materials with electrical conductivity readings in excess of 1,000 mS/cm should be avoided.

Reduce Commercial Fertilizers – Some commercial fertilizers, control-release fertilizers (CRF) in particular, can significantly increase the soluble salts found in the soil. This can be a major problem when using CRF in arid conditions. The fertilizer will begin to release following wet, warm spring conditions, but will not be leached through the soil without significant rainfall through the summer. Salts can build up to damaging levels, both on the surface and in the plant root zone.

Apply Gypsum With Irrigation – Incorporation of gypsum (calcium sulfate) followed by leaching can be effective in situation where sodium is the cause of high soluble salts (e.g., de-icing materials have been applied to roads). The calcium in gypsum will displace sodium and the sodium will then leach out of the soil profile with irrigation or rainfall (UMES 2004).

Irrigation **–** Application of irrigation water could potentially leach the salts from the soil. The amount of water depends on the soil type. In arid soils, application of 6 inches of water can reduce salinity levels by 50%; 12 inches can reduce by 80%; and 24 inches can reduce by 90% (UMES 2004). Application of irrigation water would need to take place over several days. However, for most sites, this is not practical due to high costs.

5.6 SURFACE STABILITY

Surface stability is the tendency of the soil to remain in place under the erosive forces of rain, wind, and gravity. Good surface stability is essential for establishing plants, reducing erosion, and maintaining high water quality. If the soil surface is unstable, seeds will wash or blow away. They can also move downslope through freeze-thaw or gravity before they can germinate. The same processes that stabilize seeds will also stabilize the soil surface. As soil is removed, soil productivity is reduced. With excessive erosion, plant roots are exposed, increasing the possibility of seedling mortality.

Site factors that influence surface stability and soil erosion are:

- Rainfall and wind,
- Freeze-thaw,
- Soil cover,
- Surface strength,
- Infiltration rates,
- Slope gradients,
- Surface roughness, and
- Slope lengths.

All surface erosional processes start first with the detachment of soil through the forces of rainfall, wind, or frost heave. These forces loosen seeds and soil, making them more susceptible to transportation off the site. Water moving over the surface of the soil during rainstorm events is the primary factor in moving seeds and soil into stream channels, resulting in lost seeds and water quality problems. This occurs when infiltration rates (the rate water moves through the soil surface) are lower than rainfall rates. If slope gradients are steep, slope lengths are long, or surface roughness is low, surface water picks up energy and transports greater and greater amounts of soil and seeds downslope. As this energy increases, eventually water becomes concentrated with force to cut through the surface of the soil, creating rills and gullies. The degree to which soils detach is directly related the percentage of soil cover protecting the soil (more cover, less erosion) and to the soil strength, or the capacity for individual soil particles to hold together under erosional forces. The result of soil erosion can often be detected on road cuts by noting how much sediment is in the ditch line. If the ditch is full of recently deposited sediment (recently deposited sediment usually lacks vegetation), there is a good chance that

Figure 5.40 **–** *Wind erosion not only blows seeds, soil, and mulches off the soil surface, it will also expose roots of established plants. Non-cohesive soils, like sands and silts, are most prone to wind erosion.*

sediment came from the cut slope. An inspection of the surface of the cut slope will indicate if the sediment originated there. Gravels, cobbles, and even small plants will show the results of soil movement.

5.6.1 Rainfall and Wind

Each site has unique rainfall and wind patterns that will affect the stability of the soil surface. High rainfall intensities and high winds can move seeds and soil particles off-site through erosional processes. In water erosion, raindrops begin the erosion process. Raindrops have been likened to small bombs. In heavy rainstorms, they fall with such force (possibly between 15 and 20 miles per hour) that, when they hit the soil surface, they create an impact that can blast the soil or seeds several feet away. Raindrops leave behind small craters that are compacted and sealed with fine soil particles, reducing infiltration rates.

The intensity of rainfall determines how much soil is detached. A high intensity rainfall will detach more soil particles than a low intensity rainfall. But detachment is only one aspect of erosion; it takes surface runoff to move soil and seeds downslope. If an intense rainstorm lasts only a short period of time, there will be insufficient water to exceed infiltration rates and water will absorb into the soil. If the duration is long, some water will not enter the soil, but will run over the surface carrying soil and seeds downslope. The most critical weather events, therefore, are those that bring high intensity rainstorms of long duration. These typically occur during major summer thunderstorms or Pacific winter storm systems. Precipitation in the form of snow is not typically a problem for surface erosion. Snow protects the soil surface from rainfall splash, and snowmelt usually occurs at such slow rates that even soils with low infiltration can absorb the water.

When projects are located in areas of high winds, surface soils will be susceptible to wind erosion. Wind forces will detach soil particles and seeds and move them offsite. In extreme conditions, high winds can remove several inches of surface soil, exposing roots (Figure 5.40).

5.6.1.1 Rainfall and Wind – How to Assess

It is unlikely that climate reports or weather records will give the duration and intensities of rainfall events for site level planning. Digital rainfall gauges are available that record the amount of rainfall and time it occurred. This information is used to determine duration and intensity. While the cost of this equipment is high, it is becoming more affordable. There are many types of digital rain gauges available, ranging in price and quality. It is important to select a digital rain gauge that is rugged, self maintaining, and can record for long periods of time.

Permanent wind speed equipment is available, but most likely beyond the reach of most project budgets. Site visits during different times of the year give some indication if wind is a problem. Site characteristics, such as position on slope (ridgelines are more prone to wind than valley floor) or proximity to forested environments (forests often reduce wind speeds) can be used to infer wind forces. Vegetation can also indicate the effect of wind. For example, prevailing winds can be determined from the growth habits of trees and shrubs on site. Local residents may also provide some information on local weather events.

Assessing the risk of wind erosion can be determined by knowing soil texture. Those soils most prone to wind erosion are non-cohesive soils, ranging from silts to coarse sands. Clay soils (cohesive soils) and very rocky soils are far less prone to wind erosion.

***Figure 5.41** – Continual freeze-thaw conditions can push root systems of planted seedlings out of the ground, reducing growth and potentially killing seedlings.*

5.6.1.2 Mitigating for High Rainfall and Wind

***Minimize Disturbance* –** In areas of high rainfall or sites where water quality values are high (near streams or rivers), the best engineering design is to keep the footprint of the construction project disturbance to a minimum. Not only does this reduce the risk of delivering sediment to the aquatic system, it can reduce project costs by reducing the amount of area needing revegetation.

***Integrate Erosion Practices* –** In disturbed sites, especially those near streams, the integration of erosion practices with plant establishment techniques offers the best approach to stabilizing the soil surface. These include practices such as increasing soil cover, shortening slopes, reducing slope gradients, leaving roughened surfaces, increasing infiltration rates, and quickly establishing native vegetative cover. These will be covered in the following sections.

***Figure 5.42 –** Ice crystals that form under freeze-thaw conditions can lift soil particles over 2 inches above the original surface. Later in the day the crystals will melt and the particles will drop.*

***Use Appropriate Mulching Practices* –** Assessing the potential for high winds on the site should be considered when applying mulches because mulches can be removed from the soil surface under strong winds. Some materials, such as wood strand mulches (See Section 10.1.3.10, Wood Strands), have been tested under high wind conditions and, because of higher weights and interlocking particles, these materials are more resistant to high winds. Lighter mulch materials, such as straw and hay, are more susceptible to removal by winds.

On windy sites, straw and hay are often crimped into the soil, but this operation can also cause soil compaction. Tackifiers used with hydromulches are used effectively to stabilize straw and hay mulches. Mulches placed on roughened soil surfaces can also reduce the potential that the mulches will be lost by wind.

***Place Large Woody Matierial* –** Down woody material such as trees and large bran ches can bock the soil surface from wind and rainfall.

5.6.2 Freeze-Thaw

Freeze-thaw is the process of ice formation and ice melting that occurs within the surface of the soil. In this daily cycle, temperatures drop at the soil surface at night and water begins to freeze within the soil pores, creating ice crystals. As ice crystals continue to form, water is drawn from the soil below through capillary action to replace the water that created the ice crystals. During freezing, ice crystals expand in the soil and push soil aggregates apart (Ferrick and Gatto 2004), weakening the internal structure of the soil. When soils thaw during the day, soil strength has been greatly reduced (Gatto and others 2004), leaving the soil surface significantly less resistant to erosional forces. Freeze-thaw is considered one of the least understood aspects of soil erosion (Ferrick and Gatto 2004) and yet accounts for significant annual soil losses (Froese and others 1999).

The formation of ice crystals will destabilize the seed germination environment. Freeze-thaw cycles affect germinating seeds by creating ice crystals that physically push the germinating seeds above the soil surface, exposing the emerging roots to extremely harsh conditions for seedling establishment, including low humidity, high temperatures, and sunlight. On steeper slopes, soil particles and germinating seeds will move downslope after each freeze-thaw cycle, further destabilizing the seed germination environment. Freeze-thaw processes can also affect seedling establishment. Long periods of freeze-thaw cycles can push container seedlings out of the ground, exposing roots and, in many cases, killing seedlings (Figure 5.41).

Soils most susceptible to freeze-thaw effects are those: 1) with a high silt content (or compacted sands), 2) with an adequate supply of soil moisture, and 3) that are cold. Silt-sized particles have pore sizes that are small enough to pull moisture to the freezing front through capillary action, yet large enough to form ice crystals (Ballard 1981). Soils with coarse textures, like sands, do not provide good capillary rise because the pores are too big; fine-textured soils (high in clay) have good capillary characteristics, yet do not have large enough pores for ice crystals to form (Ferrick and Gatto 2004). Sands have been reported to be frost-susceptible when they are compacted because the size of the pores is reduced, encouraging capillary rise (Gatto and others 2004). Soil cover, which includes litter, duff, and organic mulches, do not typically have good capillary rise characteristics, and therefore are less frost-susceptible. In addition, soil cover offers good thermal protection, which moderates the degree of freezing and thawing at the soil surface. The effects of freeze-thaw on surface stability increases as slope gradients steepen; the steeper the slopes, the greater the movement of seeds and soil downslope each day. Consider a seed or soil particle on a steep slope that experiences a 2 inch rise on top of an ice crystal (Figure 5.42); when the crystal melts, the seed or soil particle drops to a different point further downslope. After many freeze-thaw cycles, the distance traveled by the seed or soil particle can be significant.

5.6.2.1 Freeze-Thaw – How to Assess

Freeze-thaw processes occur typically in the spring and fall, when soil moisture levels are high and soil temperatures are cold. Soil surfaces that have undergone freeze-thaw cycles will have a very loose crust that will collapse when touched or walked upon. Gravels are often perched on pedestals, but give way under light pressure.

Project areas with bare surface soils high in silts should be considered prone to freeze-thaw processes in the spring or fall. Compacted soils high in sands are also susceptible. Soils with deep mulch or litter layers are less susceptible.

Figure 5.43 – *Soil cover protects the surface from rainfall impact. Not only is soil removed during rainstorms, affecting germination and seedling establishment, but seedlings that do emerge can be covered with soil that splashes from rainfall impact. Seedlings will not grow through an encasement of soil.*

Figure 5.44 – *Larger materials, such as gravels (A) and wood chips (B), protect the soil and sown seeds by absorbing the energy of rainfall impact. While unprotected soil and seeds are removed through splash and sheet erosion, protected soil remains in pedestals, sometimes several inches above the surface of the soil. Seeds that do remain on or near the surface have a difficult time germinating through the surface crust created by rainfall impact (C). Plants that do establish will have roots exposed by successive rainfall events.*

5.6.2.2 Mitigating for Freeze-Thaw

Apply mulch. Available research on the mitigation of freeze-thaw effects is slim, but it can be assumed that practices that insulate the soil surface and increase pore sizes will reduce some of the effects of freeze-thaw. The addition of organic mulches will provide insulation. The deeper the mulch layer, the less propensity for freeze-thaw at the surface. Hydromulch applications at typical rates of 1,000 to 2,000 lb/ac are not deep enough to moderate surface temperatures, or strong enough to resist the destabilizing effects of ice crystal formation on surface strength. Mulch applications that are too deep will bury the seeds, and seedlings will not emerge. In this case, using mulches such as pine needles and wood strands are options because application can occur at greater thickness but still allow light through for seedling emergence. If ice crystals do form and push newly emerged seedlings from the ground, these types of mulches will protect portions of exposed roots within the mulch layer from drying out, while also preventing the lifted soils from moving downslope by gravity (See Section 10.1.3.10, Wood Strands and Section 10.1.3.11, Litter and Duff). For planted seedlings, the application of very deep mulches should reduce the effects of freeze-thaw.

Till Compacted Soils – Sandy soils are very susceptible to freeze-thaw if they are compacted. Loosening soils through tillage is perhaps the best method of mitigating the effects of freeze-thaw on these soil textures (See Section 10.1.2, Tillage).

Avoid Wet Soils – Planting or sowing in soils with high water tables and poorly draining soils should be avoided. The extra moisture in these soils will feed ice crystal formation, creating a risk to establishing seedlings.

Maintain Some Overstory Canopy – Trees and shrubs will moderate surrounding temperatures, reducing the potential for freeze-thaw.

5.6.3 Soil Cover

Soil cover is the layer directly above the surface of the soil. In an undisturbed environment, soil cover is composed of duff, litter, live plants, and rock. Soil cover is very important for surface stability because it dissipates energy from rain drop impact before it reaches the surface of the soil. A good cover can protect the soil from high intensity rainfall events. Furthermore, if overland flow should occur during storm events, soil cover will slow the movement of runoff and capture sediments and seeds before they move downslope. Section 5.4, Water Loss, discusses how soil cover was important for reducing evaporation; this section will discuss its role in stabilizing the soil surface and reducing erosion.

When the soil surface lacks cover, it is subject to the direct forces of raindrop impact, overland flow, wind, and gravity. These forces not only move soil offsite, affecting water and air quality, but they also displace seeds or remove soil from around newly developing seedlings (Figure 5.43). A lack of soil cover will impact revegetation objectives by reducing the quantity of seeds that will germinate. Seeds that do germinate will be negatively affected by soil splash and sheet erosion that removes soil from around the seedling roots. The severity of soil erosion and seed movement is directly related to the percentage of bare soil.

After construction, most organic soil cover is removed. What remains is bare soil and coarse fragments (gravel, cobble, and stone). Left unprotected, bare soil will erode during rainstorms, leaving a pavement of gravel, cobble, and stone. If the amount of coarse fragments in the soil is high, then the percentage of the soil surface covered by coarse fragments will also be high. By the third year, erosion rates on unprotected bare soils typically fall to a tenth of the rate of the first year rate because of the formation of a soil cover of coarse fragments (Megahan 1974; Ketcheson and others 1999). While this process produces less sedimentation to stream systems, the high coarse fragments at the soil surface are not a good environment for seed germination. For this reason, it is important to quickly stabilize the soil surface after soil exposure; this is one of the reasons that road specifications call for temporary road stabilization during the construction period.

5.6.3.1 Soil Cover – How to Assess

Soil cover can be measured by establishing transects and recording the percentage of rock, vegetation, litter, duff, and bare soil. A monitoring protocol for measuring soil cover is presented in Chapter 12.

***Figure 5.45** – Semi-arid, arid, and cold sites often take more than one year to fully revegetate. Photo A shows the vegetative establishment one year after hydroseeding on a semi-arid site; bare soil exceeds 60%. Photo B shows the same site almost 2 years after sowing; vegetation has fully established. Soil cover methods in these cases must last several years for soil protection and plant establishment.*

5.6.3.2 Mitigating For Low Soil Cover

The primary objective of most revegetation projects is to stabilize the soil surface and create an optimum environment for seeds to germinate and plants to establish. Initial surface stabilization must remain effective until plants become established and protect the surface from erosion through vegetative cover. Therefore, the selection of surface stabilization methods must be based on: 1) the effectiveness as a soil stabilizer, 2) the quality as a seed germination and plant establishment environment, and 3) longevity.

Apply Mulch – There are a variety of mulches with varying qualities and longevities which should be considered based on the erosional potential and revegetation needs of each site (See Section 10.1.3, Mulches). Short-fiber mulches, such as wood fiber and paper mulches, applied with a tackifier are very effective in protecting the soil from rainfall impact. However, after a year, these mulches are usually no longer effective. On many sites, protection for a year is adequate for establishing a good vegetative cover. On sites that are cold, arid, or semi-arid, the establishment of vegetative cover can take longer than one year (Figure 5.45). On these sites, soil surface protection will require longer-lasting mulches such as straw, pine needles, hay, wood chips, wood strands, or erosion fabrics.

5.6.4 Surface Strength

When soil cover is removed, the surface of the soil is exposed to the erosive forces of raindrop impact, surface flow, freeze–thaw, and wind. How strongly soil particles bind together determines how much soil particles are detached and moved by these forces. Topsoils with good aggregation and high organic matter will be more stable than subsoils or soils low in organic matter. Soils high in clays have greater strength than sands and silts, which lack cohesiveness. Seeds have no cohesive properties and, when sown on the surface of the soil without mulches or tackifiers, are very susceptible to erosive forces.

5.6.4.1 Surface Strength – How to Assess

Determining the soil texture of the surface soil is a simple way to determine soil strength (See Section 5.3.1, Soil Texture). Soils low in clays (<15%) and high in sands will have low surface strength (Figure 5.46). In most cases, soils lacking topsoil will have reduced surface strength due to the lack of roots and organic matter that hold the soil particles together. The rainfall simulator can

Inset 5.3 – Bottlecap Test for Surface Stability
(from Herrick and others 2005a)

Place a soil fragment in a bottle cap filled with water. Watch it for 30 seconds. Gently swirl the water for 5 seconds. Assign one of three ratings:

M = Melts in first 30 seconds (without swirling) – Not stable

D = Disintegrates when swirled (but does not melt) – Moderately stable

S = Stable (even after swirling) – Stable also be used to determine soil strength because it measures the amount of sediment that is detached from surface soils under various rainfall intensities (See Section 5.6.5, Infiltration Rates). The USDA Natural Resources Conservation Service has developed a field test for determining surface stability for water erosion (Inset 5.3). This method rates how well surface soil samples maintain their stability after being agitated in water.

5.6.4.2 Mitigating For Low Surface Strength

Apply Tackifiers **–** Surface strength can be increased for up to a year or longer by applying tackifiers by themselves, with hydromulches over bare soil surfaces, or to bond straw onto the site (See Section 10.3.2, Hydroseeding). These products strengthen the bonds between surface soil particles. Seeds applied with a tackifier are held tightly to the soil surface, reducing the likelihood that seeds will be detached and moved.

Apply Mulch **–** Applying a long-fiber mulch to the soil surface can increase the overall surface strength because of the interlocking nature of the fibers (See Section 10.1.3, Mulches). The application of erosion mats can also increase surface strength.

5.6.5 Infiltration Rates

Infiltration is the ability of the soil surface to absorb water from rainfall, snowmelt, irrigation, or road drainage. A high infiltration rate indicates that the soil surface can transmit high rates of water input from sources such as a thunderstorm; a low rate indicates that the surface has low capability of absorbing water. When infiltration rates are lower than the rate of water input, runoff or overland flow will occur. Under these conditions, runoff can detach and transport soil particles, resulting in soil erosion and water quality problems. Overland flow can also remove sown seeds.

The size, abundance, and stability of soil surface pores determines the infiltration rates of a soil. Large stable pores created by worms, insects, and root channels will absorb water quickly and

Figure 5.46 – *Soils low in clays and high in sands have very low surface strength. Not only are they prone to surface erosion, but even walking on them can leave the surface in a very disrupted condition.*

Figure 5.47 – *When precipitation exceeds infiltration rates, water collects on the surface of the soil and begins to move downslope, causing erosion. On this site, litter and duff layers that typically protect the surface from rainfall impact have been removed, causing low infiltration rates.*

Figure 5.48 – *A portable "drop-forming" rainfall simulator developed by scientists at University of California Davis (Grismer and Hogan 2004) delivers water droplets through hundreds of needles (A). Pressure is increased or decreased to simulate rainstorm events. Droplets hit the surface of soil within a plot frame (B) and runoff water is collected at the bottom of the frame (C) to measure runoff rates and sediment production.*

have high infiltration rates, while surfaces that have been compacted, topsoil removed, or are low in organic matter will have poor infiltration rates.

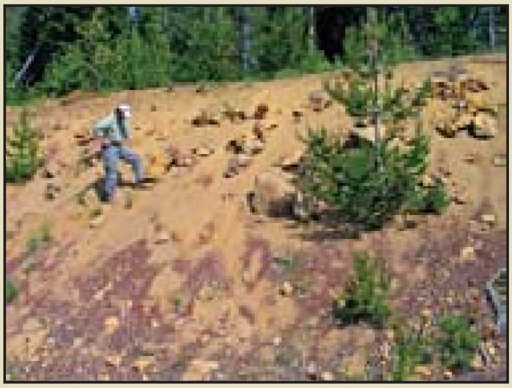
Under undisturbed conditions, infiltration rates are high, especially where a litter and duff cover exists. When soil cover is removed, the impact from raindrops can seal the soil surface, creating a crust that will significantly reduce infiltration rates. Infiltration rates are also reduced when the soil is compacted by heavy equipment traffic.

5.6.5.1 Infiltration Rates – How to Assess

The most accurate equipment for measuring infiltration rates is the rainfall simulator. This method is an attempt to create rainstorms of different intensities under controlled conditions and measure how the soil surface responds. Infiltration rates are determined when runoff occurs. Runoff water is measured at the bottom of the plot to calculate runoff rates and sediment yields (Figure 5.48). While most rainfall simulators were developed for agricultural operations, several have been developed specifically for wildland conditions. These simulators were built for transportability and conservation of water, since construction sites are often in remote locations and often far from water sources. The "drop-forming" rainfall simulator, developed for wildland use, delivers rainfall at the drop size or impact velocity determined for the climate of the project site (Grismer and Hogan 2004).

Using the rainfall simulator in revegetation planning is expensive, yet it is an important tool and should not be discounted because of the cost. Specifically, rainfall simulation used to compare the effects of different mitigating measures, such as mulches or tillage, on runoff and

Figure 5.49 – *When cut and fill slopes reach their angle of repose, non-cohesive soils move downslope at a continuous rate. The soil surface is constantly moving and never stable long enough for seeds to germinate and plants to become established. These slopes can remain barren for years. Soils that are high in sands and gravels are the most susceptible to dry ravel. In this picture, trees became established below rock outcrops, where the surface was protected from dry ravel.*



sediment production takes the guess work out of whether such measures are effective. This quantitative evaluation of erosion control methods might be essential in areas where water quality objectives are critical.

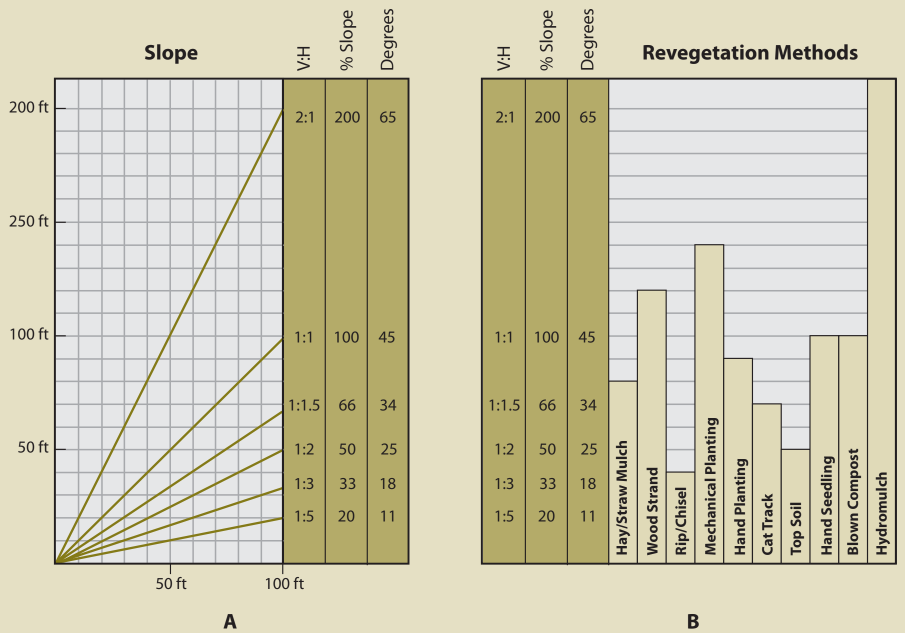
In most cases, infiltration rates are broadly estimated under routine field investigation by inference from site conditions. Infiltration rates can be considered high when the soil surface has not been disturbed and has a high percentage of cover. With compaction and loss of surface cover, infiltration rates are proportionally reduced. It is often assumed that construction activities that remove surface cover or disturb the topsoil will significantly reduce infiltration rates to levels that will create overland flow under most rainfall intensities.

5.6.5.2 Mitigating For Low Infiltration Rates

Tillage **–** Infiltration rates can be increased through soil tillage (See Section 10.1.2, Tillage) which reduces compaction, increases macro-pore space and creates surface roughness. Depending on the erosional characteristics of the site, the positive effects of tillage on infiltration rates might only remain effective through a series of rainfall events.

Incorporating Organic Matter **–** Incorporating organic matter into the soil surface can increase the longevity of infiltration rates created through tillage by forming stable macropores (See Section 10.1.5, Organic Matter Amendments). Unless macropores are interconnecting or continuous, however, they will not drain well (Claassen 2006). One method for creating continuous pores is to use long, slender organic material, such as shredded bark or hay. Compared to short organic materials, like wood chips, longer materials should increase

Figure 5.50 **–** *For engineering work, slope is generally expressed as the rise (V) over run (H). For slopes flatter than 1:1, (45° or 100%), slope gradient is expressed as the ratio of one unit vertical to a number of units horizontal. For example a 1:2 slope gradient indicates that there is one unit rise to 2 units horizontal distance. For slopes steeper than 1:1, it is expressed as the number of units vertical to one unit horizontal (e.g., 2:1 indicates that there is a 2 unit rise to 1 unit horizontal distance). In general to avoid confusion, it is wise to notate the ratio by indicating the vertical (V) and horizontal (H), when defining gradient (e.g., 2V:1H). Range and forest sciences use % slope gradient to describe slope angle. Slope gradient refers to the number of feet elevation rise over 100 feet. A 66% slope gradient indicates that for every 100 feet, there is a 66 foot vertical distance rise. Slope gradient controls what type of revegetation treatments can be used (B). The steeper the slope gradient, the fewer tools are available.*



infiltration rates. Incorporating higher quantities of organic matter will also increase porosity because of the potential of organic material to overlap and interconnect.

Surface Mulch **–** Applying surface mulch will reduce the effects of rainfall impact on surface sealing and reduce soil erosion rates (See Section 10.1.3, Mulches). It does not, however, necessarily increase infiltration rates. Studies have shown that, while sediment yield can be less with the application of mulches, runoff rates are not necessarily reduced (Hogan and Grismer 2007).

Plant Cover **–** The best long-term way to increase infiltration is to create conditions for a healthy vegetative cover. Good vegetative cover will produce soils with extensive root channels, aggregated soil particles, and good litter layers.

5.6.6 Slope Gradient

Slope angle or gradient is important in surface stability because it directly affects how soil particles will respond to erosional forces; the steeper the slope, the greater the erosional forces will act on the surface of the soil. Slope gradient is a dominant factor in water erosion and dry ravel erosional processes. In water erosion, the rate of soil loss and runoff from disturbed soil surfaces increases incrementally as slope gradient steepens. In dry ravel erosion, the surface remains stable until a specific slope gradient is reached, and then soil particles move downslope under the direct effects of gravity. This critical angle is called the angle of repose and it can be likened to the angle that accumulated sands make in an hourglass. Only non-cohesive soils, such as sandy, gravelly, or silt textured soils, have an angle of repose; soils with significant amounts of clays do not.

Dry ravel is occurring 24 hours a day. When you hear a piece of gravel or sand grain rolling down a cut slope, that is dry ravel. Not only does dry ravel create a constant supply of material to ditches, it also is impossible to revegetate unless the surface is stabilized. Seeds that germinate on steep, raveling slopes typically will not have enough time to put roots down deep enough to stabilize the surface before they roll downslope or are buried by soil particles rolling down from above. Figure 5.49 shows the angle of repose on a pumice sand parent material.

5.6.6.1 Slope Gradient – How to Assess

Slope gradient is quantified in several ways, as shown in Figure 5.50. For road construction projects, slope is usually expressed as the rise (vertical distance) over run (horizontal distance). A 1:3 road cut, for example, defines a slope that rises 1 foot over every 3 feet of distance. Biologists, including range, forest, and soil scientists, use percent slope as a measure of slope angle. This is calculated by measuring the number of feet rise over a 100 foot length. Slope gradient as expressed in degrees is not commonly used.

Slope gradient can be measured in the field using a handheld instrument called a clinometer. This equipment reads slope angle in percent slope and in degrees. Readings from a clinometer can be converted to rise over run notation using the chart in Figure 5.50. Road construction plans display the slope gradients for every cross-section corresponding to road station numbers (See Figure 3.3, in Section 3.2.3, Cross-Section View). Using these cross-sections, slope gradients can be identified on the plan map by color coding the run:rise for cut and fill slopes. For instance, 1:1 cut and fill slopes might be highlighted red for areas of concern, while those areas with gradients 1:3 or less might be light green, favorable areas for mitigation work. This exercise can quickly identify areas where the highest risk for soil erosion and seed movement might occur.

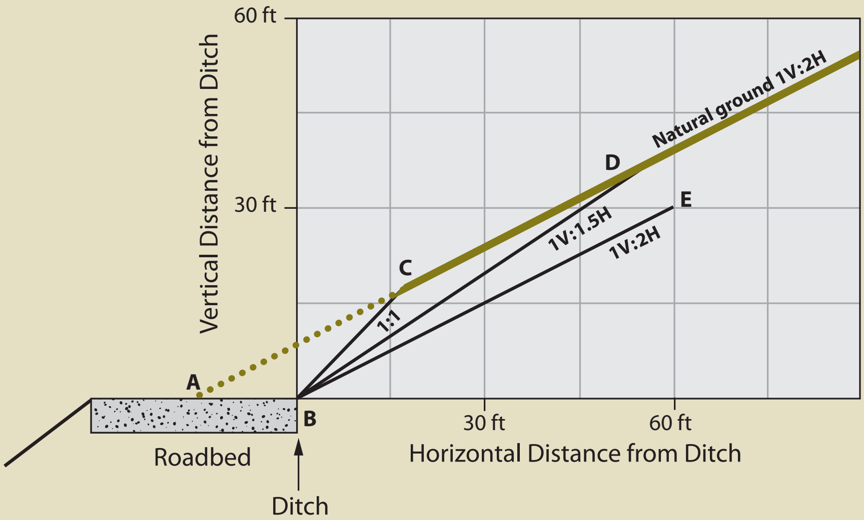
Slope angle plays a key role in revegetation planning because of its potential limitation on the types of mitigation measures that can be implemented. Figure 5.50 shows which practices are generally limited to gentle slopes and which can be implemented on steep slopes.

5.6.6.2 Mitigating for Steep Slope Gradients

Lengthen Cut or Fill Slopes **–** Slope gradient can be reduced by increasing the length of the disturbance. This will make the revegetation effort easier and more successful, but will increase the amount of area, or construction footprint, of the project.

Road planners consider many factors when they design the steepness of cuts and fills. A common design strategy is to create cut and fill slope gradients as steep as possible. This practice disturbs far less land, resulting in less area to revegetate. Because there is less exposed soil, the potential

***Figure 5.51** – The trade–off between designing steep cuts that are difficult to revegetate or creating gentle slopes that disturb more area is demonstrated in this example. The centerline (A) of a new road intersects the 1V:2H natural ground (A to D). Fifteen horizontal feet of material must be excavated from the center of the road (A) to the ditch (B) to create the road bed. The resulting road cut will have varying lengths depending on how steep it is designed. A 1:1 cut slope will expose a 25 ft cut from the ditchline (B) to the top of the cut slope (C). A 1V:1.5H slope (B to D) will lengthen this exposure threefold to approximately 80 ft. A 1V:2H slope (B to E) is not achievable since it remains parallel to the natural ground slope.*



for soil erosion is considerably reduced. Furthermore, there is a substantial cost savings with less excavation and revegetation work. Figure 5.51 gives an example of how increasing the steepness of a cut slope on a typical 1V:2H natural ground slope substantially decreases the length of disturbed soils.

The main drawback of steepening slopes, however, is that steeper slopes are much harder to revegetate, and the selection of revegetation practices available are reduced as the steepness of the slope increases (Figure 5.50). On sites with 1V:5H slopes or less, all revegetation practices are possible; on slopes approaching a 1:1 slope, the threshold of most revegetation practices has been reached, as well as the limit of what can be successfully revegetated. It is important to work with the design engineers early in the planning stages to consider the effects of slope gradient on meeting revegetation objectives.

Create Steep, Hardened Structures **–** Creating hardened structures or walls, such as retaining walls, crib walls, gabion walls, or log terrace design structures at the base of the slope will allow gentler slope gradients to be constructed above the structure. The drawback to hardened structures is that most are hard to revegetate.

5.6.7 Surface Roughness

Slopes that have roughened surfaces trap water during the initial stages of the runoff processes (Darboux and Huang 2005). Roughened surfaces consist of micro-basins that capture and store soil particles and seeds that have become detached in the erosional processes. Seeds that have been transported short distances into these depressions are often buried by sediments. Moderate seed covering from transported soil can enhance germination as long as the seeds are not buried too deeply. Micro-basins can also be relatively stable during the period for seed germination and seedling establishment. Surface roughness also reduces the effects of wind by reducing wind speed at the soil surface. However, as the micro-basins fill up with sediments, they become less effective in capturing sediments and seeds.

Figure 5.52 – *Surface roughness consists of micro-basins that are favorable to seed germination and early plant establishment.*

Figure 5.53 – *Surface erosion increases with distance downslope. On this site, sheet erosion turns to rill erosion at point B. Mitigation that shortens slope lengths to less than the distance between A to B will reduce rill erosion.*

5.6.7.1 Surface Roughness – How to Assess

There are many methods of measuring surface roughness which include paint and paper profiling, laser profiling, and pin boards. A simple field method for assessing surface roughness is using a cloth tape that conforms to the surface of the soil. In this method a tape is stretched a predetermined distance (e.g., 10 feet) and staked at both ends of the tape. Keeping the tape attached to one stake, the other end of the tape is released. Beginning at the staked end, the cloth tape is placed in contact with the soil surface and conforms to the micro-topography for the length of the tape. Tape distance is recorded where the end of the tape meets the end stake. The new distance is divided by the original distance to determine the surface area coefficient. The greater the distance between the two measurements, the greater the surface roughness.

5.6.7.2 Mitigating Measures For Smooth Soil Surfaces

Leave Surface Roughened – There is a tendency by many project engineers to "beautify" construction sites at the end of the project by smoothing soil surfaces. While basic landscape shaping is essential, the soil surface should be left as rough as possible. In many instances, leaving cut slopes "unfinished" or in the "clearing and grubbing" stage provides excellent seed bed diversity and growing environment. The diversity of micro-habitats provides greater climatic and soil environments for seed germination.

Surface Imprinting – Imprinting the soil surface to create micro-relief has been shown to be effective in reducing runoff and soil erosion and increasing plant establishment (See Section 10.1.2.4, Roughen Soil Surfaces).

Tillage – Tillage of the surface soil layers will leave the site in a roughened condition (See Section 10.1.2, Tillage). This practice has other beneficial effects on the soil besides leaving the surface in a roughened state.

5.6.8 Slope Length

Another factor influencing soil erosion and seed transport is the length of slope. As the slope lengthens, so does the potential for transport of sediment and seeds. On very long slopes, the erosive force begins as sheet erosion at the top of the disturbance and often turns into rill erosion at the bottom of the slope (Figure 5.53).

5.6.8.1 Slope Length – How to Assess

Slope length can be measured in the field or from road plans. The effects of slope length can be assessed by observing erosional features on existing disturbed areas. New or old disturbances can be used as references for critical slope lengths. As Figure 5.53 demonstrates, at some point downslope, erosional forces begin to cut rills into the surface soil. The distance downslope that this occurs can be considered the maximum length of slope for this site before severe erosion takes place. This distance will vary by the factors addressed in this section (soil cover, climate, slope gradient, surface strength, surface roughness, and infiltration rates).

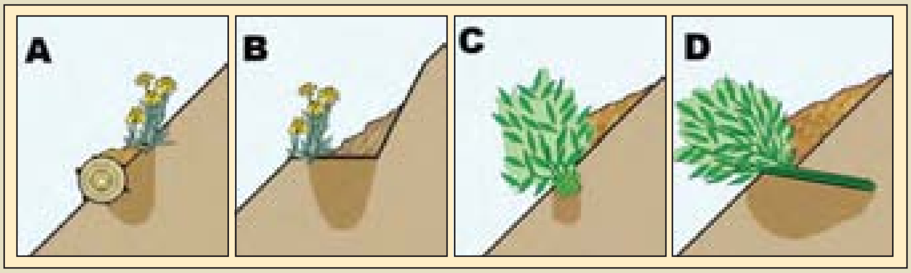
5.6.8.2 Mitigating Measures For Long Slopes

Install Barriers **–** Fiber rolls, straw waddles, downed wood, hay bales, silt fences, or compost berms can be laid on the surface as obstructions or barriers to reduce slope length. To be effective, they must be placed in contact with the soil and perpendicular to the slope gradient. Straw waddles, hay bales, and silt fences must be trenched into the soil surface.

Create Benches **–** The creation of slope breaks can reduce slope length. These breaks can be benches, steps, or trenches cut into the slope. The reduced gradient at these breaks slows the velocity of overland flow and collects sediments.

If either practice is applied in a long continuous line, they must be constructed on contour. If they are not placed correctly along the contour, water can collect and move along the structure, much like a channel, and eventually spill onto the slope below, creating rills and gullies. (The exception to this is the construction of live pole drains to redirect water off-site for slope stability [See Section 10.3.3.4, Live Fascines].) When placed properly along the contour, slope distances are shortened and the structures collect sediments and create areas for plant growth. Plants that are grown above obstructions or near the bottom edge of benches can take advantage of water and sediments that collect during rainstorms. Native vegetation can be incorporated into many of these designs to take advantage of increased soil moisture and sediment accumulation (Figure 5.54). The distance that these structures are placed apart from each other should be no greater than the critical distance observed on the site.

Figure 5.54 **–** *Structures that shorten the slope length can slow surface runoff, collect sediments and increase soil moisture. Typical treatments include: a) placement of fiber rolls, logs, straw waddles, and compost berms; b) benches, steps, and trenches; c) willow waddles; and d) willow brush layers. Strategic placement of plants can take advantage of increased soil moisture by planting where roots can access the additional moisture. Most species do not respond well to being buried by sediment and should be planted above or below depositional areas (A and B). However, some species, such as willow, root where the stems are buried, and these species can be planted where sediments are expected to be deposited (C and D).*



5.7 SLOPE STABILITY

This discussion is directed to non-engineers to simplify and make accessible basic slope stability concepts that must be understood in developing revegetation strategies. It is by no means a substitute for professional engineering expertise. Technical references for slope stability are many (including Carson and Kirby 1972; Spangler and Handy 1973; Brunsden and Prior 1984; Denning and others 1994), to which we refer the reader for a comprehensive review of this subject. For a detailed evaluation of the role of vegetation in slope stability, the reader is referred to Gray and Leiser (1982).

Creating stable slopes is essential for establishing healthy plant communities, but the reverse is equally true – establishing native vegetation is critical for stabilizing slopes. This discussion comes from the latter perspective of how to create the most favorable environment for establishing vegetation and how this approach can be integrated into the overall strategy of slope stabilization. A vegetated slope adds stability to slopes by 1) holding the soil together through a network of root systems and 2) removing water from the soil, which is the primary driving force behind most landslides.

Slope stability is the resistance of natural or artificial slopes to fail through gravitational forces. The landforms resulting from slope failures are called landslides and they are described by their morphology, movement rates, patterns, and scale. This section will focus on two general types of landslides that are common to road cuts and fills – slumps and debris slides (Figure 5.55). Slumps typically occur on deep soils that are cohesive (rich in clays). They tend to be deep seated and slow moving. Viewed in profile, the failure occurs in a circular motion, resulting in a series of tilted blocks and circular cracks. Debris slides are shallow, fast moving landslides that form on non-cohesive soils (e.g., sandy, gravelly). These landslides occur on steep slopes.

Water input is the driving force behind most slope stability problems encountered in road building projects. It comes as rainstorms, snowmelt, and often as diverted surface water from road drainage. As water increases in a potentially unstable slope, the added weight of the water in the soil plus the increased pressure of water in the pores (pore water pressure) eventually exceeds the strength of the soil, and the slope fails (Figure 5.56).

Increased water to a slope is especially a problem where a restrictive layer (a layer of soil that limits water movement) is close to the soil surface. As water moves through the surface horizon and encounters a restrictive layer, the water saturates the pores of the horizon above it, increasing the water pressure in the soil pores. The saturated horizon becomes heavier as the pores fill, and eventually the slope fails under the added weight of water and the increased pore water pressure.

Figure 5.55 – *Common landslides typically associated with road construction. Modified after Varnes (1978) and Bedrossiand (1983).*

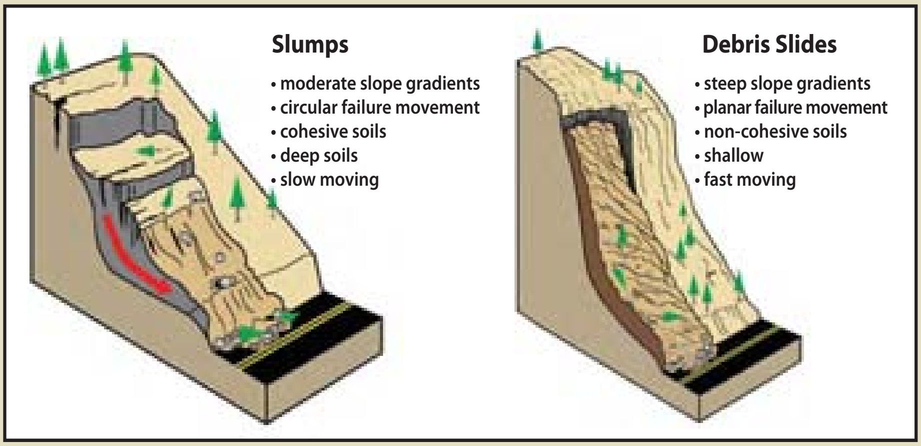


***Figure 5.56** – Water pressure is great when soils are saturated (high pore water pressure). Slopes will release this pressure through channels (created by decomposing roots in this picture, or animal burrows, worm holes, and so on). When pressures become too great for the strength of the soil, slopes fail. This picture was taken 30 minutes before this road cut failed.*

The faster water moves through soil, the less susceptible a slope is to failure. The measured rate at which water is transmitted through a soil mass is its permeability. When permeability is high, water quickly moves out of the soil pores, reducing the potential for increased pore water pressure or slope weight. When permeability is low, water slowly moves through soil and builds up in the soil pores. On gentle slopes, this is not a problem; as slope steepness increases, gravitational forces acting on the slope raise the potential for slope failure. Slope length is another factor important to water movement because the longer the slope, the greater the build up of water near the base of the slope. This phenomenon explains why many slope failures occur in the mid to lower portions of fill slopes.

Whether a slope fails or not is ultimately due to the strength of the soil. Soil strength is affected by the amount of clay present in the soil (the more clay, the greater the soil strength), how compacted the material is (the greater soil compaction, the more stable the soil), and the presence of roots (more roots are better). Often compacting soils takes priority over creating optimum soil for roots as methods for increasing soil strength. We suggest in the following discussion that the factors for increasing soil strength be considered together and integrated to produce the optimum stability, while at the same time creating the most favorable environment for native vegetation.

This section will discuss each of the following parameters as they relate to increasing slope stability through revegetation treatments:

- Permeability,
- Restrictive layers,
- Water input,
- Slope length,
- Slope gradient, and
- Soil strength.

5.7.1 Permeability

The rate at which a volume of water moves through soil material is its permeability (technically referred to as hydraulic conductivity). Soils that have moderate to high permeability rates tend to be more stable than those with low permeability rates. Where permeability is low, water fills the soil pores but does not drain quickly, adding additional weight to the slope and increasing the pore pressure. Both factors reduce the overall strength of slopes and increase the likelihood that slope movement will occur when other conditions are right.

Soils with large interconnecting pores have a higher permeability than soils with smaller pores that are less interconnecting. Soil textures that are well-graded (soils that have only one particle size) typically have a higher permeability than poorly-graded soils (soils having a range of particle sizes from clays to small gravels). For example, poorly graded granitic soils have low permeability rates because the different sized particles are neatly packed together, restricting the pathways for water flow. Well-graded soils, such as pure sands and gravels, have high permeability because pores are large and interconnecting. Compacted soils, on the other hand, often have low permeability rates because of the reduced or destroyed interconnecting macro-pores.

5.7.1.1 Permeability – How to Assess

Simple field tests, such as percolation tests, historically utilized in assessing septic leach fields, can be used for determining permeability rates. A small hole is excavated and water is poured to a specified depth. The time to drain the water from the pit is measured in inches per hour. These tests are run at different soil depths to determine if permeability rates change. Results from percolation tests are subject to great variability. Nevertheless, they can indicate the relative permeability of different soil types or different soil disturbances.

Engineering laboratory tests for determining permeability include the constant head permeameter for coarse-grain soils. In this test, a soil sample is placed in a cylinder at the same density as the soils in the field. Water is introduced and allowed to saturate the sample. A constant water elevation, or head, is maintained as the water flows through the soil. The volume of water passing through the sample is collected and this provides a direct measurement of the flow rate per unit of time. The test can be repeated at various densities to determine the corresponding permeability. The test can also be repeated for various additions of organic amendments and compaction levels to determine the effects of these treatments on permeability. Consult a soil lab for how to collect and submit samples for these tests. Where testing is not feasible, engineering and soil texts can give ranges for expected permeability based upon the soil gradation and classification. A field assessment can also give some indication of permeability rates. Subsoils or soils lacking organic matter that have a range of soil particle sizes, from clays through small gravels, have a propensity for low permeability rates, especially when they are compacted (See Section 5.3.3.1, Soil Structure – How to Assess).

5.7.1.2 Mitigating For Low Permeability

Tillage – Loosening compacted soil through tillage practices (See Section 10.1.2, Tillage) increases permeability by creating large fractures or pathways for water to flow. However, tilled soils often return to near-original permeabilities as the soils settle over time.

Organic Amendments – Long-fibered organic matter tilled deeply into the soil will increase the infiltration and permeability of the soil because larger, interconnecting pore spaces are created (See Section 10.1.5, Organic Matter Amendments). Several studies evaluating the incorporation of unscreened yard waste suggests that an optimum rate of organic matter additions for increasing infiltration and improving soil structure is approximately 25% compost to soil volume (Claassen 2006). In addition, incorporating organic matter can also increase slope stability because amended soils are lighter in weight than non-amended soils; mineral soils can weigh 10 to 20 times more than soils amended with 25% organic matter. The reduced soil weight lowers the driving forces that create unstable slopes. Additions of organic matter with high C:N ratios can limit the establishment of vegetation. Using composted organic matter will reduce the length of time that nitrogen is unavailable.

5.7.2 Restrictive Layer

A restrictive layer is any soil horizon or stratum (including unfractured bedrock) that has very low permeability. As water flows through a surface horizon with good permeability and encounters a restrictive layer, the rate of downward vertical water movement slows and water builds up in the pores of the upper layer. Since the permeability of the surface layer is higher than the restrictive layer, water moves laterally downslope above the contact. Slope failure occurs when the pores in the soils above the restrictive layer become saturated with water to a point where the pore water pressure and soil weight exceeds the soil strength. Failure occurs within the soils above the restrictive layer. The depth of slope failure depends on the thickness of the surface layer. On slopes where the restrictive layer is near the surface, slope failure, if it occurs, will be shallow (Figure 5.57). Where the contact is deeper, the soil movement will be more extensive. The types of landslides that occur with restrictive layers are debris slides.

Figure 5.57 – *In this photograph, a restrictive layer is very close to the soil surface. During a rain storm, water moved through the shallow soil layer and encountered a restrictive layer. Water then moved downslope, building up pressure, until the increased pore pressure and soil weight exceeded the strength of the soil to resist these forces. At this point, mid to lower slopes failed.*

5.7.2.1 Restrictive Layer – How to Assess

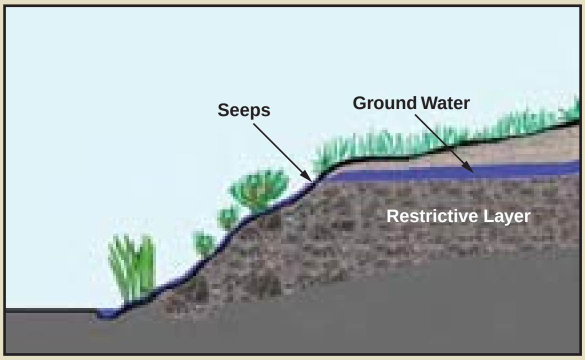
Restrictive layers in natural settings can be inferred by the presence of seeps and springs. These features occur most often at the point where a restrictive layer is intercepted or exposed to the surface. These can be intermittent features that are observed in the winter or spring that dry up in the fall or winter. The vegetation around permanent and temporary seeps and springs is typically composed of water-loving species, such as sedges (*Carex* spp.) and rushes (*Juncus* spp.). Figure 5.58 shows how a seep is created when a cut slope intersects a restrictive layer.

On construction sites, restrictive layers can be created by placing a loose soil over a highly compacted subsoil. These layers can be identified in the field by determining soil strength using a soil penetrometer or shovel to find compacted or dense soils (See Section 5.3.3, Soil Structure). This layer is then assessed for the approximate amounts of silt and clay using the field texturing method. Dense or compacted soil layers that are high in silts and clays are likely to be very restrictive to water movement. Field permeability tests can be used to determine the rates of water flow (See Section 5.7.1.1, Permeability – How to Assess). Often restrictive layers are not observed until after construction when they manifest themselves as intermittent seeps or wet areas in cut and fill slopes. Geotechnical investigation will determine if these features are due to shallow water movement associated with restrictive layers or interception of deeper subsurface water interception.

5.7.2.2 Mitigating For Restrictive Layers

Tillage – If restrictive layers are within several feet of the soil surface, site treatments that break up portions of this layer can increase the permeability and increase stability. Site treatments that accomplish this are bucket tillage, deep ripping, spading, and fill cut (benching and backfilling) which are discussed in Section 10.1.2, Tillage. The drawback to tillage is that it will reduce soil strength in the short term until roots occupy the soil and increase soil strength. Temporary irrigation systems have been installed on sites where quick establishment of

Figure 5.58 – *Groundwater moves downslope above restrictive soil layers. Seeps are seen in road cuts where the restrictive layer is exposed. Increased soil water that occurs above restrictive layers can increase slope instability.*



grass cover during summer and fall months is essential for slope stabilization prior to winter precipitation (Hogan 2007).

Organic Amendments **–** Where possible, the incorporation of organic matter will help keep the restrictive layer from returning to its original soil density and allow more time for roots to become established (See Section 10.1.5, Organic Matter Amendments). As mentioned above, soil strength might be reduced until vegetation has become established, but the negative effects of reduced soil strength could be offset by the increased permeability and reduced soil weight of the organic amendments.

Live Pole Drains **–** Live pole drains are constructed to intercept water from seepage areas and remove it through a system of interconnecting willow bundles (which act as a drain) to more stable areas, such as draws, ditches, or other waterways (See Section 10.3.3.4, Live Fascines). The interception and flow of water encourages the establishment and growth of willow cuttings along the length of the live pole drain.

5.7.3 Water Input

Water, which is the driving force behind most landslides, comes through rainfall, groundwater flow, snow melt, or diverted from other areas through road drainage. Landslides often occur after a series of strong winter storms have delivered a high amount of rainfall over a short period of time. Under these conditions, soils have not had sufficient time to drain before the next storms arrive. When warm storms bring rain to slopes with snow pack (called "rain on snow events"), water from rain plus melting snows is very high, increasing the probability for the occurrence of landslides on potentially unstable sites. Landslides can occur where water from road ditches or other road features drain water onto marginally unstable slopes. Major site factors that affect water input are: 1) rainfall duration and intensity, 2) rain-on-snow events, and 3) road drainage.

5.7.3.1 Water Input – How to Assess

See discussions under Section 5.2, Water Input for how to assess water input.

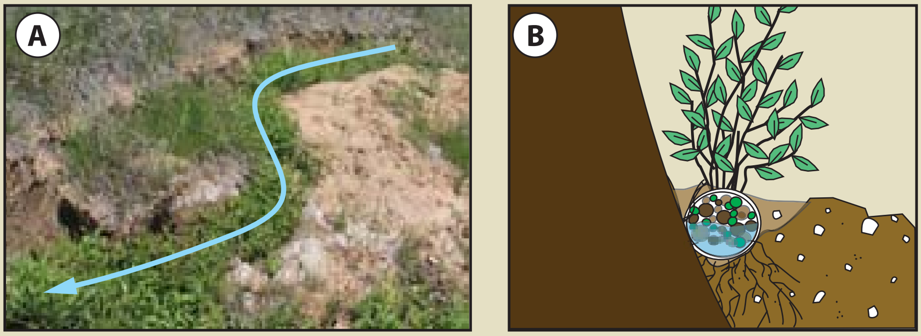
5.7.3.2 Mitigating For High Water Input

Proper Surface Drainage **–** Increased water is the driving force behind slumps and debris slides. Designing proper water drainage is probably the most important measure to implement for slope stability (Gedney and Weber 1978). Where road water is inadvertently routed into potentially unstable areas, there is a greater potential for slope failure (Fredricksen and Harr 1981). Road projects are designed to move storm water away from or out of unstable slopes as quickly as possible through road and slope drainage structures.

Species Selection **–** Select species that have adapted to wet soils. These include sedges (*Carex* spp.), rushes (*Juncus* spp.), bulrushes (*Scirpus* spp.), willows (*Salix* spp.), cottonwoods (*Populus* spp.), and cedars (*Thuja* spp. and *Chamaecyparis* spp.). Since each species has a unique way, or strategy, of modifying the moisture regime of a site, planting a mixture of species is a way of assuring that all strategies are represented on the site. For instance, willows establish quickly and can draw large quantities of moisture from the soil, but only when the willows have leaves. Cedars, on the other hand, are slower to establish, but longer lived. They can withdraw moisture from the soil during the winter months, unlike deciduous species. When they are well established, they will intercept large amounts of water in the crowns, preventing precipitation from reaching the soil. Trees have a great ability to significantly deplete moisture at considerable depths (Gray and Leiser 1982). Wetland species, such as rushes and sedges, unlike many trees and shrub species, are not limited by saturated soils. They thrive and draw down moisture where other species will perish.

Live Pole Drains **–** The live pole drain (Polster 1997) is a biotechnical engineering technique where continuous willow bundles (See Section 10.3.3.4, Live Fascines) are placed across a slope, much like an open drain, to redirect water to a more stable area (channels, draws, and so on). Where small slump failures have occurred during or after construction, live pole drains can be installed to increase slope drainage, add root strength, and remove soil moisture from the slide mass.

***Figure 5.59** – Slumps are characterized by scarps, cracks, and benches. Water collects on the benches and in the cracks where it is transmitted into the slide mass, creating continued instability. Water can be removed through a series of hand-dug surface ditches. Using the cracks as guides for the location of ditches, they are filled in with soil and dug wide enough for a willow fascine (See Section 10.3.3.4, Live Fascines) to be placed in the bottom (A). Called "live pole drains" (Polster 1997), these structures not only quickly move surface water off the slide to more stable areas, but the willow cuttings in the fascines, encouraged by the presence of high soil moisture, grow into dense vegetation (B) that stabilize the slide through the deep rooting and dewatering.*



5.7.4 Slope Length

Slope length is important in stability because the longer the slope, the more water can concentrate in the lower portion of the slope. Increased water will increase pore water pressure and soil weights, decreasing the stability of the mid to lower sections of long slopes. This is one reason why slumps are often observed in the mid to lower slope positions of longer fill slopes.

5.7.4.1 Slope Length – How to Assess

Slope length can be obtained from road plans or measured directly in the field using a tape.

5.7.4.2 Mitigating For Long Slopes

Live Pole Drains – Using live pole drains (discussed in the previous section), shortens the distance water is transmitted through the hill slope by intercepting surface and subsurface water in ditches at frequent slope intervals. Captured water is transmitted downslope through a system of continuous fascines to a stable channel (Figure 5.59).

Create Benches – Another method of reducing slope length can be the creation of a slope break. These are benches, steps, or trenches cut into the slope. The reduced gradient at these breaks slows the velocity of overland flow and collects sediments. However, unless the water is directed off the slope, total water input to the slope is not reduced.

5.7.5 Slope Gradient

As slope gradient increases, the destabilizing gravitational forces acting on the slope become greater. On a level surface, the gravitational force stabilizes the soil mass. As the slope gradient increases, the amount of force available to resist sliding along the failure surface decreases.

5.7.5.1 Slope Gradient – How to Assess

Assessing slope gradient is discussed in Section 5.6.6.1, Slope Gradient – How to Assess.

5.7.5.2 Mitigating For Steep Slopes

Mitigating measures for steep slopes are discussed in Section 5.6.6.2, Mitigating for Steep Slope Gradients.

5.7.6 Soil Strength

Soil strength (technically referred to as shear strength) is the characteristic of soil particles to resist downslope forces. The major physical factors contributing to increased soil strength are: 1) reduced porosity (compacted soils), 2) greater range of particle sizes (poorly graded soils), 3) greater angularity of the soil particles, 4) greater surface roughness, and 5) presence of silts and clays that add cohesive strength (Hall and others 1994).

The biological components contributing to increased soil strength are the: 1) matrix of roots that reinforce the surface horizon, 2) roots that anchor an unstable soil mantle to stable subsoils or rock, and 3) stems (e.g., trunks of trees) that add support to the soil immediately uphill (Hall and others 1994) (Figure 5.60). The physical factors, unfortunately, do not always support the biological factors. For example, porosity should be of particular interest to the revegetation specialist. From an engineering standpoint, low porosity soils have greater soil strength than soils with high porosity because soil particles are packed closer together and interlock. Reducing porosity is accomplished through various methods of compaction. From a vegetation standpoint, however, this practice is very limiting to plant establishment and vegetative growth (See Section 5.3.3, Soil Structure). Balancing the needs of creating a healthy soil for optimum vegetation while still maintaining slope stability until established vegetation adds root strength to the soil is a challenge to engineers and revegetation specialists. Creating soils with high porosity will decrease soil strength in the short term. However, if this practice increases the productivity of the site, the long-term result is often a net increase in soil strength (Gray and Leiser 1982).

The growth habits of native species can greatly influence slope stability because each has a unique rooting pattern and root tensile strength. For instance, grass roots are very fibrous and abundant in the surface horizon, adding surface stability when the grass cover is high. Grass and forb roots, however, are not as strong and do not penetrate as deeply into the soil as tree roots, and add little strength at deeper depths (Gray and Leiser 1982). The roots of shrub and tree species, on the other hand, are long and deep rooted, with relatively high tensile strength (Gray and Leiser 1982). The main advantage of these species is the long vertical roots (taproots) that can cross failure planes and bind the soil strata together.

__Figure 5.60 –__ Plant roots and stems increase slope stability by (A) reinforcing the surface horizon through a matrix of roots, (B) anchoring surface horizons to rock or subsoils, and (C) stems supporting the soil upslope.

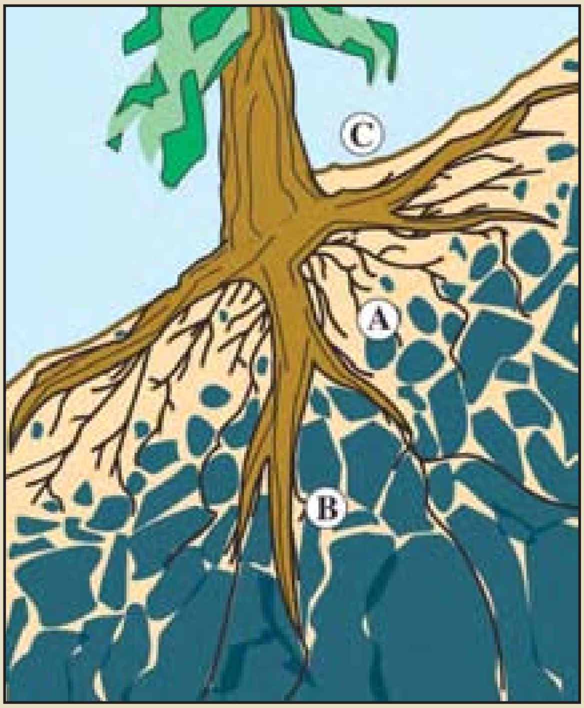


Figure 5.61 – *This debris slide (noted by its shallow, steep appearance) took place two years after construction when the grass and forbs were fully established. Establishing shrub species, rather than grass and forb species, to steep, potentially unstable slopes would be better for long term stability because shrub species are deeper rooting and have higher root tensile strength.*

5.7.6.1 Soil Strength – How to Assess

While the revegetation specialist will probably never perform an engineering test for soil strength, it is important to understand that there are routine assessment methods used for this determination. These tests are especially important to consider if the revegetation specialist is advising that soils on potentially unstable sites be deeply tilled or amended with organic matter, since these practices can reduce soil strength until vegetation is established.

A common method engineers use to estimate soil strength is to correlate soil classification (from sieve analysis and the characteristics of clay particles) with published literature values. Shear vanes or cone penetrometers are good methods to approximate the strength of fine-grained soils in the field. Published research is used to correlate field instrument readings with laboratory shear strength test results.

The triaxial shear test is a more precise laboratory method to determine shear strength of soils. In this test, a long cylinder of the soil is placed in a latex membrane and submerged in a clear plastic cylinder filled with water. A vertical pressure is applied to the cylinder at a slow rate until the soil sample shears. Very sensitive strain gauges measure the soil displacement, applied forces, and any pore water pressures that develop. Various water pressures are applied to the cylinder to simulate the confining pressure of soil depth (Brunsden and Prior 1984). This test can be used to determine the shear strength of soils that have been amended with organic materials.

5.7.6.2 Mitigating For Low Soil Strength

Biotechnical Engineering Techniques – Many biotechnical slope stabilization techniques use vegetative cuttings from willows or other easy-to-root species to structurally reinforce the soil. As these materials root, they add further stabilization to the slopes through interconnecting root systems and soil moisture withdrawal. These practices include stake planting, pole planting, joint planting, brush layers, and branch packing (See Section 10.3.3, Installing Cuttings).

Shrub and Tree Seedlings – On drier sites, where willow cuttings are less likely to survive and grow, shrub and tree seedlings can be used. While these species are slower growing, they usually have deeper root systems and persist longer once they are established. Grass and forb species can quickly establish on drier sites, but soil strength is limited to the surface of the soil profile where the roots are most abundant. On potentially unstable sites, grasses should be grown between shrub and tree seedlings to add soil strength to the surface soil while tree and shrub species become established. On dry sites, however, grasses must be excluded around seedlings or vegetative cuttings until they have become established. Because of the steep, shallow nature of many of these sites, planting seedlings is not always practical or successful. Hydroseeding or hand sowing, covered by a surface mulch that will protect the surface from erosion for several years while the shrubs become established, should be considered.

Soil Improvement – Improving soil productivity will thereby increase the density of roots and increase slope stability (Hall and others 1994). Mitigating measures that improve water storage, organic matter, and nutrients should, with time, increase slope stability. Some practices, such as soil tillage, reduce soil strength in the short-term. However, once plants have become established, more roots occupy the soil and slope stability is increased. Tillage should be integrated with practices that quickly reestablish vegetation to assure that slope stability is not compromised in the short term. On slopes where root strength is critical for stability in the first year after construction, irrigation might be considered in order to quickly establish a dense vegetation cover.

5.8 WEEDS

Weeds are unwanted vegetation on a construction site or surrounding areas before, during or after revegetation. Roadsides can be major conduits for weeds, including invasive, noxious, introduced, and exotic species problematic not only for roadside ecology, but also for the general ecosystem health of surrounding lands and economic well-being of adjacent farmers, ranchers, gardeners, and other land managers. A poorly revegetated roadside can contribute to the spread of weeds and detract from environmental health. On the other hand, a good native revegetation plan can benefit surrounding environments. The best management will focus not on fighting weeds, but on establishing healthy, weed-resistant communities of desirable vegetation.

For the revegetation specialist, the term "weeds" denotes any species (usually non-native) that is limiting to successful revegetation with native plants due to increased competition. Weeds may be listed on federal, state, or local lists as noxious weeds or invasive species. The exact list of weed species will generally be determined on a project-by-project basis.

Categories of weeds include:

- Invasive,
- Noxious,
- Competing,
- Introduced, and
- Exotic.

The potential for weed species to become established after construction is a function of two site parameters:

1) **The growing environment.** Are areas within the construction project favorable environments for weed establishment? These areas are often highly disturbed sites with bare soils.
2) **Weed sources.** Are there existing weed populations and seed sources on the site prior to construction, or is there a potential that weeds can be brought into the site during construction? Sources of weeds are existing seed banks, infested adjacent lands, or transported from infested areas by vehicles.

Construction projects should consider the development of a weed management strategy that addresses how to control the plant environment and the plant source in the early stages of planning. Ideally, this strategy should be implemented 2-3 years prior to actual construction,

Inset 5.4 – General Advice for Managing Weeds (Sheley 2005)

- The goal should be to develop weed resistant plant communities.
- The first priority should be to protect uninfested areas and areas that have desirable species available to colonize the site once the weed species are treated.
- Establish not only early seral species, but a diversity of mid-and late-seral species filling ecological niches in order to prevent invasion of weeds.
- Any prevention program should be comprehensive and complete.
- There are no silver bullets. Managing weeds is time consuming, complex, and an iterative process. Try things and then adapt.
- Early detection and rapid response is critical to preventing weed infestation. Develop a systematic, thoughtful detection strategy early in the planning phases. Look for new patches or problematic sources before they spread, and treat appropriately.

Figure 5.62 *– Invasive plants such as Himalayan blackberry [*Rubus discolor *(Weihe & Nees)] (left) and Scotch broom [*Cytisus scoparius *(L.) Link] (right) are aggressive colonizers of disturbed sites such as roadsides (Photo by Sally Long, Dorena Genetic Resource Center.)*

continued through the construction phase, and up to 3 years post-construction. Depending on the severity of undesirable vegetation, additional long term treatments may be needed. Treatment of material sources and spoils areas should also be included in planning.

5.8.1 Growing Environment For Weeds

The strategy for keeping weeds out of a project area should focus ultimately on developing a growing environment that encourages healthy native plant communities over weedy species. The presence or introduction of weeds into an area does not necessarily mean that these species will become established or spread. There must first be an opening or space in the native plant community for the plants to grow. These conditions almost always occur in a disturbed area, in openings where native plants and soil have been removed or disrupted. Secondly, the disturbed environment must be favorable for the undesirable species to take hold and thrive. This requires that the soils and climate be optimal for the environmental needs of the species. Third, the weed species must have an advantage over native species. If the weeds are more resilient or robust in their growth habits in both adjacent lands and disturbed sites (that is, cuts and fills) then they are more likely to become established.

5.8.1.1 Growing Environment For Weeds – How to Assess

Each undesirable plant species has unique environmental needs which must be considered when assessing if a site environment is conducive to invasion by that species. The following are site factors to evaluate:

- ***Bare soil surface*** – Most weed seeds need bare soil to germinate and become established. Protocols for monitoring bare soil are presented in Chapter 12.
- ***Soil nitrogen*** – Many weeds out-compete native plants on soils that are high in nitrogen because they are more adapted to utilizing nitrogen during early plant establishment. Unless fertilizers are added to the site, soil nitrogen levels are typically low after construction.
- ***Light*** – Weeds tend to require full or partial sunlight to thrive (Penny and Neal 2003).
- ***Soil quality*** – The potential that a healthy native plant community can be established after disturbance reduces the possibility for weed invasion. Optimum native plant establishment is dependent on the condition of the soil and climate. A compacted site, lacking topsoil and organic matter, is poor for establishing a native plant community which would ultimately keep weeds from invading. Unlike perennial plants, the roots of most annual weed species occur in the surface layer (Jackson and others 1988; Claassen and others 1995) and do not require deeper soils to survive and grow. Annual species therefore will have an advantage over perennials on compacted soils or shallow soils.

Based on the assessment of these factors, risk maps can be developed showing: 1) the location of weed sources in or adjacent to the project, and 2) the optimum habitats for each weed species. The combination of these maps will show the high risk areas and can be used to develop a strategy for weed control.

5.8.1.2 Reducing or Eliminating Weed Growing Environments

Protect Uninfested Ground and Minimize Ground Disturbances – Reducing the footprint of the project results in less area being disturbed and exposed to possible weed invasion.

Develop Optimum Environments for Quick Native Plant Recovery – Developing mitigating measures that create an optimum environment for native plant recovery will limit the establishment and spread of weeds (Sheley 2005). Site factors that restrict downward root growth of native perennial plant roots (e.g., compacted soil) give the advantage to weed species. Treat seed-bed preparation as an investment.

Retain Shade – To reduce the vigor of undesirable plants, retain as much shade as possible.

Apply Mulch – A mulch can be applied to the surface of a disturbed soil to create a poor germination environment for weed seeds (See Section 10.1.3, Mulches). The mulch should have high void spaces (typical of long-fiber mulch materials) and low water-holding capacity. These characteristics are unfavorable for seed germination. The deeper the mulch, the greater the control of weed establishment. Depending on the weed species, 2 to 4 inches of mulch are required to effectively control the establishment of many weed species (Pellett and Heleba 1995; Ozores-Hampton 1998; Ozores-Hampton and others 2002; Penny and Neal 2003).

Oversow Native Seed Mix – Sowing native seeds at high rates will "flood" bare soil with the seeds of desirable species, reducing the "germination sites" where weed species can become established. The objective of this strategy is to fill the voids first with desirable species to crowd out unwanted species (See Section 10.3.1, Seeding).

Establish Desirable Non-Native Plants If Establishment of Natives Is Not Feasible – Due to surrounding site limitations, project parameters, timelines, or other circumstances, using locally adapted native plant materials may not always be possible. For example, if the project is surrounded largely or entirely by contiguous populations of cultivars, using locally adapted plant materials may largely be a waste. If the surrounding area is primarily native species, careful selection of cultivars should be considered. Many cultivar species, both native and introduced, have the potential to cross with their locally adapted native equivalent genera (See Section 6.4.1, Ensure Local Adaptation and Maintain Genetic Diversity).

Avoid Applying Nitrogen Fertilizers in First Year – High rates of nitrogen fertilizers can encourage the growth of weedy annuals at the expense of the establishment and growth patterns of native perennials (McLendon and Redente 1992; Claassen and Marler 1998), whereas perennial grasses have a competitive advantage at lower nitrogen levels (Welker and others 1991). Application rates of up to 108 lb/ac N(121 kg/ha N) have been shown to promote the establishment of introduced grasses over less competitive native grasses (DePuit and Coenenberg 1979). High rates of nitrogen fertilizers can also affect revegetation efforts by decreasing species richness and increasing the presence of non-native species (Munshower 1994; Wedin and Tilman 1996).When nitrogen fertilizer is applied at seeding, root systems of native perennials establish in the upper portion of the soil. The decrease in deep roots gives the annual weed species a competitive growth advantage (Claassen and others 1995). Limiting the amount of nitrogen fertilizer used the first year (during vegetation establishment) will help force the roots of perennials deeper into the soil where there is more moisture. The deeper root

Inset 5.5 – Prevention: Working Groups to Establish Weed-Resistant Plant Communities
(adapted after Sheley 2005)

In order to develop weed-resistant plant communities, representatives of working groups that best fit the site are necessary. Working groups have the following components:

- Annual forb component
- Taprooted forb component
- Bunchgrass component
- Rhizomatous perennial grass component

These species occupy multiple niches and can prevent the invasion of weed species. For more information, see Chapter 6.

system increases the competitive advantage of the native perennials over the annual weeds. This strategy, however, does not preclude the need for fertilization. It might be that fertilizers are not applied until a year after sowing, when the native plants have become established (See Section 10.1.1, Fertilizers).

Apply High C:N Materials to High Nitrogen Sites **–** If soils are high in nitrogen, applying a high C:N material (e.g., wood products or hay) to the surface of the soil, or mixed into the soil, is another strategy to reduce the amount of available nitrogen for annual weed growth (REAP 1991; St John 1999). Over time, the organic material will break down and release nitrogen for uptake by perennials.

5.8.2 Weed Sources

Weed species come from sources already on the site, or are brought into the site from outside sources. They are typically propagated from transported seeds. In rare cases, they can arrive as live plants and plant parts (e.g., blackberry stems). Reproductive materials are brought in on construction equipment, cars and trucks, shoes and socks. The source of these materials are often sand, gravel, and rock used for road construction materials. All too often, weeds arrive during the revegetation efforts in contaminated mulches, topsoil, and uncertified seed sources.

5.8.2.1 Weed Sources – How to Assess

During the early phase of planning, vegetation surveys, noxious weed inventories (conducted during the environmental assessment), and topsoil surveys will locate and identify weeds. From these surveys, a noxious weed map can be developed which can then be used in the development of a weed control strategy for the project site. County weed boards and county and state road management staff may also be a source of information, as they track and treat weeds.

The backbone of a weed control strategy is a thorough understanding of the physiology and ecology of the weed species. The questions to answer for each potential species include:

- How do they propagate?
- How do they spread?
- What is their rate of spread?
- What are their growth habits during the year?
- How long do they survive?
- What is their life cycle?
- Are they annual, biennial, or perennial?
- Is there potential for an ecological progression to more aggressive species (e.g., cheatgrass infestations may give rise to more aggressive species such as knapweed)?
- What are the control methods and how effective are they?
- What are their environmental needs?
- What are their soil type preferences?
- What are their nitrogen needs?
- What sort of environment is needed for seed establishment (e.g., bare soil)?
- What are their climate preferences?
- Do they grow well in direct sunlight or do they prefer shade?

5.8.2.2 Preventing the Introduction of Weed Sources

Control of weeds falls into two categories – prevention and treatment**.** Preventing the introduction of a weed species is always the preferred strategy because it is easier and more economical to prevent the introduction of a weed species than to control or eliminate it once it has become established. If prevention fails, however, and weeds have become established, then treatment strategies should be implemented to contain and eliminate the problem.

Identify and Monitor Weed Populations – Locate weed populations early in the planning phases. Early detection and rapid response is critical to preventing weed infestation. Develop a systematic detection strategy. Identify and treat new patches before they spread (Sheley 2005).

Clean Equipment When Leaving Weed-Infested Sites – When equipment or vehicles have been used in an area where weed species are present, it is important to thoroughly wash the tires, wheel wells, and chassis to eliminate the possibility that weed seeds are spread when the equipment is transported to another site. Portable wash stations may be set up for treating newly arriving equipment.

Clean Hydroseeding Tanks, Range Drills, Other Seed Delivery Systems – Unless equipment is brand new, seed delivery systems have been used at other projects and can contain plant species that are not wanted on the next site. A thorough cleaning and inspection of this equipment is essential in eliminating the potential introduction of weeds. Hydroseeding tanks must be washed out and range drills air-blown before entering the project site.

Know the Quality of Seed Sources – Native grass and forb seed sources can contain weed seeds that were harvested along with the native seeds. The quantity of undesirable species present in propagated seed sources is dependent on the weed control practices and seed cleaning technology implemented by the seed producer. Because of the possibility of contamination of native seeds with weed seeds, seed testing must be conducted for all seeds that are purchased or procured. Purity tests will reveal the contaminants in a seedlot, including weed seeds, other plant seeds, and inert material. Testing is conducted through certified seed labs according to the Association of Seed Technologists Association (AOSTA) standards. Seed labs test for the presence of state-listed noxious weeds and other crop species. It is important to check state and federal lists to determine if any local weed species should be added to the testing list. Do not buy seeds with an undesirable or untested weed component.

Know Quality of Mulches – Buy mulch that is free of weed seeds. Hay and straw mulches are of special concern. Some states certify hay or straw as "weed-free." This means that the material is free of noxious weeds. It does not mean that the material is free of seeds, however. Some straw comes from the stubble left after a seed harvest of native grasses, which often includes unharvested seeds. These seeds are viable and will establish into plants when the straw is

Figure 5.63 – *Hay bales often contain seeds that will germinate on the site. Prior to purchasing hay, find out what species were grown in the field. Some states have certified weed-free programs. However, "weed-free" does not mean the hay will be seedless. Some of these seeds might not be desired in your project area.*

Figure 5.64 – *Know the origin and quality of the topsoil. Topsoil sources contain seeds of the species that grew on them prior to salvage. In this picture, the topsoil pile on the right (B) was salvaged from a nearby pasture and the pile on the left (A) from an undisturbed native forest site. The pasture topsoil pile revegetated quickly (within 3 months after stockpiling) because of the abundance of non-native seeds in the soil. The forest topsoil revegetated slower because there were fewer seeds. Application of the pasture topsoil (B) resulted in a site dominated by introduced pasture plant species.*

applied. If this is the origin of the straw, it is important to obtain the species and seed zone of the seed crop to determine if this material is appropriate for your project. A site visit prior to hay or straw cutting is a good way to assess if there are seeds of weed species in the material (Figure 5.63).

Know Quality of Compost Sources – Compost sources are not always free of weeds, especially if the materials were not composted properly. Compost temperatures must reach lethal temperatures and remain there long enough for plant seeds to be rendered nonviable. Fresh, moist compost piles, where temperatures are maintained between 140 to 160 °F for at least several days, will kill most pathogens and weed seeds (Epstein 1997; Daugovish and others 2006). When obtaining compost, make sure that the supplier complies with standards that meet the time-temperature requirements to ensure destruction of weed seeds. Testing and analysis information is available from the United States Composting Council (See Section 10.1.5, Organic Matter Amendments).

Inspect Gravel, Sand, and Rock Sources – Prior to acquiring road building materials such as sand, gravel, and rock, determine if this material comes from a source that is free of undesirable weeds. A plant survey of the source area will identify whether the material is suitable.

Inspect Haul Routes and Waste Areas – Treat or avoid infested areas.

Know the Quality of the Topsoil – The topsoil survey should identify areas of weeds (See Section 5.11.1, Survey Topsoil). These areas should be mapped out and avoided when the topsoil is salvaged. If the topsoil is purchased, the piles should be inspected prior to approval (Figure 5.64).

Do Not Store Sand, Gravel, Rock or Topsoil Near Weed Populations – Inspect the areas where topsoil, gravel, rock, sand, or other materials to be used on the construction project will be stockpiled. If there are weeds nearby, it is very likely that seeds will end up on these piles, especially if the piles are to remain there for over a year.

Restrict Livestock Grazing from Areas Infested by Weeds – Cattle can bring weed seeds from offsite where they have been grazing. Until native vegetation has become established, it is important to keep livestock out of the area.

5.8.2.3 Treating Weed Sources

If weeds are present on a project site prior to construction, or become established during or after construction, then treatments for control or eradication of these plants from the site must be assessed. The types of treatments fall into 4 categories (adapted from Massu 2005).

Manual – Hand-pulling weeds can be the easiest and quickest method of weed control. There are several methods or strategies for weeding. One strategy, the Bradley Method, prioritizes the areas to be weeded, starting in the areas with the least infestation (best stands of native plants) and proceeding to the worst. Once the weeded area is revegetated in native plants, weeding is continued into the more infested areas.

Mechanical – Mowing and cutting are mechanical treatments that can reduce the spread of seeds if they are done prior to the development of seed heads. Steaming and foaming are other mechanical treatments that can kill seeds and young plants.

Biological – Biological control agents exist for some weeds (Massu 2005). Information on biological controls can be found at http://www.aphis.usda.gov/ppq/weeds.

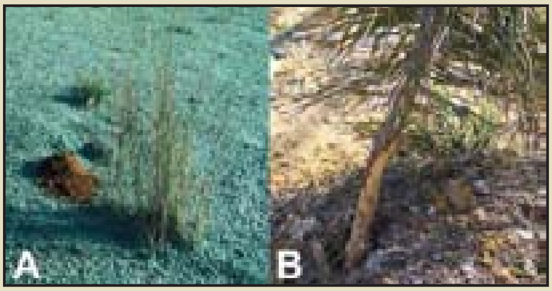
Chemical – Herbicides should only be used with the objective of establishing desired species. There are many effective herbicides on the market but not all are registered for commonly occurring weed species. When selecting an herbicide, it is important to find those products that are effective in controlling the target species yet have a minimal effect on non-target species. Using an appropriate application rate is an important factor for obtaining the optimum effectiveness of the herbicide. In addition, timing the application when desirable species are dormant could effectively protect the species. Treating areas with herbicides, prior to native seeding, requires care and a working understanding of the herbicides being used. To avoid toxic effects on establishing native vegetation after herbicide treatment, it is important to know the effectiveness, longevity, selectiveness, and application rates of the herbicides being considered for the project. Herbicides should only be used to temporarily open a site; the long-term goal is to establish vegetation to take the place of the weeds.

5.9 PESTS

Many plant and animal species pass through or inhabit a newly revegetated site. When these organisms become problematic, they are called "pests." Part of good revegetation planning is to recognize the conditions where species might become pests on the project. This chapter focuses on mammals, insects, and diseases, that are the most common types of pests found on revegetation projects.

Many problems can be prevented through good design and management. For example, matching the appropriate plant species and stocktypes to the site reduces the potential of damage by insects and diseases. Where deer populations are high, planting unpalatable species reduces the risk that deer will over-browse newly planted vegetation or be encouraged to browse near the highway, creating a hazard to motorists. In many cases, the best investment is to preclude problems by protecting plants instead of attempting to control or destroy pests after they move in. However, not every sign of an animal or disease is cause for concern. Some loss due to herbivory or disease should be expected. Planning for some replanting after the first season is a good strategy to help establish native plants while allowing for some herbivory. During early establishment, when plants are most susceptible to life-threatening damage, treatment might be necessary. When this is the case, consider the system as a whole and select the least impactful, long-term treatment. For example, protection of plants with a physical

Figure 5.65 – *Burrowing mounds (A) are a good indication of the presence of northern pocket gophers. One gopher can make up to 3 mounds per day. Besides covering surface vegetation with up to 18% of the surface area in mounds (Laycock and Richardson 1975), gophers also eat grass and forb roots, weakening or killing plants. Tree seedlings are killed when the stem and roots are eaten, as shown in (B).*



barrier or a repellent spray might be better in the long-term than introducing a poison into the food chain that might also affect the animals that prey on the pests.

The following is a general discussion of mammals, insects, and diseases that can cause the most problems to reestablishing native vegetation. This is by no means a complete listing of issues or of mitigating measures. The reader is directed to other sources, such as Cleary and others (1988) and Helgerson and others (1992), for more a more thorough discussion of this topic.

Foraging mammals, such as deer, elk, gophers, and voles, may remove or destroy portions of the plant foliage or root systems. Feeding insects will weaken and, in some cases, kill establishing plants by feeding on roots, stems, and foliage. Diseases can be transported to the site on nursery stock and manifested under stressful transplanting conditions. Problems are usually encountered where the species were not appropriate for the site (e.g., dry species planted in a wetland), where there was not enough diversity in the species being planted, or on sites where soils were limiting (e.g., poorly drained soils). Unfortunately, the effects of pests on revegetation are not always easy to assess prior to implementation. Often the pest is not discovered until after revegetation has taken place.

5.9.1 Mammals

Mammals forage on the foliage, bark, and roots of young seedlings. In moderation, mammals will do minimal amount of damage to a revegetation project. Where herbivory is high, however, these animals can cause major damage to a newly planted site. The mammals of greatest concern to revegetation are the northern pocket gopher, deer, elk, and livestock.

5.9.1.1 Northern Pocket Gophers

Pocket gophers forage on all parts of the plants depending on the season of the year. Seedling stems are often completely debarked, thereby killing the tree (Figure 5.65). Gopher damaged seedlings lean to one side and are easily pulled from the soil (Helgerson and others 1992). Equally disruptive to plant establishment is the amount of soil that is brought to the surface during burrowing. Fresh gopher mounds can account for up to 18% of the soil surface (Laycock and Richardson 1975) and often bury newly establishing grasses, forbs, and seedlings. Gophers prefer soils that are low in rock fragments (<25%) and favor grasses and forbs over shrubs and trees. Succulent, perennial forbs, such as lupine (*Lupinus* spp.), buckwheat (*Eriogonum* spp.), and yarrow (*Achillea* spp.), are preferred over grasses (Bonar 1995). When present on a site, this small mammal can be an immense problem to establishing most plant species, especially those being planted from seedlings.

The potential of a revegetation project to become populated by gophers is a function of: 1) the presence of gophers in the adjoining lands, and 2) the favorability of the project site as gopher habitat. It should be assumed that if the project site borders areas populated by gophers, they will naturally move into the openings created by the road construction project. If the construction project is a poor habitat for gophers (e.g., rocky, steep, high slash), gophers will likely be less of a problem.

Prevention and Treatment – Leaving snags near gopher infested sites can help reduce populations by providing perches for raptors to prey on gophers. Physical barriers such as plastic netting have mixed results in reducing gopher damage. Another strategy is to create an unfavorable environment for gophers, including soils high in rock fragments, steep slopes, and sites with heavy slash (Bonar 1995). Planting seedlings at higher density or replanting seedlings that have been killed by gophers is another strategy. Since grasses and forbs are a preferred food source for gophers, planting shrubs and trees and covering the site with a deep mulch may discourage high populations.

Control of pocket gophers can be accomplished at various levels of effectiveness by trapping or baiting, encouraging predators, and protecting with netting or barriers. Trapping and toxic baiting appear to be the most widely used method of gopher control (Bonar 1995).

5.9.1.2 Deer And Elk

The new vegetative growth from tree and shrub seedlings is a preferred food source for deer and elk. Damage is observed as clean, sharp cuts to the branch or leader stems. Deer and elk typically leave scat and tracks on the sites where they browse. The scat is observed as scatterings

Figure 5.66 – The annual browsing of this Douglas-fir seedling by deer has created a seedling that is bushy and stunted with many buds. Frost damaged seedlings have a similar appearance.

or piles of large oval pellets. Trees that are annually browsed by deer or elk will remain stunted or low-growing for many years (Figure 5.66).

Prevention and Treatment – During the planning stages, consultation with the local wildlife and reforestation experts will help assess the potential for herbivory by deer and elk herds. Visits to areas adjacent to the project site can also give an indication as to the amount of damage that can be expected.

Planting non-palatable species in areas where high deer or elk populations are expected is a good preventive measure. Protecting seedlings from deer and elk browsing can be accomplished through fencing, application of animal repellents, installing plastic netting around the seedling, and planting large seedlings. Animal repellents are applied on or around the seedling with the objective of rendering the seedling unpalatable for browsing.

Fencing large planting areas to keep out elk and deer is used in places where herds are large. However, placing physical barriers, such as netting or tree shelters, around individual seedlings is the most common method of protecting seedlings. Rigid and non-rigid netting are commercially available products and are made from photo-degradable plastics that should break down after several years in the field (Figure 5.67). They are placed around the seedling after it is planted. Tree shelters will also protect seedlings during the early stages of establishment. Section 10.4 discusses these treatments in more depth.

5.9.1.3 Livestock

Damage to revegetation projects can be high in areas that are intensively grazed by cows or sheep. At high livestock populations, planted seedlings can be injured by rubbing and

Figure 5.67 – Rigid plastic netting is placed around seedlings after planting to protect the young seedling from animal browsing. The plastic is photo-degradable and breaks down in several years after the seedling is established.

trampling. Seedlings are typically not browsed. Newly establishing native grass and forb cover can be harmed by the high-pressure hoof marks tearing up the new roots and surface soil, leaving the site exposed to non-native annual species.

Prevention and Treatment – Restricting the entry of livestock for several years after planting or sowing, or until native grasses and forbs have established, is the best prevention measure. This is typically accomplished by fencing the entire area being revegetated. Fencing is most effective when it is installed prior to establishing native vegetation. For this reason, having the fence installed as part of the road contract will assure that livestock is controlled prior to revegetation work. Working with the local USDA Forest Service or USDI Bureau of Land Management range conservationist will be necessary to assure that damage by livestock is kept to a minimum.

5.9.2 Insects

There are a variety of insects that can damage newly planted seedlings. These will be discussed briefly in this section. Since this is a specialized field, the reader is advised to consult technical or academic expertise if insect problems are found to be extensive on a revegetation project. Insect damage is grouped into four classes (Helgerson and others 1992), based on where insect feeding occurs:

- Sap-suckers – foliage,
- Root beetles – root system,
- Terminal feeders – terminal shoots, and
- Secondary bark beetles – stems.

It is very difficult during the planning stages to determine if insects will be a limiting factor. However, the local agency reforestation personnel should be consulted to determine which insects pose potential damage.

5.9.2.1 Insects – How to Assess

Damage to seedlings by insects is often overlooked because the injury usually occurs long before the seedling shows visible signs of stress. By this time, the insect has often left the scene, leaving only the telltale sign of activity. When dead or dying seedlings are discovered, it is important to systematically evaluate the seedling from the root system to the terminal bud for the presence of insects, insect damage, and disease (which will be discussed in the following section). If insects are found, individuals should be collected for later identification. It is important to look under the leaves for aphids and scrape the entire seedling with a sharp knife to observe boring and tunneling. Much of the damage caused by insects and disease occurs under the bark of the stems and roots themselves. A hand lens is helpful to detect microscopic damage. The following discusses some of the most prominent insects that damage conifer seedlings. Non-conifer species will have their own unique associated pests. Nevertheless, determining to which of the 4 classes the insect belongs is a start in making an appropriate assessment.

Sap-Suckers – Sap-suckers include the Cooley spruce gall adelgid (*Adelges cooleyi*) and the giant conifer aphids (*Cinara* spp.) which feed on succulent foliage of tree seedlings. While these can cause shoot deformity and foliage loss, aphids will normally not kill seedlings. The appearance of aphid ants (which cultivate aphid populations) on the leaves are indications that aphids are present.

Root Beetles – The root bark beetles (*Hylastes nigrinus*) and root-collar weevil (*Steremnius carinatus*) girdle the roots and stems of conifer seedlings and will weaken or kill newly planted seedlings. The damage can be mistaken for herbivory by small mammals, but the lack of teeth marks and the below-ground location of the damage are indications that the damage is caused by root beetles.

Terminal Feeders – The larvae of this group of insects feed on the terminal shoots of young conifers, killing much of the new growth. Continued annual attack by these insects can severely stunt conifer seedlings. The major insects include white pine weevil (*Pissodes strobi* [Peck]), ponderosa pine tip moth (*Rhyacionia zozana*), western pine shoot borer (*Eucosma sonomana*), and the cone worm (*Dioryctria* spp.).

Secondary Bark Beetles – The Douglas-fir engraver beetle (*Scolytus unispinosus*) attacks the stems of stressed seedlings, creating galleries under the bark that weaken or kill Douglas-fir seedlings.

5.9.2.2 Mitigating For Insects

Plant a Variety of Species – Insects are often host-specific, meaning they attack only one species. For this reason a preventative measure is to plant a variety of species. If an insect infestation occurs, it would not affect all the seedlings planted.

Plant Healthy Stock – Insects often attack weakened seedlings or seedlings under stress. Planting only healthy seedlings, appropriate to the site, reduces the potential damage by insects.

Create a Healthy Soil Environment – Seedlings grown on poor sites, or on sites outside of the species environmental ranges, will be placed under stress and become candidates for insect damage. Planting seedlings on optimal growing sites will produce healthy seedlings resistant to insect damage. Judicious use of fertilizers (that is, avoid overfertilization) is also important for pest prevention. For example, sucking insects often attack plants that have been over-fertilized with nitrogen.

Install Bud Caps – Some terminal feeders can be controlled through the use of bud caps which are placed over the terminal in the spring prior to shoot growth (Goheen 2005). Bud caps are materials made out of paper or fine cloth that temporarily cover the terminal and prevent adult insects from laying eggs on the bud.

5.9.3 Diseases

Diseases affect all species used in revegetation, but assessing and mitigating for individual species is normally not done on revegetation projects. If disease occurs, it is often the result of trying to establish plant species in the wrong environment. For instance, species adapted to dry environments will be susceptible to root diseases if planted in wet soils where root pathogens are present. Species that have evolved to wet soil conditions are less likely to be affected. While diseases might be present on a site, this does not necessarily mean that plants will be affected. Much like humans, plants are always surrounded by a variety of pathogens, but it is not until they are put under stress that they become more susceptible to infection. The resistance of a plant to disease is therefore dependent on its health.

Planting appropriate species, using genetically appropriate stock, purchasing high quality plant materials, improving the soil, and mitigating for climate extremes all play an essential role in creating healthy plants capable of resisting diseases. If diseases are found on seedlings after planting, often they came from the nursery. While diseases will weaken the seedlings from the nursery, it is unlikely that the diseases will spread through the soils or site and infect other plants. Since the revegetation environment is dissimilar to the nursery or agricultural environment, diseases from the nursery tend not to persist on the plant materials once they are installed. Plants that have a minor infection might recover when grown in the wild. Diseases that run rampant in grass seed beds at seed production facilities are less likely to infect grasses when they are seeded on revegetation projects because the growing environment in the wild is very different.

5.10 HUMAN INTERFACE

An often overlooked factor of revegetating roadsides is the unplanned effects humans can have on site recovery. The human interface is the disturbance resulting from human activities that limit plant establishment and growth. These potential disturbances must be considered very early in the planning stages to assure that they are integrated into the revegetation plan. Disturbances fall into two categories – road maintenance and recreation use. Roads must be maintained, but sometimes road maintenance activities negatively affect the establishment and growth of vegetation. Road corridors can also be sites of unplanned recreational use by off-road vehicles, which can leave a site compacted and devoid of vegetation.

5.10.1 Road Maintenance

Roads are periodically maintained for many reasons which include: 1) clearance for sight and safety, 2) weed control, 3) fire hazard reduction, 4) winter safety, 5) erosion control, and 6) utilities maintenance. Each of these activities affect plant growth in either a positive or negative way.

5.10.1.1 Road Maintenance – How to Assess Impacts on Revegetation

Road maintenance objectives should be understood at the beginning of the project. A meeting should be held with the agency that will be overseeing the maintenance of the road after construction to discuss how to integrate revegetation and road maintenance objectives. Questions or issues to resolve include:

- Will the ditches be cleaned out or bladed? If so, how far up the cut slope will this activity cause instability?
- Will herbicides be used (Figure 5.68)? If so, how far from the road shoulder? How often?
- How far away will trees be cut for "line of sight" and will this distance change on curves?
- What utilities are in the road corridor and will vegetation affect them?
- Are the roads treated with gravel during the winter for traction? If so, how much gravel is annually applied? How far is it swept into the road shoulder or road corridor? Are the gravels recovered by scraping the shoulders?
- Is fire an issue and will fire protection treatments include thinning of vegetation?
- What about salts or other non-herbicide contaminants?

This is a partial list, and every project will have its own set of questions. The more these issues can be addressed early in the planning stage, the more effective will be the revegetation plan.

5.10.1.2 Mitigating For Road Maintenance Impacts

Blading for Erosion Control – Ditchlines at the base of steep cut slopes are depositional areas for rock and soil that have moved down from the slopes above. The rock and soil may fill the ditches, disrupting the flow of water in the ditch and creating potential road drainage problems during storms. Blading is the removal of the material that has filled in the ditchline and is a normal maintenance procedure for erosive cut slopes. This operation not only removes plants that were established in the ditchline, but also destabilizes the surface slopes immediately above the ditch. This can affect the revegetation of the entire slope. Mitigating measures include engineering design that reduces slope gradients (See Section 5.6.6.2, Mitigating for Steep Slope Gradients) or changing the road drainage system so that cleaning of ditches is not necessary. If neither measure is possible, assess whether it is worth implementing revegetation treatments, since revegetating unstable slopes is usually not successful.

Herbicide for Vegetation Control – Contact the government agency responsible for controlling weeds or vegetation in the road corridor and discuss their strategy for weed control. In areas where vegetation must be maintained, signs can be issued to notify operators not to apply herbicides (Figure 5.69). Do not apply revegetation treatments to areas where herbicides will be used to control roadside vegetation.

Graveling for Winter Safety – In areas where gravels are applied to road surfaces for traction during snow or icy conditions, there will be a buildup of gravels on the sides of the road through

Figure 5.68 – *Road maintenance treatments for control of vegetation include the use of herbicides on roadsides. There is no need to seed these areas if they will be treated chemically. A meeting with road maintenance personnel to understand how roadside vegetation will be managed can save revegetation costs and efforts.*

Figure 5.69 – *Placing no-spray signs is a method of identifying areas to protect from herbicide application.*

sweeping of the road surface or snow-blowing. Vegetation that has been established in these areas is often completely covered with gravel when the snow melts. It is important to learn if the road maintenance agency will recover this gravel for reuse, or let it accumulate. If gravel is recovered, this area will be in constant state of disturbance. Determine the salvage distance and do not apply seeds in this zone. In areas where gravels are not salvaged, select the species that will survive and grow in this unique growing environment. One strategy is to select species that respond favorably to being covered by gravels. These include species such as manzanita and willows that root from their stems when covered by soil or gravel. Tap-rooted species, such as lupines, can take advantage of such conditions because they can access moisture deep in the gravel deposits (Figure 5.70). Examine shoulders of existing roads to identify species that have adapted to these conditions and use these species for revegetating these areas.

Clearance for "Line of Sight" and Safety – Trees and shrubs are often thinned or removed in areas where line-of-sight is impeded. Good communication with the government agency responsible for maintaining the road during the planning phase will help identify those areas not suitable for shrub and tree species. Select grasses and forbs or low growing shrubs (<2 to 3 ft tall) for these areas.

Protection of Utilities – Do not plant trees under or near utility structures, such as power lines. Discuss the planting plans with the maintenance agency to find out if there are other utilities that need protection.

5.10.2 Recreational Use

The road corridor is often used for recreational purposes that can disturb established vegetation. This recreation is not usually sanctioned or intended, but it exists in certain areas nonetheless. Recreational disturbances include off-road vehicle travel, mountain bike use, trails to recreational sites, and Christmas tree cutting.

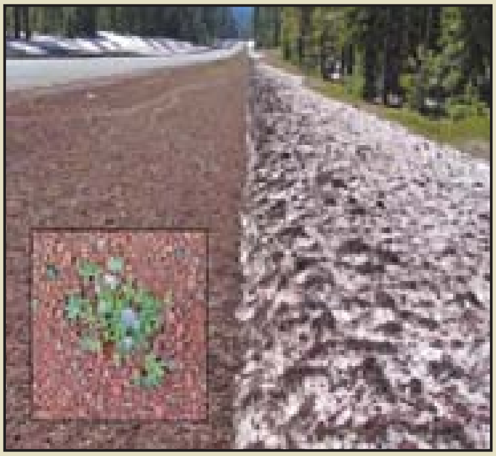


Figure 5.70 – *Gravel applied to road surfaces in the winter for traction is swept or blown to the side, burying vegetation. Some species, such as* Lupinus *spp. (inset in lower left of photograph), have adapted to these conditions and do well. Species such as pinemat manzanita* (Arctostaphylos nevadensis) *also do well when covered by gravels because the plant will produce roots from buried stems.*

5.10.2.1 Recreational Use – How to Assess Impacts on Revegetation

The environmental assessment should identify the public's demand for these activities and how they will affect short and long term vegetation goals. Obliterated roads, for instance, are often desirable places for off-road vehicles because they are open and flat. Roads bordering recreation destinations, such as favorite fishing holes, will have demands for access trails or scenic views that the public does not want blocked by tall vegetation. Public scoping should identify these needs.

5.10.2.2 Mitigating For Recreation Impacts

There are several approaches to mitigation, most of which are forms of awareness, protection, and exclusion. Intruders can be excluded physically with barriers, such as ditches, fences, and large rocks. Before these measures are put into place, communication should be tried first. For example, a sign explaining native revegetation efforts may help make potential users aware that they should take their activities elsewhere. Local residents are often great sources for ideas on how to approach these problems; off-road vehicle clubs are another. Educating the public on the purpose for the revegetation treatments can go a long way towards protection. Short paragraphs in the local newspapers or on the FHWA website for each project will help. Using local contractors to implement the revegetation work brings ownership to the project and the people can be great sources for support in the community.

5.11 INVENTORY SITE RESOURCES

Most project sites contain resources that can be used to meet revegetation objectives. Identifying site resources early in the planning process is essential so that potential resources are not inadvertently wasted. The more you can work with the resources and assets of the site, the more cost-effective, efficient, and effective the revegetation efforts will be. Physical resources to inventory include topsoil, duff, and litter, parent materials, woody materials, plant materials

Figure 5.71 *– Example of a form for collecting topsoil information.*

Project: Summerville Highway – Topsoil Salvage

Plot Number	C_1	C_2	C_3	C_4	C_5
Location	1+300	1+350	1+400	1+450	1+500
Site Condition	Undisturbed	Undisturbed	Undisturbed	Undisturbed	Undisturbed
% Slope	30	45	35	45	40
Aspect	N	N	NE	S	S
Topsoil Depth	12"	14"	14"	6"	6"
Topsoil Texture	loam	loam	loam	loam	loam
Topsoil % Rock	30	25	20	40	45
Subsoil Texture	Sandy loam	Sandy loam	Sandy loam	Clay loam	Clay loam
Subsoil % Rock	40	35	45	45	35
Total Soil Depth	> 60"	> 60"	> 60"	> 40"	> 40"
% Soil Cover	100	100	100	100	100
Soil Surface Cover	Litter, duff	Litter, duff	Litter, duff	Litter, duff	Litter, duff
Depth of Cover	1"	1"	2"	0.25"	0.25"
Parent Material	Granite	Granite	Granite	Basalt	Basalt
Fracturing	Massive with some fracturing	Massive with some fracturing	Highly fractured	Highly fractured	Highly fractured
Sample Depth	0-14"	0-14"	0-14"	0-14"	0-14"

Figure 5.72 – *Slash material can be chipped on site to reduce fire hazards and increase line of sight. In this photograph, brush and trees on cut slopes are cut, chipped, and blown back on the slopes as mulch.*

(seeds, seedlings, and cuttings), large rocks, and water (seeps, springs, creeks). Intangibles should also be considered, such as community cooperation and the local knowledge base.

5.11.1 Survey Topsoil

One of the most important site resources for revegetation is topsoil. If considered early in the planning process, topsoil can be salvaged and reapplied to disturbed sites after construction. This is one of the best ways of increasing productivity on a disturbed site (See Section 10.1.4, Topsoil).

Topsoil is inventoried early in the planning process to evaluate topsoil quality and depth; costs, removal, and storage feasibility; and any other associated costs. Topsoil recovery is an expensive operation requiring knowledge of soil attributes. For this reason, a thorough soil survey must be conducted on those locations that will be disturbed. An example of soil and site information commonly collected for topsoil recovery is shown in Figure 5.71. The road in this example is planned through undisturbed forested lands. Soils data is collected every 50 meters (at road stations) due to the variability of the soils in this area. Where soils are very uniform, distances between plots can be increased. Soil texture, rock fragments, and depth of the topsoil are measured in the field. At selected intervals, or on different soil types, a sample is collected for lab analysis.

During topsoil survey, other site attributes that could affect the quality of topsoil should be noted. The most obvious are the locations of all noxious weeds. These sites should be avoided during topsoil salvage operations since the reapplication of these soils would spread these species across the project area.

The outcome of the topsoil survey is a short report and map in the revegetation plan showing the areas to salvage topsoil and the depth of salvage. If there are great differences between topsoil depths to salvage, this should be shown on the map. The report should discuss the fertility of the topsoil, how it should be stored, and whether the duff and litter is removed and stored separately. Areas should also be identified where topsoil should not be collected. The most typical areas are those which support undesirable non-native vegetation.

5.11.2 Survey Duff And Litter

Duff and litter are the dead plant material that has accumulated on the surface of the soil. The level of decomposition differentiates litter from duff. Litter is the layer of recently fallen, undecomposed leaves, needles, and branches; duff (which occurs immediately below the litter layer) is litter that is decomposed beyond recognition. The duff layer is dark, light-weight organic layer that occurs under forest environment. It is a large reserve of nutrients and carbon, and has a high water-hold capacity. Litter and duff layers protect the soil from erosion by absorbing the energy of rainfall impact and reducing overland flow. The litter and duff layers combined can be very thick, ranging from 1 to 4 inches depending on the productivity and climate of the site.

Litter layers typically have viable seeds that have fallen from the overstory vegetation. Under the right conditions, these seeds will germinate. If collected, stored and reapplied correctly, this natural seed bank can be used as a seed source. See Section 10.1.3.11, Litter and Duff for discussion of methods for collection and application.

Litter and duff layers can be assessed at the same time that topsoil surveys are conducted. The measurement is simple; using a ruler at collection intervals, record the thickness of the litter and duff layers.

5.11.3 Subsoil And Parent Material

Certain subsoils and parent materials can be salvaged during road construction and used to produce manufactured topsoil (See Section 10.1.4.5, Manufactured Topsoil). Textures low in rock content, including sandy loams, silt loams, loam, and sandy clay loams, are often good materials for manufactured soils. These are often found in areas where the parent materials are derived from alluvial or windblown deposits. They include river sands, pumice, volcanic sands, and loess.

5.11.4 Woody Material

Woody material consists of live and dead plant materials that will be wasted in the construction of the road project. This material includes tree boles, root wads, bark, and branches. During clearing and grubbing, these materials are often concentrated in piles and burned. All of these materials can be chipped or mulched and used as surface mulches (See Section 10.1.3.7, Wood Fiber) or soil amendments (See Section 10.1.5, Organic Matter Amendments). Large wood can be used for biotechnical engineering structures, obstacles for erosion control or as down-woody material for site productivity. Using these materials for revegetation purposes will lower overall project costs.

5.11.5 Plant Materials

As discussed under Section 10.2, plant materials consist of seeds (See Section 10.2.1, Collecting Wild Seeds), plants (See Section 10.2.3, Collecting Wild Plants), and cuttings (See Section 10.2.2, Collecting Wild Cuttings). If collected and stored correctly, these materials can be used to revegetate disturbed sites. Surveys of the project site prior to construction will indicate location and abundance of plant materials.

5.12 PHASE TWO SUMMARY AND NEXT STEPS

Planning Phase Two identifies site factors that limit revegetation, defines mitigating measures, and inventories site resources. The next phase is Phase Three, where vegetation will be assessed and analyzed in order to match plant materials and revegetation methods to the site attributes. In Phase Four, a comprehensive strategy is developed that integrates the components from each phase into the Revegetation Plan.

6 PLANNING PHASE THREE: VEGETATION ANALYSIS

6.1 INTRODUCTION

We are now in Phase Three of the process of planning. Phase One began with defining the overall objectives of the revegetation project, the management areas (revegetation units), and the natural models (reference sites). Phase One included conducting preliminary assessments of vegetation, climate, and soils, as well as defining appropriate Desired Future Conditions (DFCs) for each revegetation unit. In Phase Two, site factors that might limit or aid the establishment of vegetation were identified and analyzed, including which limiting factors in the roadside environment could be mitigated. Now that the environment has been defined, the task is to fully analyze the vegetation of the site.

In Phase Three, you will gather information about native vegetation on the reference sites and revegetation units. With this information, you will be able to refine the DFCs and consider the most appropriate revegetation methods to meet your objectives. By the end of Phase Three, you should have:

- Completed the vegetation assessment of all reference sites, creating a comprehensive species list and defining plant communities and successional processes;
- Determined which species and groups of species will be used on the project; and
- Identified target plant requirements and created a menu of potential stocktypes and plant establishment methods for revegetating the site.

In Phase Four, elements from these previous phases will be pulled together into a comprehensive revegetation strategy.

6.2 VEGETATION ASSESSMENTS

The objective of assessing vegetation is to: 1) create a comprehensive species list, 2) define plant communities, and 3) identify successional processes. To do this, information about species and communities that was gathered in Phase One is revisited and supplemented as necessary with additional fieldwork. This information will be used to select species, stocktypes, and planting strategies for revegetation.

To develop a comprehensive species list and define plant communities and processes, you will need to revisit your maps and literature, and review the field data that you collected from reference sites in Phase One. These include:

- Vegetation and soils maps including noxious weed maps;
- Plant association guides;
- Maps and literature about threatened, endangered, or sensitive species;
- Information about roadside management practices;
- Species lists and vegetation descriptions from literature and/or local contacts; and
- Species lists and vegetation descriptions from reference sites and project area.

6.2.1 Organize the Comprehensive Species List

Compile a comprehensive species list and organize your list into life forms:

- Trees,
- Shrubs,
- Annual grasses,
- Perennial grasses,
- Annual forbs,
- Perennial forbs, and
- Sedges and rushes.

6.2.2 Define Plant Communities and Ecological Settings

Species should also be identified according to plant communities and ecological settings, as described in Phase One. For example, communities should be grouped as they appear in different ecological settings:

- Hot/dry,
- Warm/dry,
- Cool/moist, and
- Cold/dry.

6.2.3 Identify Successional Processes

Species should be identified according to their successional group:

- Early seral,
- Mid seral,
- Late seral, and
- Climax.

The next step is to analyze the above information so that you can select species, nursery stocktypes, and outplanting methods to match the needs of your project.

6.3 DEVELOP SPECIES LISTS FOR THE PROJECT

From the vegetation assessment, each species on the comprehensive species list is considered for potential use on the project. This is accomplished by screening potential species through the following criteria:

1) Workhorse species,
2) Working groups (groups of workhorse species),
3) Specialist species, and
4) Research and trial species.

6.3.1 Determine the Workhorse Species

"Workhorse species" is a term used to describe locally-adapted native plants that have the following characteristics:

- Broad ecological amplitude (that is, occurring in many different environments),
- Abundance, and
- Ease of propagation and ability to survive well on roadsides.

If native species fulfill all three requirements, they will be the main species used in revegetation. Tables 6.1 and 6.2 illustrate how the process of selection works.

6.3.1.1 Amplitude

Workhorse species have broad ecological amplitude, occurring in many different environments. The main criterion for workhorse species is amplitude (Table 6.1), or the recurrence of the species across a wide array of ecological settings. For example, if surveys revealed the same species on both hotter, drier environments and north-facing slopes on the project, that species has a high ecological amplitude.

6.3.1.2 Abundance

Abundance indicates the quantity, dominance or cover of species on each revegetation unit (0=never, 1=rare, 2=common, 3=abundant) (Table 6.1). It is summarized for the road project by adding together the abundance ratings given for the species in each revegetation unit.

Table 6.1 *– Analyzing amplitude and abundance. From species data collected at all reference sites, develop a comprehensive species list for analysis.*

Abundance indicates the quantity, dominance, or cover of species on each revegetation unit (0=never; 1=rare; 2=common; 3=abundant). It is summarized for the road project by adding together the abundance ratings given each revegetation unit. In the case of Achillea millefolium*, the abundance is 13 (out of a total of 15), indicating that it is a dominant species in all revegetation units.* Allium fibrillum *has a relatively low abundance of 2, which indicates that it is not abundant on this project.*

Amplitude indicates the relative presence of a species on a project. It is the sum of the presence of each species in each revegetation units. For instance, Achillea millefolium *was found on reference sites of all 5 revegetation units, so the amplitude is 5 indicating that this species is widely distributed.* Allium acuminatum *on the other hand, was found only on one reference site of a revegetation unit, and therefore has an amplitude of 1.*

	1	2	3	4	5		
Scientific Name	**Warm. Dry**	**Cool, Moist**	**Cold, Dry**	**Riparian**	**Meadow**	**Amplitude**	**Abundance**
Achillea millefolium (common yarrow)	2	3	2	3	3	5	13
Abies grandis (grand fir)	3	3	1	2	1	5	10
Abies lasiocarpa (subalpine fir)	0	1	3	2	1	4	7
Acroptilon repens (Russian knapweed)	2	0	0	0	1	2	3
Agastache urticifolia (horsemint)	3	1	3	2	3	5	12
Agoseris aurantiaca (orange agoseris)	3	2	3	0	1	5	9
Agoseris glauca (pale agoseris)	2	1	1	0	1	4	5
Agoseris grandiflora (bigflower agoseris)	2	1	2	1	1	5	7
Allium acuminatum (tapertip onion)	0	0	0	3	0	1	3
Allium fimbriatum (fringed onion)	2	0	0	0	0	1	2
Allium macrum (rock onion)	0	0	0	3	0	1	3
Allium madidum (swamp onion)	0	0	0	2	0	2	5

6.3.1.3 Ease of Propagation

Species that have high amplitude and are abundant may also lend themselves to propagation. Ease of propagation usually involves the following characteristics:

- Plant materials (seeds, seedlings, or cuttings) are relatively easy to collect and process;
- Seeds, plants, and cuttings are easy and inexpensive to propagate and culture in a nursery;
- Seeds store well (longevity);
- Seeds do not have special requirements for breaking dormancy.

It is now possible to determine which species are potential workhorse species for your project. The species that score high in amplitude, abundance, and ease of propagation will be the

***Table 6.2** – Selecting species to propagate. The comprehensive species list can be used to determine the species that are most appropriate to use on the project. Workhorse species criteria are based on amplitude, abundance, and ease of propagation. A species such as* Achillea millefolium, *for instance, fits all criteria. Whether this species is propagated depends on whether it is a member of a particular working group and the objective of the project. Since this species fits into the "visuals" working group, and visuals are an important objective of this road project, this species will be selected for propagation.* Agastache urticifolia *is also showy and has a high amplitude and abundance. However, very little is known about the propagation of this species. This species has the potential of being a workhorse species, but will be placed on development status until more information or trials can be established to determine how easy it is to propagate.*

Allium fibrillum *and* Allium macrum *are specialist species that occur together in a unique habitat. Since this road project provides an opportunity to enhance this habitat, these species are placed in a "conservation" working group. These species are considered specialists because they have low abundance, low amplitude, and little is known about how to propagate them. These species will be selected for propagation, however, because of the important role they play in restoring a unique habitat. Since little is known about seed propagation, seeds will be sent to the nursery for propagation into bulbs. The comprehensive species list also identified* Acroptilon repens, *a noxious weed species, in several of the revegetation units.*

Scientific Name	Life Form[1]	Succession[2]	Origin[3]	Weeds[4]	Amplitude	Abundance	Ease of Propagation	Work Horse	Working Group	Specialist	Development
Achillea millefolium (common yarrow)	PF	E	N	–	5	13	Easy	Existing	Visual		
Abies grandis (grand fir)	T	L	N	–	5	10					
Abies lasiocarpa (subalpine fir)	T	L	N	–	4	7					
Acroptilon repens (Russion knapweed)	PF	E to M	I	N/A	2	3					
Agastache urticifolia (horsemint)	PF	E	N	–	5	12	Unknown	Potential	Visual		Trials
Agoseris aurantiaca (orange agoseris)	PF	E	N	–	5	9					
Agoseris glauca (pale agoseris)	PF	E	N	–	4	5					
Agoseris grandiflora (bigflower agoseris)	PF	E	N	–	5	7					
Allium acuminatum (tapertip onion)	PF	E	N	–	1	3			Conser-vation	High Priority	
Allium fimbriatum (fringed onion)	PF	E	N	–	1	2					
Allium macrum (rock onion)	PF	E	N	–	1	3			Conser-vation	High Priority	
Allium madidum (swamp onion)	PF	E	N	–	2	5					

[1] **Life forms:** First letter stands for annual (A) or perennial (P). Second letter stands for trees (T), shrubs (S), grasses (G), forbs (F), sedges and rushes (W).

[2] **Succession:** Early seral (E), mid-seral (M), late seral (L), and climax (C).

[3] **Origin:** Native (N), introduced (I).

[4] **Weeds:** Passive (P), aggressive (A), noxious (N).

Figure 6.1 – Example working group. A comprehensive species lists for recovered reference sites was created during the assessment phase. Four species commonly occurred together in many of the reference sites. Venus penstemon (Penstemon venustus), *scarlet gilia* (Ipomopsis aggregata), *phacelia* (Phacelia heterophylla), *sedum* (Sedum stenopetalum), *and (not pictured) mountain brome* (Bromus carinatus) *emerged as a potential "working group" for this site. This working group of four forbs and one grass was utilized to revegetate the south- and west-facing (hot-dry) slopes on this project. (Weston-Elgin Road Project, Umatilla National Forest, Oregon.)*

workhorse species you will choose to utilize on the project. Table 6.2 gives an example of how workhorse species were identified from a comprehensive species list.

6.3.2 Develop Working Groups

The goal of roadside revegetation is not merely to establish plants, but to create functioning, sustainable plant communities. For revegetation purposes, a "working group" is a mix of workhorse species developed for a specific ecological function or management objective. One of the best ways to identify working groups is to review the comprehensive species list and determine which workhorse species commonly occur together on similar reference sites. For example, if five species that commonly occur together on recently disturbed reference sites have been identified, you have probably identified a working group.

Working groups should also meet both short- and long-term project goals. When designing working groups, remember that it is possible to establish different species at different times. For example, grasses may need to be established early for controlling surface erosion. Outplantings of shrubs or trees could be done later to increase species diversity and encourage long-term slope stability. Workhorse species and working groups are not only mid and late seral, but also climax species.

The groups are further defined by their ability to fulfill certain management criteria. For example, can this group of plants be utilized (perhaps with some modification) to perform functions that fulfill project objectives, such as weed control, conservation goals, soil stabilization, or visual enhancement?

6.3.2.1 Weed Control

One of the most important ecological functions that plants can serve during revegetation is to occupy the site so there is no niche available for invasive species to establish. By occupying ecological niches from spring to fall with a combination of annual and perennial native species, site resources such as moisture, nutrients, and space, are denied to undesirable species. Working groups that are effective in controlling weeds are usually composed of a mix of forbs, grasses, grass-like species, and trees and shrubs that exploit the whole growing season and occupy multiple ecological niches (Sheley 2005).

6.3.2.2 Visual Enhancement

A high-visibility site might call for a species mix to include wildflowers and other showy plants for roadside beautification. These species can be practical "workhorses" that provide valuable functions, but also maximize color and visual enhancement throughout the season (Figure 6.1).

***Figure 6.2** – Example of a specialist species. Aspen do not meet "workhorse" criteria because they are challenging to propagate and require special protection during outplanting. However, for a project in Umatilla National Forest, Oregon, aspen are important for ecological reasons and societal goals; therefore, aspen are included in revegetation as a "specialist" species.*

6.3.2.3 Erosion Control

On sites where erosion control is an important management objective, the working group would be based on plants that are highly effective for erosion control. This includes species which germinate and grow quickly, produce a high ground cover, generate biomass throughout the season, and survive for several years.

6.3.2.4 Conservation Enhancement

As a functioning plant community, the working group increases the ecological health and biodiversity of project sites. In some cases, a working group will specifically focus on a group of species that are important for ecological and/or societal reasons. These can include sensitive species or species that are desired by the public.

6.3.3 Identify Specialist Species

Working groups will not always be made up of workhorse species and there may be a need to propagate "specialist" species. The development of the working groups for a revegetation project will determine which additional specialist species will be needed. Since there may be very little information about the propagation of specialists, the number of species placed in this category should be prioritized and limited. If only a small number of specialist plants are needed, then other revegetation methods besides seed propagation should be considered. These include wild and nursery grown cuttings and plants. Some areas may contain special microclimates or soils that require a unique mix of species, or working group, that are typically not available. Seeps, springs, and serpentine soils are examples of some special environments. The important concept is that, for each project objective, a working group can be developed to meet that objective.

6.4 IDENTIFY TARGET PLANT REQUIREMENTS

Now that you have a list of which species to use for revegetation, the challenge is to determine how to propagate them and what is the best plant material for a particular site or objective.

One of the most useful tools for selecting the plant materials best suited to the project is the Target Plant Concept (Landis and others 2006). The Target Plant Concept is a holistic way of integrating how aspects of plant propagation, project site characteristics, and outplanting methods affect the selection of appropriate plant materials. The concept is based on the premise that there is no such thing as an "ideal" all-purpose seed mix or stocktype that will always work in any situation. Instead, the fitness of the plant material is determined by its appropriateness to the site in which it will be outplanted.

The Target Plant Concept consists of 6 requirements for establishing native plants (Figure 6.3). At this point in the process, two of them have been covered: the objectives for establishing vegetation, and the factors that possibly play the largest role in limiting plant survival and growth on each revegetation unit.

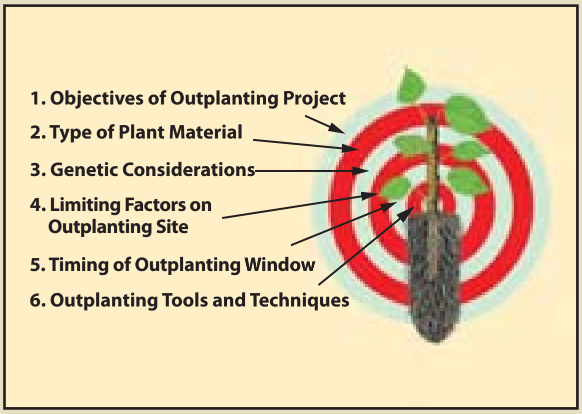


***Figure 6.3** – The Target Plant Concept identifies 6 requirements for establishing native plants (adapted from Landis and Dumroese 2006).*

The remaining questions to ask are:

- What are appropriate genetic sources for each species?
- What type of plant material should be used (seeds, cuttings, or plants)?
- What methods will be used to install plant materials and what post installation plant care is appropriate?
- What is the proper season for outplanting or seeding (the outplanting or seeding window)?

6.4.1 Ensure Local Adaptation and Maintain Genetic Diversity

It is important to know the original collection source of seeds, plants, or cuttings to help ensure better long-term adaptation to local conditions and protect the genetic resources of local plant communities. Seed transfer guidelines (how far plant material can be transferred from point of origin to the project) have been developed for many forest tree species. This was the outcome of years of research that revealed that failures in tree planting establishment were sometimes the result of moving seeds too far from their source of origin. Although work is underway, guidelines for plant material movement are lacking for many native grasses, forbs, and shrubs used in revegetation activities. As a result, many native plants of inappropriate or unknown origin are being sold and planted in revegetation projects, despite the strong concerns. Mechanisms are available to help revegetation specialists choose appropriate materials (Insets 6.1 and 6.2).

6.4.2 Consider Plant Establishment Methods

Once species have been chosen and genetically appropriate sources of plant materials have been identified, the next step is to determine the most appropriate plant materials for the project. Revegetating with native plants commonly involves multiple methods to reestablish vegetation on the project site. Possibilities to consider are:

- Maximizing natural regeneration/recovery,
- Direct seeding, and
- Outplanting nursery stock.

In areas with relatively good soil stability that are bordered by healthy populations of viable native species, the existing seed bank and natural regeneration processes is a key part of re-establishing native vegetation on road sites. Minimizing the road footprint and damage from road construction is an important aspect of any type of planning, but will be especially key if revegetation tactics will involve supporting natural regeneration over more intensive revegetation interventions. In these cases, as long as topsoil is saved, the disturbance from road construction might serve to scarify the native seed bank. Often the option of maximizing natural regeneration is not sufficient to fully revegetate a roadside environment; nevertheless, it should always be considered as a possibility. Salvaging and reapplying duff and litter layers to disturbed surfaces can aid in maximizing natural regeneration. The revegetation plan should

Inset 6.1 – Locally Adapted Plant Materials
(Excerpted and adapted from Withrow-Robinson and Johnson 2006)

For revegetation success, much more is involved than just creating a list of native species. Seed origin and genetic foundation (number of parent plants) must also be considered. Origin of seed collections and genetic foundation are often overlooked in revegetation projects. However, these are key factors to help ensure survival of the plants and protect local genetic resources.

Distinguishing Native and Local

The definition of what is "native" and what is "local" is not always agreed upon. For many people, a native species is one that was in the area before European settlement. However, many of these "natives," including trees and shrubs common in riparian communities, are widely distributed across many states and huge geographical regions. In Oregon, for example, native trees such as Douglas-fir (*Pseudotsuga menziesii*), ponderosa pine (*Pinus ponderosa*), western white pine (*Pinus monticola*), Oregon white oak (*Quercus garryana*), and black cottonwood (*Populus trichocarpa*) all range from Canada to Mexico, and, in some cases, from the Pacific to beyond the Rocky Mountains. Many herbaceous plants, such as yarrow (*Achillea millefolium*), also have very broad distribution. Each is native to, and survives in, a wide range of conditions across a broad landscape beyond Oregon. This is possible because local populations of each species have adapted to local conditions that vary with elevation, latitude, rainfall, temperature, and much more. For widely distributed species, "native" does not necessarily mean "local." Plants from the Cascade Mountains in Oregon would not be expected to be well adapted to the Oregon Coast Range. The same species may occur in both locations, but the climates and soils to which the local populations have adapted are very different between these two areas. This principle has been illustrated through decades of experience with forest tree species in North America and Europe. Local plant material sources have been shown to perform better than non-local sources of native species in many reforestation projects. Such experiences in forestry indicate that strict attention to source of origin for planting materials in revegetation activities is important.

Transfer Guidelines

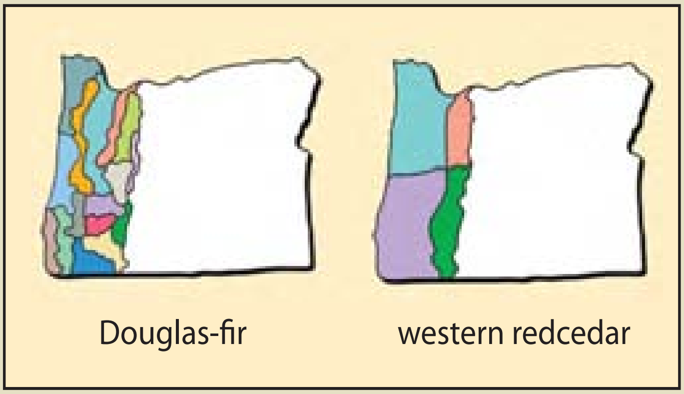
In recognizing the need to use native species of local origin, it is important to determine how far plant materials can be moved and still be considered local. This question can be addressed through the use of transfer guidelines that recommend how far seeds or other plant materials can be transferred from their point of origin.

There is no magic number to indicate how far a plant might be successfully moved (e.g., within a 50 mile radius). One problem is that "local" is best defined in terms of the environment (local climate and soils) rather than in absolute distance. Many factors contribute to the environmental conditions to which a plant species must adapt, including rainfall, maximum and minimum temperatures, aspect, soil drainage and pH. The scope of adaptation also varies greatly between species. Some species (generalists) can be moved much farther than others (specialists) and still be well adapted to local conditions and regions. Thus, transfer guidelines vary from species to species and from region to region. Developing useful transfer guidelines is a slow process, incorporating several research approaches and computer models. Although guidelines have been developed for only a small number of native plants, work is underway on important herbaceous species.

Seed Zones and Elevation Bands

A common type of transfer guideline used to help managers identify appropriate sources of plant materials is the seed zone map developed for most of the western states. The seed zone map divides each state into geographic areas within which plant materials can be transferred with a minimal risk of being poorly adapted. Seed zones help identify where plant materials originated and how far they can be moved. Figure 6.4 shows seed zones for western redcedar and Douglas-fir. These zones represent areas of fairly uniform environmental conditions. In mountainous regions, elevation bands within each zone are used to further define adapted areas.

Figure 6.4 – Example of seed zones for Douglas-fir and western redcedar (St. Clair and Johnson 2003; Withrow-Robinson and Johnson 2006).



Seed zone maps are not perfect, since variation of adaptive traits is often continuous across the landscape rather than showing distinct boundaries as delineated in a seed zone map. Forest tree seeds and seedlings that are available from seed companies and nurseries are usually identified by their seed zone, which makes it easier to purchase appropriate materials for your project. However, for many other species of interest, it can be difficult to find plant materials of known origin.

One variation of the seed zone approach that could be used for other native species is the focal point seed zone. Beginning with a known point, such as a project area, this approach uses the same environmental factors, genetic information, and GIS technology that are used to develop seed zones or to construct customized focal point zones for that project area. The focal point approach is conceptually straightforward and logical, but has some practical limitations relating to source tracking and maintaining availability of growing stock. It is currently used more for herbaceous (non-woody) plants grown directly for seeds than for woody plants. This approach also gives the revegetation specialist the opportunity to "shop" for reliable plant material sources whose origin is within the customized focal point seed zone. Several organizations (e.g., the Native Seed Network) have established systems to track the collection and propagation of native species using the focal point seed zone approach.

Seed zones are further delineated by elevation bands. Depending on the species, elevation bands are delineated in increments of 500 to 1,000 ft. Some species, such as western white pine (*Pinus monticola*) can be moved across all elevations.

Ecoregions

Ecoregions may be substituted for seed zones to guide the transfer of plant materials. Ecoregions are defined areas of similar geographic, vegetative, hydrologic, and climatic characteristics, that are divided into different levels, each level representing increasing degrees of detail. Because ecoregion maps identify areas with similar environmental characteristics, they may be useful to help determine initial seed zones. Several ecoregion maps have been developed. The map developed by the U.S. Environmental Protection Agency (EPA) has four levels, from coarse (Level I) to fine (Level IV). When other transfer guidelines are lacking, EPA Level III ecoregions, in conjunction with elevation bands, may be suitable to serve as temporary seed zones. Genetic research in forest trees has led to further divisions for most species and seed zones that are smaller than Level III ecoregions, so this might be considered a minimum starting point for guiding source selection of other revegetation species.

Since research-based transfer guidelines for most native plants do not exist as yet, the issue is often simply overlooked. This may lead to mistakes in selecting plant materials. Buying whatever plant materials are available from an easy or inexpensive commercial source can lead to the introduction and use of inappropriate plant materials. On the other hand, restricting acquisition to plant materials from the project site, or its immediate area only, can lead to loss of genetic variation and other issues such as delays in obtaining sufficient number of seeds. Neither is a satisfactory solution, and some guidance is needed. Until there is genetic data for each native species used in revegetation, seed transfer guidelines using seed zones, focal point seed zones, and ecoregions are a fairly safe and conservative option for most native species. What is known from a century of forestry experience is that seed source is an important issue that should not be ignored by revegetation specialists.

Genetic Variation

Another important issue in selecting native plant materials is maintaining genetic variation in the populations established in revegetation work. Plant populations must be genetically variable to be able to adapt to new stresses. Collection and propagation procedures need to conserve sufficient genetic diversity to buffer environmental changes in both the short term (years) and long term (decades or centuries). Also, a sufficient number of unrelated seed parents (in outcrossing species) must be included to ensure that inbreeding will not become a problem in the future. Both issues come down to numbers; the more plants that contribute to the new population, the more genetic variation will be captured and the lower the likelihood that relatives will mate (less inbreeding). These criteria should be considered by managers, whether they are buying plant materials or collecting their own.

Failing to consider genetic variation when selecting plant materials can potentially have significant consequences on the viability and sustainability of revegetation efforts. Yet it is easy to imagine how variability can be eroded. If plants are propagated from a very small and inadequate sampling of the population, genetic variation of the propagated plants will be greatly reduced.

Reproductive strategies vary widely between species. No single collection and propagation protocol will ensure the genetic integrity of all types of plants used in revegetation. However, the issue of genetic variation cannot be ignored. The following considerations should be given when collecting native plant materials:

- ***Number of parents.*** There is sufficient genetic research for woody forest species to recommend having a minimum of 20 unrelated seed parents represented in a collection in order to capture most of the genetic variation in a population. A similar number of individual parents should be included in cutting beds of clonally propagated species. Additional plant material would be needed if contribution by parents (of seeds or cuttings) is unequal. For dioecious species, attention to male-female ratios is essential to ensure adequate representation of both sexes. For species such as grasses, it is important to consult a geneticist familiar with those plant groups for guidance as to what an adequate parent population might be.
- ***Source sites (stands).*** To represent the population of a seed zone well, seeds or cuttings should be collected from multiple sites within the zone. A similar numbers of parents should be sampled from each site. Seek out larger communities to help meet parent selection criteria.
- ***Individual parents within a selected source.*** Individual maternal parents (seed trees) should be well separated from each other, yet not isolated from other trees. This will allow cross pollination by numerous paternal parents. A similar amount of seeds should be collected from each parent.

Inset 6.2 – What To Do If There Are No Locally Adapted Native Seed Sources Available

(Adapted from Erickson and others 2003; Aubry and others 2005)

The volume of seeds needed for a revegetation project may not always be available in sufficient quantities, particularly when plans have changed or the revegetation specialist has not been involved until the latter stages of the project. In these instances, there are three choices available to the revegetation specialist: 1) wait several years until the appropriate seeds are available; 2) use non-native cultivars or non-local native cultivars; or 3) use introduced species that are non-persistent, non-invasive, or sterile.

Defer Seeding

If the appropriate species or seed sources are not available, then consider not seeding until the appropriate seeds become available. In the interim, soil cover for erosion control should be considered.

Non-Local Native Species

Native species that do not occur naturally in the local ecosystem, or native plant material that does not originate from genetically local sources, may be considered. These types of plant materials may include commercial cultivars. A cultivar is "a distinct, often intentionally bred subset of a species that will behave uniformly and predictably when grown in an environment to which it is adapted" (Aubry and others 2005). These cultivars are generally not preferable for wildland use due to concerns over adaptability, genetic diversity level, and the potential for genetic contamination, or "swamping," of local native gene pools, including those of threatened, endangered, and sensitive plants (Millar and Libby 1989; Knapp and Rice 1994; Linhart 1995; Montalvo and others 1997; Lesica and Allendorf 1999; Hufford and Mazer 2003). Because commercial cultivars are typically selected for agronomic traits, such as high fecundity, vegetative vigor, and competitive ability, their use may also adversely impact resident natural populations through direct competition and displacement. Moreover, cultivars of native species (and introduced look-alikes such as sheep fescue [*Festuca ovina*]) can be very difficult to distinguish from native germplasm. This could severely complicate efforts to collect and propagate local material and waste valuable economic resources. Because of these concerns, cultivars should be used sparingly, with project objectives clearly understood. Consult with the seed producer or distributor before buying seeds and ask for the most appropriate cultivar for your area, where the source for the cultivar was collected (geographic location and elevation), and how many collections were made. The seeds should be certified with a certification tag attached to each seed bag. Tests for seed germination, purity, noxious weeds, and seeds per pound should be obtained.

Introduced Species

When appropriate seed sources are not available, sterile hybrids or annual/biennial/perennial introduced plant species that are non-persistent and non-invasive may be considered. Preferred non-native species are those that will not aggressively compete with the naturally occurring native plant community, invade plant communities outside the project area, persist in the ecosystem over the long term, or exchange genetic material with local native plant species. Some of these species include sterile hybrids, such as Regreen (a wheat x wheatgrass sterile hybrid) and annuals such as common oat (*Avena sativa*) and common wheat (*Triticum aestivum*). Exotic species that have not already been introduced into the area, or that have been found to be aggressive and/or persistent, should be avoided. Non-native species that were commonly used in the past should be avoided include Kentucky bluegrass (*Poa pratensis*), smooth brome (*Bromus inermis*), crested wheatgrass (*Agropyron cristatum*), orchardgrass (*Dactylis glomerata*), yellow and white sweetclover (*Melilotus officinalis* and *M. albus*), alsike clover (*Trifolium hybridum*), and alfalfa (*Medicago sativa*), to name a few. These species are generally no longer recommended due to their highly aggressive nature, resulting in widespread losses or displacement of native species and plant communities in western wildlands.

acknowledge aspects of the revegetation process that are expected to develop naturally (Clewell and others, 2005).

However, if native seed regeneration is not sufficient to revegetate the site, additional plant materials will need to be obtained and established. Plant materials may include:

- Seeds,
- Cuttings, and
- Plants.

Determining which plant material to select for revegetation depends on the type of species being grown. For example, conifer trees have been shown to establish better and faster from plants than from seed or cuttings. On the other hand, grasses can be established from plants, but growing grass plants and planting them is very expensive compared to using seeds. Some species, however, do not produce reliable crops of seeds and therefore other plant materials, such as cuttings, will have to be used. Tables 6.3 and 6.4 compare the advantages and disadvantages of different establishment methods and stocktypes. Various Implementation Guides (Chapter 10) describe obtaining plant materials in greater depth.

6.4.2.1 Seeds

Seeds are collected in the wild from native stands of grasses, forbs, shrubs, trees, and wetland plants. This plant material is used for seeding projects, such as hydroseeding of cut and fill slopes or other large areas of bare soil. Seeds of grass and forb species are best used for direct sowing, whereas seeds of shrubs and tree species are best used to grow nursery plants. If large amounts of grass or forb seeds are required for a project, seed collections can be increased through seed increase contracts. It can take up to three years to obtain enough seeds for a revegetation project – one year to collect the wild seeds and one to two years for seed increase. One of the advantages of utilizing seeds as the plant material is that seeding can be an inexpensive method of reestablishing plants for a large area. Guides to collecting wild seeds, increasing seeds, and salvaging and topsoil, duff, and litter are available in Chapter 10.

6.4.2.2 Cuttings

Cuttings are taken from stems, roots, or other plant parts and directly planted on the project site or grown into rooted cuttings at a nursery for later outplanting. Only a few species, such as willow (*Salix* spp.) and cottonwood (*Populus* spp.), can be easily established from direct sticking of cuttings on a project. Other species, such as quaking aspen (*Populus tremuloides*), can be established from cuttings in a controlled nursery environment, but not in the field. Propagating plants from cuttings of most species is not possible under most growing conditions. Cuttings are collected in the wild in the winter months and either stored or immediately planted on the project. If large quantities of cuttings are required, cuttings can be propagated by growing them in stooling beds for several years at a nursery or other growing facility. Guides to working with cuttings are presented in Chapter 10.

6.4.2.3 Plants

Trees and shrubs are typically established using nursery stock rather than by direct seeding for several reasons. First, obtaining seeds from most tree and shrub species is expensive; in many years, they can be difficult to find or collect. Second, shrub and tree seeds germinate and grow into seedlings at a slower rate than grass and forb species, giving them a disadvantage on the sites where grasses and forbs are present. Starting shrubs and conifers from large plants instead of seeds gives them a competitive advantage over grasses and forbs because roots are often longer and better developed, allowing access to deeper soil moisture. Grass and forb species are seldom established from nursery-grown plants because of the high cost. Exceptions are when grass or forb seeds are rare or hard to collect or increase; if species are difficult to establish from seeds on disturbed sites; or when the project requires restoring threatened or sensitive species.

Plants are typically grown in a nursery. However, for some projects, plants are salvaged from the construction site or adjacent areas. Sometimes salvaged plants are simply relocated quickly from one area to another. At other times, they may be transplanted into a nursery and replanted at a later time. Plants that are grown in a nursery require a lead time of one to two years from the time of ordering to availability. A variety of stocktypes are available from the nursery,

***Table 6.3** – Comparison of plant material types for revegetation planning (adapted from Dorner 2002).*

Type	Advantages	Disadvantages
Balled-in-burlap The plant is grown in the field, dug up with its roots and surrounding soil, and wrapped in a protective material such as burlap.	• Well-developed root systems increase chances of survival on site • Provide shade and earlier establishment of upper canopy on site	• Expensive • Large and heavy to transport
Bare-root The plant is sold without any soil around its roots.	• Less expensive • Easier to transport to site, lightweight to carry around for planting • Roots have not been restricted by containers	• Require care not to let root systems dry out before planting. • Difficult to establish in dry sites or sites with warm, sunny spring seasons.
Container The plant is sold in a container of potting media or soil with drainage holes. Sizes and shapes of containers range from very small to very large.	• Well-established root systems with intact soil • Provide "instant" plants on site • Available in a variety of sizes, many are available year-round • Can be planted all year long	• Native soil not used in nursery, transplant shock may occur when roots try to move into native soil • Can be expensive • Can be difficult to transport to and around site if large numbers are used • Can be difficult to provide irrigation until established, may actually require more maintenance than plug
Liners/Plugs A small plant, rooted cutting or seedling that is ready for transplanting. They are often used for herbaceous plants and grasses.	• Well-established root systems with intact soil. • Easy to transplant, plant material pops out of containers easily	• Same as above • Smaller plants may take longer to establish, require more initial maintenance
Cuttings A piece of branch, root or leaf that is separated from a host plant and used to create a new plant. These may be placed in a rooting medium or stuck directly into the ground for planting.	• Inexpensive to produce; Cuttings may easily be taken on site or from nearby site • Easy and light to transport Known to work well in rocky areas or areas difficult to access	• No established root systems • Timing of taking cuttings and planting them is important, varies among species limited to dormant periods
Salvage Native plants that are removed from a site (to a nursery, storage area, or directly to another field location) before ground disturbance at that site occurs. (Can also refer to salvaged cuttings or seed sources.)	• Can use plant material that would otherwise be destroyed • Plant material could be local to site • Relatively inexpensive • Small or young salvage plants often adapt more readily to transplant than do mature specimens	• Different native plants respond differently to being dug up, some loss could be expected • Requires fairly intensive measures to protect plants and ensure they have adequate irrigation

including small to very large plants; plants in containers or those without soil around the roots (bareroot); and plants grown in greenhouse environments or field-grown plants (Figure 6.5). Selecting a stocktype will depend on the needs of the project, as there are multiple options for propagation and establishment, and many stocktypes to choose from.

For any stocktype, various desired characteristics should be defined including age, size, change of survival on the site, ability to compete with other vegetation and/or tolerate animal impacts; and methods that will be necessary to outplant and maintain the stocktype. For bareroot stocktypes, size, age, and potential survival rates should be considered. For cuttings, consider if the project requires containerized cuttings (with a root system in a container), heeled cuttings (with roots, but no container) or simply cuttings to stick directly in the ground on the project site. For cuttings, length, caliper, and issues of storage are also important factors. For container plants, no standard terminology exists for describing the different types of container plants available (Landis and others 1992). They are usually described by their container type, referring to the volume and usually the shape of the container. Size and age of the plant is also described. When ordering container plants, consider age, caliper, height, root size and depth, and any other special characteristics that might help the plant survive in the field (Table 6.3).

Salvaging plants from the project area can be an important component of protecting native plant diversity on the project site. Sometimes salvaged plants are simply relocated instantly from one area to another. Other times, they may be transplanted or moved to a nursery area, cared for, and then re-planted at an appropriate time. "Salvage" may also involve harvesting cuttings or seeds from plants that are going to be removed during the road construction process.

Depending on the species, genetics, site limiting factors, and specific project objectives, some idea of the appropriate "target" stocktypes will already be defined. For example, some plants respond well to certain propagation methods, some will be salvaged ("wildings") from the site, and some are obvious candidates for direct seedling applications in order to facilitate fast regeneration. The needs and characteristics of a particular species will help determine if direct seeding, nursery propagation, or other methods are the more appropriate strategy. There are many options to consider. Some of these options are summarized in Table 6.4.

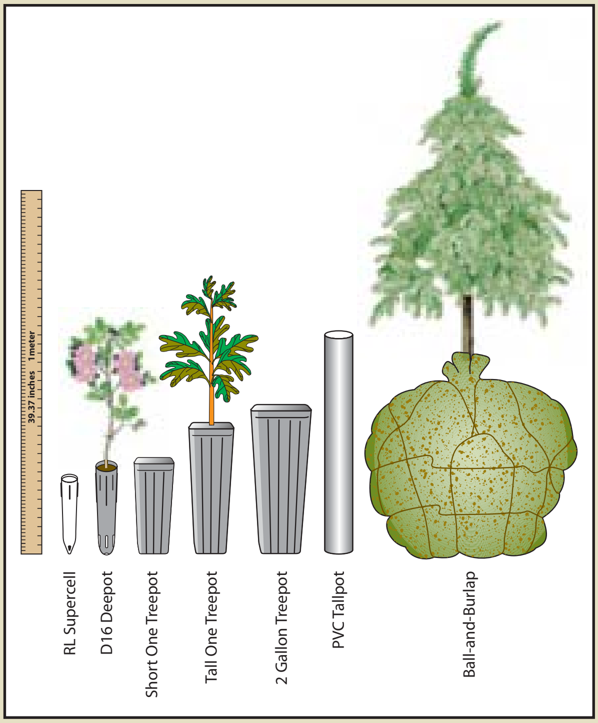
Table 6.4 *– Comparison of different plant establishment methods (adapted from Landis and others 1992).*

	On-Site Methods			
Characteristic	**Wild**	**Cuttings**	**Seeds**	**Nursery Plants**
Efficient use of seeds and cuttings	N/A	NO	NO	YES
Cost of establishment	HIGH	MODERATE	LOW	MODERATE
Ability to establish difficult species	YES	NO	NO	YES
Option of using specific genotypes	NO	NO	YES	YES
Precise scheduling of plant establishment	YES	YES	NO	YES
Control of stand composition and density	YES	YES	NO	YES
Matching stocktypes to site conditions	NO	NO	NO	YES
Depletion of adjacent plant stands	YES	YES	NO	NO

6.4.2.4 Scheduling

Timing is a key factor for obtaining plant materials because many native plants or seeds are not widely available from nurseries and seed companies. Even if a species is available, the odds are that it is not from a local source that is genetically adapted to your project site. Therefore, the earlier you start planning the better. It usually takes a lead time of two to three years to administer seed collection, seed increase, and seedling propagation contracts. Sometimes you may need to allow three years to achieve sufficient quantities of seeds. Plants (seedlings, cuttings, and so on) ordered from nurseries take a great deal of advanced planning for both seed collection and for plant propagation. Failure to realize the lead time necessary for seed collection and propagation of appropriate native plant materials is one of the most common mistakes made in revegetation projects.

Figure 6.5 – *Nursery stock is available in many container sizes and shapes. Consider the advantages and drawbacks of different options before ordering plants.*



6.4.3 Select Plant Material Installation and Maintenance Methods

There are many methods of installing plant materials on the project site. Seeds can be applied through hydroseeding equipment, disked or drilled into the soil surface, broadcast sown, imprinted, and/or covered with a variety of types of mulch. There are also a variety of techniques for installing cuttings and plants, including an expandable stinger (Figure 6.6), waterjet stinger, pot planter, auger, and regular old shovel. These methods are discussed in Chapter 10.

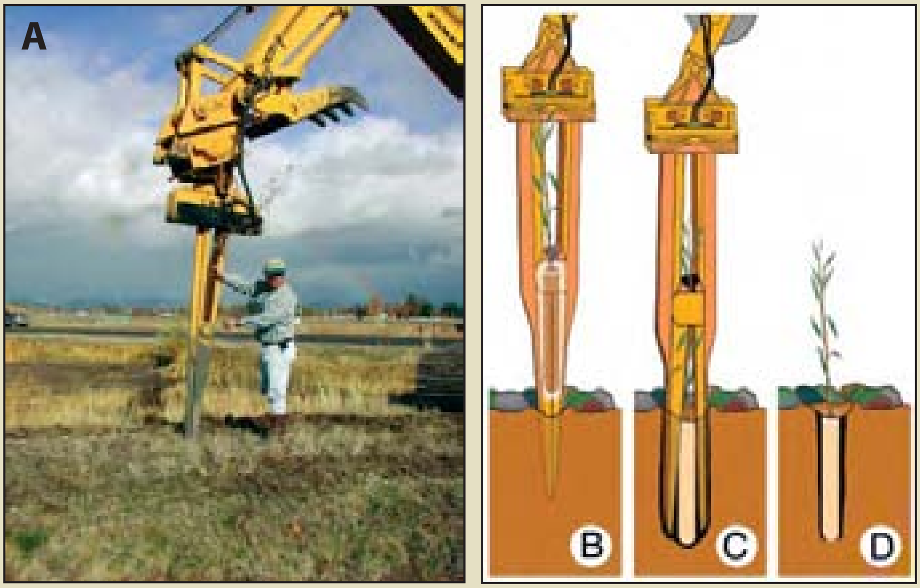
After plant materials have been installed, care is required until they are well-established. This includes protection from browsing animals, high temperatures, winds, competing vegetation, and drought. Measures that can be taken to mitigate for browsing animals include installing netting and tree shelters, as well as applying animal repellents. Seedlings can be protected from high temperatures and wind with shade cards, tree shelters, and large obstacles, such as logs. Competing vegetation is controlled through weeding, mulch, or herbicides. In extremely dry conditions, soil moisture can be supplemented by using irrigation systems.

6.4.4 Determine Outplanting Windows

In addition to ensuring you have enough lead time to successfully carry out native revegetation goals, you also need to determine the seasons for planting. There are advantages and disadvantages to carrying out operations at any time in the year and determining the timeframe should be based on the species, plant material, and site factors.

The optimum time of year to outplant for greatest plant survival is called the outplanting window. It is determined by graphing the annual precipitation, temperatures, and snow accumulation of a site. This information can be obtained from climate stations, as described in Phase One. Outplanting windows are also defined by the species, stocktype, and outplanting

***Figure 6.6** – Match stocktypes to outplanting options and equipment available. The expandable stinger (A) is a special planting machinery that attaches to the arm of an excavator. Long-tube stocktypes are placed in the stinger and pushed in the soil (B). The stinger opens and plants the seedling in the soil (C, D). This machinery can reach very steep, rocky slopes that are inaccessible for manual planting.*



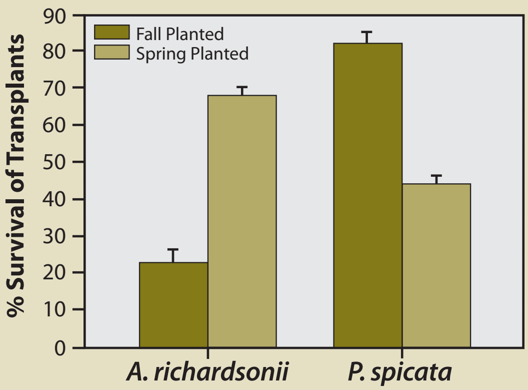
methods. For example, two different species of bunch grass might have very different survival rates depending on when they were outplanted. Figure 6.7 shows survival rates for bluebunch wheatgrass (*Pseudoroegneria spicata*), which survived better when planted in fall, and spreading needlegrass (*Achnatherum richardsonii*), which did better when planted in spring.

Several factors are important for determining outplanting windows. These include 1) soil temperatures in late winter and early spring, 2) precipitation during spring and early summer, 3) soil temperatures in fall, 4) precipitation in fall, and 5) snow cover. Three examples of identifying outplanting windows are provided in Figures 6.8, 6.9 and 6.10. Applying the following set of guidelines to the climate data will help clarify the optimum times to plant.

6.4.4.1 Soil Temperatures in Late Winter and Spring

Seedlings must develop new roots soon after they are planted to become established and survive the hot (and in many regions, dry) summer of the first growing season. For most species, new root growth occurs when soil temperatures exceed 42 °F. Waiting for soil temperatures to warm to 42 °F in the spring before outplanting, however, will shorten the period of time when

***Figure 6.7** – Outplanting must be timed properly for best results given site conditions and species requirements (reproduced from Page and Bork 2005).*



Case Study: Low Elevation, Western Cascade Site

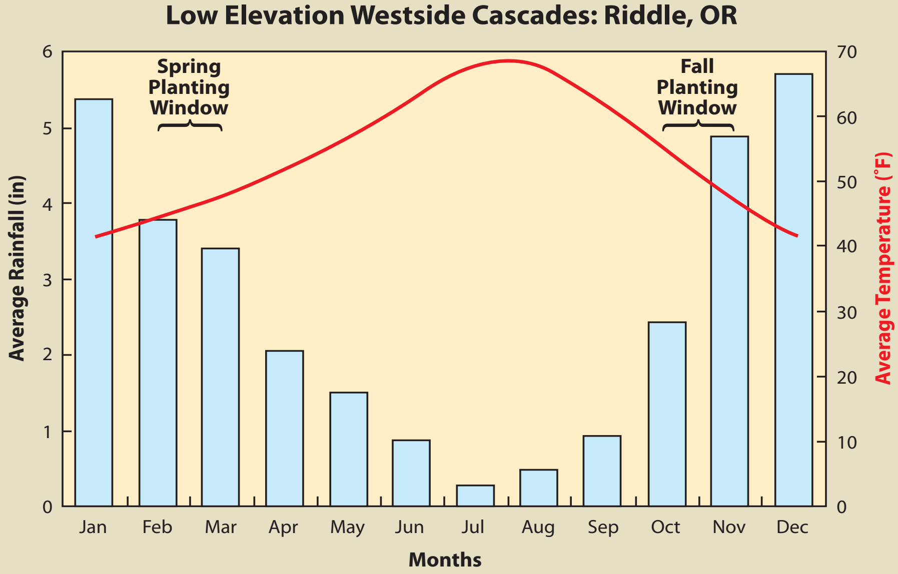


***Figure 6.8 –** The project site is located near Tiller, Oregon, where winters are wet and relatively mild, and summers are dry and hot. North slopes support Douglas-fir, incense cedar, and madrone. South slopes support ponderosa pine, oaks, and grasses. During the summer months, strong drying winds blow up the valley in the afternoon. Weather station records, from a U.S. Regional Climate Station located several miles away, show daily maximum summer temperatures in July and August averaging 84 °F.*

The site has two planting windows. The spring planting window starts after the risk of the last winter cold front in mid-February has passed and ends two months before monthly precipitation dips below 1.5 inches. The fall planting window begins as soon as the first fall rains wet the soil profile and ends one month prior to soil temperatures dropping below 42 °F.

Long dry summers, coupled with high temperatures and strong winds, create challenges to establishing seedlings. Outplanting in the fall or in mid to late winter is essential in order to develop new roots. Removing grass and other vegetation from around the seedling and applying a mulch fabric in March increases soil moisture. In places, tree shelters and shade cards placed around seedlings can protect them from the drying effects of the afternoon wind.

Hydroseeding in October with mulch and tackifier will keep seeds in place long enough to germinate in November. Complete seedling establishment will occur by the following April.

Case Study: Cool, Arid Site

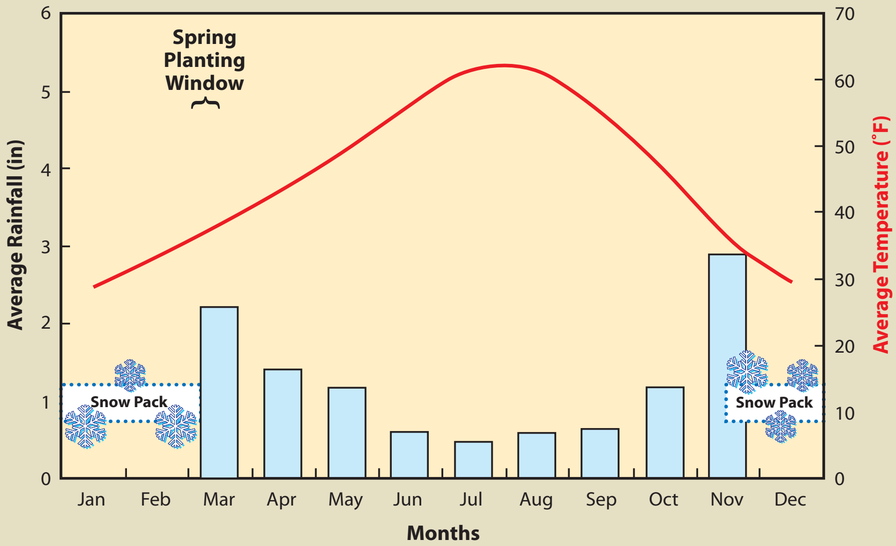


***Figure 6.9** – The climate at this project site is typified by dry, mild summers and cold winters with a snow pack extending from late fall to late winter. (Climate data was from a weather station located near the town of Chiloquin, Oregon.) Ponderosa pine, quaking aspen, and bitterbrush are the dominant vegetation on the site. The planting window begins immediately after snowmelt. Precipitation drops off significantly in April and May. Planting must be completed no later than the first week of April when monthly precipitation drops below 1.5 inches. Note that soil temperatures during the recommended planting windows are cooler than 42 °F. Nevertheless, it is more important to plant early on arid sites than wait until soil temperatures warm. Rainstorms in the fall do not deliver enough moisture to recharge the soil before mean fall temperatures drop below 42 °F. Early planting can take place in the fall if seedlings are irrigated at the time of planting. Seedlings on south slopes should be mulched to conserve soil moisture, while seedlings on cooler north aspects would benefit from, but may not require, mulch.*

Grass and forb seeding in September and October is essential since most seeds from this area require a stratification period. Seeds will not germinate in the fall because of the lack of continuous fall moisture and low temperatures. Germination occurs immediately after snowmelt in the spring. Seed germination can be poor because the soil surface dries out quickly due to low humidity, high solar radiation, and low precipitation. Mulching the seedbed with ground wood fiber or straw will maintain high humidity around germinating seeds. Spring seeding can be successful if seeds are soaked for several days prior to seeding and if seeding is done as soon as snows have melted.

Case Study: High Elevation Site

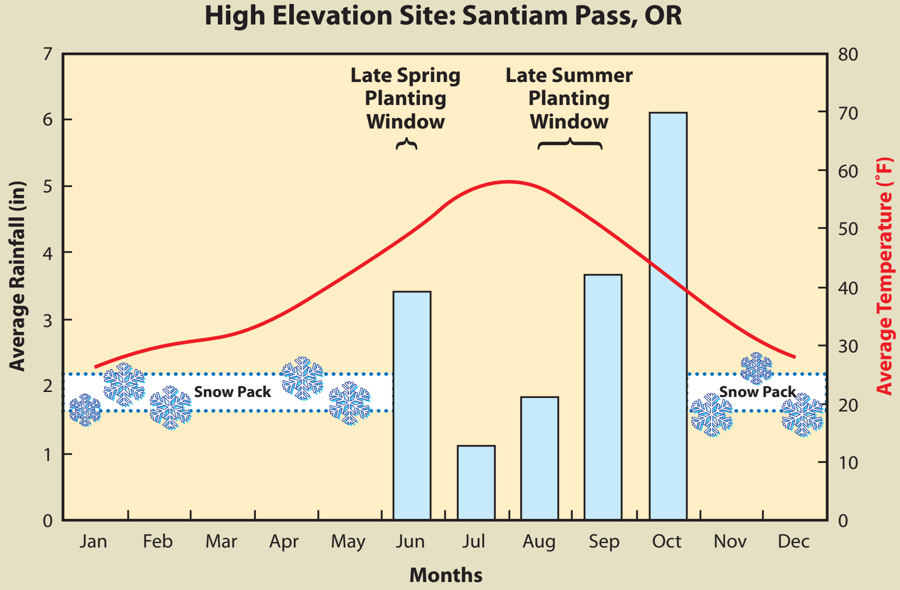


***Figure 6.10 –** This site is located in the high Cascade Mountains at 4,800 ft elevation. Mixed stands of mountain hemlock and noble fir occupy the site. Snowpack begins in November and is present on the site until May, just as summer air temperatures increase. Seedlings must be planted as soon as the snow leaves the site. Thunder storms will typically wet the soil by late summer, opening a second planting window sometimes as early as late August. Competing vegetation must be controlled around container seedlings planted at this time to maintain high soil moisture for the remainder of the fall. Scalping vegetation immediately after planting and applying a mulch will help maintain high soil moisture. As temperatures begin to drop in late summer, evaporative demands on the planted seedlings are reduced. Planting must be completed by late September to ensure that seedlings will have some time to develop new roots. North sites will have cooler soil temperatures and should be planted sooner than south aspects.*

Weather station data indicate average minimum air temperatures are cold during the growing season. Applying tree shelters around seedlings will increase daily air temperatures, creating a more favorable environment for seedling growth. North aspect seedling plantings might benefit more from tree shelters than south aspect plantings.

Sowing can take place in the late spring, immediately after snowmelt, and again in the fall. Late spring sowing will be significantly enhanced by applying mulch over the seedbed and/or pregerminating seed prior to sowing. Seeds of species that do not require stratification should germinate within a month after sowing in late spring. Species requiring stratification should be sown in the fall.

soil moisture is available to the seedling. For this reason, a common restoration strategy is to outplant seedlings as soon after the last threat of a deep frost in the winter has passed, even if the soil temperatures are below 42 °F.

6.4.4.2 Precipitation in Spring and Summer

Much of the western United States experiences dry summers, with winters receiving most of the precipitation. Under this regime, soils lose their moisture in the summer and recharge from storms that occur in the fall and winter months. Plants have adapted to this climate by growing new roots and leaves during the spring, when soil moisture is high, and shutting down or becoming dormant in the summer, when soil moisture is depleted.

The most critical factor for seedlings that are outplanted in the spring is the length of time available for the seedling to develop new roots before soil moisture is depleted. Sites with little or no precipitation in the spring or summer will dry out faster than sites with high spring and summer precipitation. A rule of thumb is that an average monthly precipitation of less than 1.5 inches will do little to recharge a dry soil during late spring through fall. Figures 6.8, 6.9, and 6.10 show spring outplanting windows for three very different project sites. On low elevation sites west of the Cascade Mountains, the planting window can be fall and spring (Figure 6.8), whereas high elevation sites might have a planting window only in late spring (Figure 6.10).

6.4.4.3 Soil Temperatures in Fall

If outplanting is planned for late summer or early fall, it is important that soils have high moisture and temperatures are warm enough to encourage new roots to grow into the soil before winter arrives. On cold sites where seedlings are not protected by snow, the upper portions of the soil profile will typically freeze. Fall outplanted seedlings that have not established new roots below the frost line risk desiccation by wind or sun exposure in the winter months because no water is available to the seedling. For greatest success, soil temperatures should remain above 42 °F for at least one month after seedlings are planted in the fall for root development and seedling establishment prior to winter. Figure 6.10 shows a late summer planting window on a high elevation site where precipitation is high in September and soil temperatures are above 42 °F.

Soil temperatures are significantly warmer on south aspects, which means that outplanting windows on south exposures are often wider and extend further into the fall than planting sites on north aspects, given soil moisture is adequate for root growth. Weather stations do not report soil temperatures. However, they can be extrapolated from average monthly air temperatures with a certain degree of reliability. Placing recording thermometers in the soil before construction will give more exact soil temperatures.

6.4.4.4 Precipitation in Fall

When outplanting seedlings in the fall, high soil moisture is essential for seedling survival and growth. Fall soil moisture is typically very low, and the only means of recharging a dry soil is through rainstorms or irrigation. Two or more inches of rain over a period of at least several days is often required to moisten most dry soils. Many sites in the western United States, however, seldom have rainstorm events great enough to moisten the top 12 inches of soil before cold soil temperatures occur. Fall planting on these sites has a low potential for seedling survival. On sites with sufficient fall precipitation, planting windows are open as soon as a rainstorm event wets the surface 12 inches of soil.

6.4.4.5 Snow Cover

Seedlings should not be planted through snow, so outplanting windows are open before snow accumulation and after snowmelt. Be aware, however, that cold water from melting snow keeps soil temperatures low. Soil temperatures should be monitored during or following snowmelt.

6.4.5 Determine Sowing Windows

The outplanting windows for seed sowing may be different than those for planting nursery stock. Optimum planting times for seeds are called "sowing windows." Sowing windows change by site environment, sowing methods, and seed needs. Seeds will germinate and develop into healthy, viable plants when: 1) seed stratification requirements are met, and 2) seeds are in a warm, moist environment during germination. Seed stratification requires a cold, moist period, ranging from a few weeks to several months, during which time the seeds are conditioned for germination. This usually occurs naturally in the western United States during the early to mid spring, but it can be induced artificially in seed coolers.

After seed stratification requirements have been met, a moist, warm period must follow in which seeds and soil do not appreciably dry down. Drying during this time can prevent germination and kill new germinants. In the western United States, these conditions are best met by sowing seeds in the late summer to early fall. On warm, moist sites (e.g., Figure 6.8), seeds that require a very short stratification period will germinate in the early fall and begin to establish ground cover before winter rains occur. Fall-sown seeds requiring stratification will have moisture and temperature requirements met during the winter months. On drier sites (Figure 6.9), fall-sown seeds will not germinate due to lack of precipitation.

If fall sowing is not possible, sowing can take place in the late winter or early spring. Sowing at this time generally results in less vigorous stands of grass and forb seedlings because there is a shorter period of favorable conditions for seeds to germinate and seedlings to become established. Another drawback of spring sowing is that some species will not receive the required cold, moist period to break seed dormancy and germinate. Once germination has occurred, several months of periodic precipitation with average air temperatures exceeding 40 °F are required for successful establishment of ground cover.

Spring sowing can be enhanced in several ways. A mulch applied over the seeds will help maintain higher seed moisture levels and keep soil moisture in the soil for a longer period. Seeds requiring stratification can be artificially stratified for spring sowing to achieve earlier germination (Cook and others 1997). Care must be taken that the seeds do not mold or begin to germinate during this period, or dry down for sowing. The effect of hydromulch equipment on germinating native species seeds is unknown at this time; seeds may be damaged if sown using this method.

6.5 NEXT STEPS

By the end of Phase Three, you will have completed an assessment and analysis of the native vegetation on your revegetation units and reference sites. You will have refined your DFCs for short- and long-term goals; gained an understanding of the species, plant communities, and successional processes; analyzed species and communities in order to select the species to be used for revegetation; and reviewed potential plant material types and seeding or outplanting methods to consider in order to revegetate the site. Now it is time to move to Phase Four, where all the elements will be integrated into a comprehensive strategy for road design, site treatments, and revegetation – the Revegetation Plan.

7 PLANNING PHASE FOUR: INTEGRATE AND STRATEGIZE

7.1 INTRODUCTION

In Phase One of the planning process, project objectives were clarified and revegetation units and reference sites were defined. Preliminary Desired Future Conditions (DFCs) were developed for each revegetation unit. During Phase Two, site attributes were defined, including limiting factors, options for mitigation, and available resources. In Phase Three, vegetation was analyzed to consider species, stocktypes, and plant establishment options. In Phase Four, the final phase of planning, the work of all the previous phases is pulled together. Phase Four integrates the understanding of site limitations and resources, mitigation options, species, and seeding or outplanting methods into a comprehensive strategy for revegetating the site. This integrated strategy will culminate in the Revegetation Plan.

The steps for developing the revegetation plan in Phase Four are as follows:

- Finalize revegetation units and DFCs,
- Integrate survey information and develop potential revegetation strategies,
- Compare and select revegetation strategies, and
- Assemble plan.

A case study is provided to illustrate the thought process for the development and selection of revegetation strategies on a project.

7.2 FINALIZE REVEGETATION UNITS AND DFCS

Phase Four provides the opportunity to review, refine, and finalize revegetation units and the DFCs for each unit. The boundaries of revegetation units may be revised now that the sites have been more thoroughly surveyed. Additional ecological or management-based information may support creating additional revegetation units. Alternately, if management will be similar, an area originally divided into several revegetation units might be consolidated into one. Once the revegetation units are finalized, the DFCs for each unit can be finalized as well.

DFCs can be revised based on the information gathered during these assessments. For example, with more detail about the local native species and their specific requirements, some factors may emerge as less or more limiting for the species in your project. Water input might be low on the site. However, if native drought-tolerant (xeric) species abound, water will be less limiting for these species than if you were attempting to revegetate with more water-loving (mesic) species. It is possible that less mitigation for water will be necessary than originally assumed. The process of refining DFCs is essential in order to ensure that the objectives are feasible given the native species and ecological processes on the site.

Reference sites provided information on existing vegetation and illustrated what might happen on a site in one year, five years, or several decades. These reference sites model how revegetation units might be expected to respond to change and management. The potential successional development of each revegetation unit should be reviewed. Asking what the revegetation units could look like in both short-term (1-3 years) and long-term (5, 10, 15+ years) timeframes is part of the process for finalizing DFCs.

An example of how DFC's were developed for a project is described in Inset 7.1. In this case study several reference sites were selected, ranging from desirable to undesirable vegetation conditions. Defining site characteristics from a range of reference sites helped develop a realistic DFC for the project.

Site assessments that define limiting factors for each revegetation unit in Phase Two become the basis for developing a revegetation strategy. For example, Figure 7.2 shows how limiting factors were summarized for a proposed project. By listing the limiting factors, the revegetation specialist can focus on only the most important site parameters requiring mitigation. Figure 7.3 lists the potential mitigating measures available in this case study for each limiting factor.

7.3 INTEGRATE AND DEVELOP REVEGETATION STRATEGIES

There are no "silver bullet" products or treatment methods that will transform a project site into a functioning plant community. A comprehensive understanding of the site and how revegetation treatments alone or in combination with other treatments will affect soil characteristics, plant establishment, and future successional processes is the key to successful revegetation. Several revegetation strategies can be developed for each revegetation unit by creating various combinations of mitigating measures. It is important to assess how these strategies compare with each other and how the combination of mitigating measures within a strategy will interact.

Strategies are often developed around major actions or themes. For instance, the three strategies in the case study shown in Inset 7.2 were based on mitigating for the lack of topsoil by:

- Strategy 1: Adding fertilizer,
- Strategy 2: Reapplying topsoil, and
- Strategy 3: Blowing compost mulch.

These are very different approaches, and the resulting strategies will vary considerably.

Developing revegetation strategies is an integrative and collaborative process between vegetation and soils specialists and the project engineers. This requires a good understanding of the site limitations, site resources, and experience with a variety of mitigating measures. All reasonable possibilities should be considered before any are rejected.

7.4 SELECT A REVEGETATION STRATEGY

The spreadsheets shown in Figures 7.2, 7.3, and 7.4 are helpful in summarizing site attributes for defining limiting factors, keeping track of potential mitigating measures, and comparing revegetation strategies for each revegetation unit. Following this process can lead to an informed decision on selecting a revegetation strategy for each revegetation unit.

Figure 7.4 illustrates how strategies can be qualitatively compared. In this method, limiting factors are identified for positive or negative effects on plant growth. Each of these characteristics is assessed for the conditions expected after construction with no mitigation measures employed, and qualitatively given a rating as follows:

- - - Severely limiting	+ Not limiting
- - Limiting	+ + Beneficial
- Somewhat limiting	+ + + Very beneficial

The selection of one strategy over others should be based on revegetation objectives and feasibility of applying the treatment, including considerations for economics, available skills, and resources.

When selecting a strategy, both short-term and long-term planning are required. Mitigating limiting factors for long-term revegetation success however, does not always directly aid in early establishment of plant materials. Success during early plant establishment depends almost entirely on conditions in a narrow environment at the soil surface (six inches above and below the surface), while conditions must focus on soil quality at much deeper depths and aerial factors much higher than the soil surface. Until plants can grow out of this narrow surface zone, they will continue to be affected by climate extremes (moisture, temperature, and so on), competition, and animal damage. The first few weeks after the installation of plant materials is often the most critical period in the revegetation process; plants should not be considered "established" until at least 1 to 2 years of growth. Developing revegetation strategies that meet both short and long-term revegetation goals is not always possible and there will be times when meeting short-term revegetation goals might have to give way to assuring long-term site recover.

7.5 ASSEMBLE THE REVEGETATION PLAN

At the end of Phase Four, revegetation strategies for all revegetation units have been selected. If the planning process went well, writing the actual plan should simply be a compilation of the various strategies. Revegetation Plans vary in length and depth. At a minimum, a plan will typically include the following components:

- Revegetation objectives,
- Description and map of each revegetation unit;
- Desired future conditions (DFCs) for each revegetation unit;
- Analysis of site attributes (limiting factors and resources) and type of vegetation;
- Description of mitigating measures;
- Description of the revegetation strategy, including plant materials/stocktypes and application methods for each unit;
- Key contacts and responsibilities;
- Budget and timelines;
- Strategies for monitoring achievement of DFCs; and
- Strategies for correcting shortcomings based on monitoring information.

An example Revegetation Plan is provided in Chapter 8.

7.5.1 Networking

The revegetation plan is a valuable tool for communicating with the Federal Highway Administration, other government agencies, and the general public. The degree that a revegetation project succeeds is often proportional to the quality of these interactions. It requires identifying the agency players, affected or key community members, and local and regional workforce (See Chapter 2) and understanding their concerns. The best written plans are of little value if these relationships are not established and maintained. It is important to share versions of the plan with, and solicit input from, others involved in the project.

7.5.2 Timelines

From inception through implementation and monitoring, construction projects span many years. A timeline can help organize the series of steps required for a successful revegetation project, and should include all aspects and details of the project. The timeline is basically a "to do" list with corresponding "due dates." Awareness of timing is crucial, especially when obtaining plant materials. More information on timelines is provided in the Implementation Guide to Obtaining Plant Materials (See Section 10.2).

7.5.3 Fiscal Concerns

Budgets are necessary to estimate costs. Methods to build budgets and timelines are outside the scope of this publication, but there are many resources available to assist with the process.

When the Planning Phase is complete, it will be time to move to the Implementation Phase. During implementation, the Revegetation Plan will be translated into task orders and prescriptions that specify how, when, where, and by whom the plan will be implemented.

7.6 NEXT STEPS

Phase Four, the final phase of the planning process, integrates all the information gathered from the previous three phases. The understanding of limiting factors and resources, mitigation options, species, and planting methods are combined into a comprehensive strategy for revegetating the site. The steps of Phase Four are to: 1) finalize revegetation units and DFCs; 2) integrate survey information and develop potential revegetation strategies; 3) compare and select revegetation strategies; and 4) assemble the plan. A case study with a decision matrix illustrates how to weigh various options and strategies to choose the most appropriate ones for the project. Phase Four culminates in the writing of the Revegetation Plan, which details the strategy and provides schedules and budgets for the project. The Revegetation Plan is an important tool for communicating with agencies, individuals, and the community about the project. An example Revegetation Plan is provided in the next chapter.

Inset 7.1 – Case Study – Define Site, Limiting Factors, and Desired Future Conditions

Revegetation Unit Description

Five revegetation units were defined for this road project. The revegetation unit in this case study was defined from surveys of several reference sites and local reports.

Soils are generally deep sandy loams (less than 20% rock fragments) derived from pumice parent material. Topsoils are 6 to 8 inches deep. Duff and litter layers are 2 to 3 inches deep. Infiltration rates are very high unless duff and litter layers are removed and soil is compacted. Slope gradients are less than 5H:1V, except for a few areas that approach 2H:1V. The climate is semi-arid, with an annual precipitation of 10 inches, delivered as snow in winter and intense thunderstorms in the summer months. Winters are very cold; summers are warm. Evapotranspiration rates are high from spring through fall. Vegetation on undisturbed reference sites is dominated by ponderosa pine, quaking aspen, bitterbrush, ceanothus, and Idaho fescue.

Figure 7.1A – *Reference Site 1. This site has been barren since construction. Soils are compacted and sheet erosion is active.*

Figure 7.1B – *Reference Site 2. This reference site is composed of squirreltail* (Sitanion hystrix) *and Oregon sunshine* (Eriophyllum lanatum), *representing the desired future condition of this project.*

Disturbance Description

All vegetation will be removed and roots and stumps grubbed. Topsoil will be removed, leaving at least 2 feet of subsoil for rooting. Soils will be compacted, and the site is expected to appear similar to the photo of Reference Site 1 (Figure 7.1A).

Limiting Factors and Mitigating Measures

Figure 7.2 shows the potential limiting factors associated with this revegetation unit. Figure 7.3 displays possible mitigating measures that could be employed to overcome each limitation.

Desired Future Condition

The revegetation objectives for this unit are to develop a low growing stand of native grasses and forbs that are not attractive as deer forage, exclude invasive weeds, and add visual interest to a high recreational use road. Based on reference sites or recently recovered disturbances, vegetative cover of a well-established grass and forb stand is 50% to 70% in mid summer, with 10% to 30% bare soil. Vegetation establishment is very low the first year, with less than 20% cover typically occurring. DFC thresholds after the first year include: 20% vegetative cover, 30% bare soil, no knapweed. DFC thresholds after the third year include: 65% vegetative cover, 30% bare soil, no knapweed. Vegetative cover must be composed of 90% native vegetation.

Figure 7.2 – Case Study – Define limiting factors on the site.

Critical Plant Factors	Parameters		Site Characteristics
1 Water Input	Precipitation	✓	3" of rainfall in summer, thunderstorms July - Aug
	Interception		none
	Infiltration	✓	low infiltration when compacted
	Road Drainage		none
2 Water Storage and Accessiblity	Soil Texture	✓	low - sandy texture
	Rock Fragments		relatively little gravels and no cobbles or rock
	Soil Structure	✓	expected to be compacted
	Rooting Depth	✓	deep soils, but likely to be restricted by compaction
	Mycorrhizal Fungi	✓	expected to be little to none
3 Water Loss	Wind		low - protected by surrounding forests
	Aspect		no southern aspects
	Competing Vegetation		little competing vegetation in first several years
	Soil Cover	✓	low - high surface evaporation
4 Nutrient Cycling	Topsoil	✓	none
	Site Organic Matter	✓	very low
	Nitrogen & Carbon	✓	very low
	Nutrients	✓	very low
	pH & Salts		moderate pH, low salts
5 Surface Stability	Rainfall & Wind	✓	intense thunderstorms in summer, high rainfall splash
	Freeze-Thaw	✓	moderate to high when surface is compacted
	Soil Cover	✓	low
	Surface Strength	✓	low - no cohesion in sands
	Infiltration	✓	low
	Slope Gradient		low slope gradients favorable to surface stability
	Surface Roughness		expected to be rough
	Slope Length	✓	30 feet slope run, on compacted soils can get rills
6 Slope Stability	Permeability		low
	Restrictive Layer		NA
	Water Input		NA
	Slope Length		NA
	Slope Gradient		low slope gradients reduces risk of landslides
	Soil Strength		NA
7 Weeds	Weed Sources	✓	populations of knapweed along road corridor
	Growing Environment		poor for weeds
8 Pests	Mammals	✓	deer populations in spring and fall; some gopher
	Insects		minor
	Diseases		minor
9 Human Interface	Road Maintenance		some gravels from sanding roads - minimal effect
	Recreational Use		snowmobile traffic - minimal

Figure 7.3 – Case Study – List possible mitigating measures for limiting factors.

Critical Plant Factors	Parameters		Possible Mitigating Measures
1 Water Input	Precipitation	✓	irrigate, deep sow, mulch, high density sowing
	Interception		
	Infiltration	✓	deep tillage, harrow, disk, mulch
	Road Drainage		
2 Water Storage and Accessiblity	Soil Texture	✓	compost, clay
	Rock Fragments		
	Soil Structure	✓	deep tillage, compost, topsoil
	Rooting Depth	✓	deep tillage, compost
	Mycorrhizal Fungi	✓	topsoil addition, mycorrhizal inoculum
3 Water Loss	Wind		
	Aspect		
	Competing Vegetation		
	Soil Cover	✓	mulch, deep sow
4 Nutrient Cycling	Topsoil	✓	topsoil addition, manufactured topsoil
	Site Organic Matter	✓	incorporated litter duff, mulch, logs
	Nitrogen & Carbon	✓	nitrogen-fixing species, topsoil, fertilizers, compost
	Nutrients	✓	topsoil, fertilizers, compost
	pH & Salts		
5 Surface Stability	Rainfall & Wind	✓	mulch
	Freeze-Thaw	✓	mulch
	Soil Cover	✓	mulch
	Surface Strength	✓	mulch, tackifier
	Infiltration	✓	disk, harrow, compost
	Slope Gradient		
	Surface Roughness		
	Slope Length	✓	reduce slope length
6 Slope Stability	Permeability		
	Restrictive Layer		
	Water Input		
	Slope Length		
	Slope Gradient		
	Soil Strength		
7 Weeds	Weed Sources	✓	prevent and control, quick native revegetation
	Growing Environment		
8 Pests	Mammals		sow non-palatable or non-desirable species
	Insects		
	Diseases		
9 Human Interface	Road Maintenance		
	Recreational Use		

Inset 7 .2 – Case Study – Design Potential Revegetation Strategies

From the list of possible mitigating measures, design several revegetation strategies.

Strategy 1

- Subsoil till the top two feet of soil to break up compaction.
- Fertilize with a slow-release fertilizer.
- Use working group of nitrogen-fixing species (lupine, ceanothus and bitterbrush) and hydroseed in fall with wood fiber mulch.

Short-term and long-term effects

Subsoil tillage reduces compaction and increases surface stability by roughening the surface, increasing infiltration and reducing freeze-thaw potential. Subsoil tillage also increases rooting depth.

Fertilizers will provide nitrogen and other nutrients for seedling establishment. Sufficient nitrogen may not be present to meet vegetation cover thresholds, but higher nitrogen levels in the soil might encourage annual weed growth.

Emergence of sown seeds could be poor, especially if there are periods of dry spring weather during germination. Surface soil holds very little moisture in exposed, dry areas, and the wood fiber in the hydromulch will not provide enough moisture around seeds for germination. Mycorrhizal inoculum is important on dry sites, but has not been added to the hydroseed mix. This could result in poor establishment of seedlings.

Discussion

This is the least expensive strategy, and the least likely to create conditions for long-term revegetation. Nevertheless, the deep, non-compacted soils, though lacking in organic matter, should be able to support a good stand of nitrogen-fixing species. This could restore nitrogen to the soil and build soil biomass over time.

Strategy 2

- Salvage and reapply 6 to 9 inches of topsoil, then subsoil till to 24 inches.
- Apply seeds through hydroseeding equipment and cover with an application of straw mulch and tackifier.
- Use a working group of visually pleasing species (predominately showy forb species).

Short-term and long-term effects

Topsoil will increase the water-holding capacity in the surface soil, as well as rooting depth, nutrients, organic matter, infiltration rates, and mycorrhizal inoculum. Knapweed (*Centaurea* spp.) infestation is possible if care is not taken to avoid areas of knapweed during soil salvage operations. Long-term nitrogen needs for the site are met with the additions of topsoil, but short-term nitrogen availability for seedling establishment might be low. Subsoil tillage increases rooting depth, surface stability through surface roughening, and infiltration. Tillage also reduces the freeze-thaw potential. Application of straw will increase germination and early seedling establishment due to higher humidity around seeds during germination. Straw also protects the soil surface from rainfall splash during thunderstorms. Straw can be a source of weeds if certified straw has not been purchased.

Discussion

This is the most expensive measure, but will potentially support the highest amount of plant cover over the long-term. All major limiting factors have been mitigated in this strategy.

Strategy 3

- Apply 2-inch layer of compost to soil surface using a compost blower.
- Apply seeds and mycorrhizal inoculum during this operation.
- Use a working group of visually pleasing species (predominately showy forb species).

Short-term and long-term effects

Soil moisture is increased around the seeds due to the higher water-holding capacity of compost. Seeds are buried during compost blowing, increasing the chances of germination and establishment. Smaller seeds buried under the deeper thicknesses of compost will have poor emergence. Nutrients are supplied through the compost for short- and long-term plant community needs. Nutrients are not as accessible on the surface of the soil, requiring a portion of the grass and forb root systems to be growing into the compost. Mycorrhizal fungi are supplied through commercial inoculum. Soils are still compacted, limiting rooting depth.

Discussion

This strategy should be adequate to establish plants. Since soils are still compacted, meeting long-term vegetative cover targets might be difficult. This strategy could be improved if the compost were applied to previously tilled soil, or applied to the surface and then tilled into the soil to mix the compost and loosen the soil.

SELECT REVEGETATION STRATEGY

Comparing the revegetation strategies with their effects on the limiting factors of the site, a selection of the most appropriate revegetation strategy can be made.

Since the amount of topsoil was of limited supply for the project, Strategy 2 (topsoil placement) was selected for the gentler terrain where it could be easily placed. Strategy 3 (mulch application) was selected for the steeper gradients. Strategy 1 was not selected because it was the least likely to meet the revegetation objectives (DFCs) of the project.

Figure 7.4 – Case Study – Compare revegetation strategies. Evaluate each strategy using a qualitative system for comparison.

Critical Plant Factors	Parameters		No Action	Strategies		
				1	2	3
1 Water Input	Precipitation	low	- - -	- - -	- - -	- - -
	Interception					
	Infiltration					
	Road Drainage					
2 Water Storage and Accessiblity	Soil Texture	low	- -	- -	+	-
	Rock Fragments					
	Soil Structure	none	- -	+	+	-
	Rooting Depth					
	Mycorrhizal Fungi	low	-	-	+	+
3 Water Withdrawal	Wind					
	Aspect					
	Competing Vegetation					
	Soil Cover	low	-	-	+	+
4 Nutrient Cycling	Topsoil	none	- - -	- - -	+ +	- - -
	Site Organic Matter	none	- -	- -	+	+
	Nitrogen & Carbon	none	- - -	-	+ +	+
	Nutrients	none				
	pH & Salts					
5 Surface Stability	Rainfall & Wind					
	Freeze-Thaw	mod-high	-	+	+	+
	Soil Cover	low	-	-	+	+
	Surface Strength					
	Infiltration	low	- -	+ +	+ +	+ +
	Slope Gradient			+	+	
	Surface Roughness					
	Slope Length					
6 Slope Stability	Permeability					
	Restrictive Layer					
	Water Input					
	Slope Length					
	Slope Gradient					
	Soil Strength					
7 Weeds	Weed Sources					
	Growing Environment					
8 Pests	Mammals	deer use		-		
	Insects					
	Diseases					
9 Human Interface	Road Maintenance					
	Recreational Use					

SUNRIVER TO MT. BACHELOR DRAFT REVEGETATION PLAN

MARCH 2006

OR PFH 244-1(1)
Deschutes National Forest
Deschutes County
Oregon

DRAFT

BACKGROUND

This revegetation plan outlines the basic actions that will be taken by the USDA Forest Service in association with Western Federal Lands Highways Division (WFLHD) of the Federal Highway Administration (FHWA) to revegetate the Sunriver to Mt. Bachelor Highway project [OR PFH 244-1(1)]. Construction is scheduled to begin in spring 2006, with revegetation implementation to begin in fall 2006.

The Sunriver to Mt. Bachelor project is located entirely on the Bend/Fort Rock Ranger District, Deschutes National Forest in Central Oregon.

ROLES, RESPONSIBILITIES, AND CONTACTS

The entire project is bordered by National Forest lands. The environmental specialist will be the main contact during the planning phase. During construction, the project engineer will be the main contact. After the project has been completed, the county engineer and environmental specialist will be the contacts.

The project as planned (see Sunriver to Mt. Bachelor Highway Environmental Assessment) will minimally affect soil conditions along the roadway. Cuts and fills will be designed to minimize erosion. The erosion and sediment control plans will be developed by the WFLHD and will be the responsibility of the contractor. The Forest Service will have a limited role, primarily in providing guidance for temporary stabilization practices. Key to this guidance will be the selection of appropriate materials and methods that will not deter future revegetation efforts.

REVEGETATION OBJECTIVES

The following revegetation objectives were addressed in the Environmental Analysis (EA) for cuts, fills, and abandoned roads:

- Enhance scenic beauty using native grass, forb, shrub, and tree species;
- Control noxious weeds using only EA approved herbicides and native grass and forb species;
- Maintain slope stability using native grass, forb, and shrub species;
- Minimize soil erosion with native grass, forb, shrub, and tree species; and
- Maintain biodiversity of the surrounding plant communities by planting locally adapted native species.

***Table 8.1** – Project contacts.*

Contact	Organization	Phone	E-mail	Role
Jim Scott	USDA Forest Service			FS Agreement Liaison
April Jones	USDA Forest Service			Lead Revegetation Specialist
Jill Smith	USDA Forest Service			Revegetation Specialist
Adam Riles	Deschutes National Forest			Local FS Liaison and Permitting Specialist (Bend/Fort Rock District)
Carlos Escobar	FHWA			Project manager – general FHWA project oversight.
Lindsey Chen	FHWA			Project Engineer
Sam James	FHWA			Design Engineer
Philip West	FHWA			Environmental Specialist – agreement coordinator, main contact between FHWA and other regulatory agencies, including DEQ and EPA
Carol Clint				Deschutes County – Director of Public Works

The revegetation objectives for the source and waste areas are for suitable native grass and forb vegetation for erosion control and wildlife forage.

PROJECT CONSTRAINTS

The following are the major anticipated constraints to successful revegetation:

- Limited topsoil;
- Wind at higher elevations;
- Frost pockets;
- Hot, dry south slopes in summer;
- Animal damage – gophers and deer;
- Noxious weeds – spotted knapweed (*Centaurea maculosa*);
- Non-native invasive species – mullein (*Verbascum thapsus*);
- Threatened and endangered plants – greentinge Indian paintbrush (*Castilleja chlorotica*);
- Covering of plants with gravel applied to roads in winter;
- Herbicides – limited chemicals and NEPA cleared sites;
- Oversteepened slope gradients;
- Snow damage from plowing/blowing accumulation;
- Winter desiccation; and
- Driving on obliterated roads.

LAWS, REGULATIONS AND POLICIES

Following Forest Service National Policy, only genetically appropriate, locally adapted native plant materials will be used in the revegetation of this project.

Laws governing surface water quality are not major constraints on this project, since there are no perennial or intermittent streams, lakes, or wetland areas within the project area or adjacent areas.

Table 8.2 – *Collection, propagation, and revegetation schedule.*

Project Size								
Length: 21.7 km (13.5 mi)								
Area: 16.6 ha (41 ac)								
Activity Timeline	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**
Seed collections	X	X						
Seed increase	X	X	X					
Cuttings collection		X	X					
Cuttings/container plants, stool-beds		X	X	X				
Hydroseeding			X					
Plant shrubs/trees			X	X				
Monitor				X	X	X		X

Table 8.3 *– Cost and production schedule of plant materials.*

	Schedule/Nursery	Cost/lb	Total lb	Total Cost
1. Seed Needed				
Grasses				
ACOCO (*Achnatherum occidentale ssp. occidentale*)	Collected – sown for production fall 2004 – Currans	$22.50	31	$697.50
BRMA4 (*Bromus marginatus*)	Collect 2005 – sown for production fall 2005 – Currans	$5.19	159	$825.21
ELEL5 (*Elymus elymoides*)	Collected – in production – Currans	$19.75	102	$2,014.50
FEID (*Festuca idahoensis*)	Collected – stored for district	$11.00	200	$2,200.00
Forbs				
ERBL2 (*Ericameria bloomeri*)	Collect 2005 ??	$50.00	2	$100.00
ERLA6 (*Eriophyllum lanatum*)	Recollect 2005 – will sow for production – Lucky Peak	$50.00	100	$5,000.00
IPAGA3 (*Ipomopsis aggregata ssp. aggregata*)	Collected – in production – Stone	$50.00	20	$1,000.00
LUAR3 (*Lupinus argenteus*)	Collected – sown for production fall 2004 – Lucky Peak	$50.00	60	$3,000.00
LULE2 (*Lupinus lepidus*)	Collect 2004/5 – will sow for production – Lucky Peak	$50.00	53	$2,650.00
PECI2 (*Penstemon cinicola*)	Not propagated – failed in production			
PEEU (*Penstemon euglaucus*)	Collected (in production) – Stone	$50.00	25	$1,250.00
PEHU (*Penstemon humilis*)	Collected – in production – Stone	$50.00	12	$600.00
PHHA (*Phacelia hastata*)	Recollect 2005 – sown for production fall 2005 – Lucky Peak	$50.00	12	$600.00
Shrubs				
ARNE (*Arctostaphylos nevadensis*)*	Collected (DGRC)	$100.00	1	$100.00
ARPA6 (*Arctostaphylos patula*)*	Collected (DGRC)	$100.00	1	$100.00
CEVE (*Ceanothus velutinus*)	Collected (DGRC)	$200.00	2	$400.00
PUTR2 (*Purshia tridentata*)	FS seed bank (Bend)	$35.00	1	$35.00
Trees				
ABCO (*Abies concolor*)	FS seed bank (DGRC)	$265.00	0.5	$132.50
PIAL (*Pinus albicaulis*)	FS seed bank (DGRC)	$265.00	0.5	$132.50
PICO (*Pinus contorta*)	FS seed bank (Bend)	$265.00	1	$265.00
PIMO3 (*Pinus monticola*)	FS seed bank (DGRC)	$265.00	0.5	$132.50
PIPO (*Pinus ponderosa*)	FS seed bank (Bend)	$265.00	1	$265.00
	Schedule/Nursery	**Cost/ Plant**	**No. of Plants**	**Total Cost**
2. Shrub Cuttings				
ARNE (*Arctostaphylos nevadensis*) (short one treepots)*	Fall 05/Spring 06 (DGRC)	$2.50	320	$800.00
ARPA6 (*Arctostaphylos patula*) (short one treepots)*	Spring 06 (DGRC)	$2.50	320	$800.00
3. Container Plants (Native spp.)				
ARNE (short one treepots)	Spring 06 (DGRC)	$3.50	320	$1,120.00
ARPA6 (short one treepots)	Spring 06 (DGRC)	$3.50	320	$1,120.00
CEVE (short one treepots)	Spring 06 (DGRC)	$2.00	395	$790.00
PUTR2 (D40)	Spring 06 (DGRC)	$2.00	67	$134.00
4. Conifers				
ABCO (short one treepots)	Spring 06 (DGRC)	$2.00	160	$320.00
PIAL (D25)	Spring 06 (DGRC)	$1.00	43	$43.00
PICO (1 gal)	Sow Spring 05/Xplant Spring 06 (Stone)	$4.00	301	$1,204.00
PICO (Q-plug+1)	Spring 06 (Stone)	$0.50	1375	$687.50
PIMO3 (D25)	Spring 06 (DGRC)	$1.00	87	$87.00
PIPO (1 gal)	Sow Spring 05/Xplant Spring 06 (Stone)	$4.00	53	$212.00
PIPO (Q-plug+1)	Spring 06 (Stone)	$0.50	1097	$548.50

Total disturbed area = 16.6 ha (41 ac)
*A total of 640 plants each for ARNE and ARPA6 are needed. Both seedlings and cuttings will be attempted to fulfill this order.

NOXIOUS WEEDS

Prevention

As stated in the EA, the contractor will be required to clean all equipment and vehicles before entering and leaving National Forest lands to minimize spread of state- and county-listed noxious and non-native plants. Mud, dirt, and plant parts will be removed from project equipment before moving equipment into project areas. Also, the contractor will be required to use gravel from a known weed-free site. Both Deschutes Bridge and Dutchman Pits were found by Forest Service personnel to be free of noxious weeds. Any other potential sources will have noxious weed surveys completed before being used. The contractor will be responsible for environmental clearance on other potential sites. The contractor will be required to monitor and flag the known knapweed sites, and remove any plants before project work begins. The Forest Service has record of known knapweed sites and will supply this information to the contractor. The contractor will be required to use weed-free staging areas. Vehicles or heavy equipment will not be allowed to park, or be staged at the junction of FS Roads 40 and 41, or at the junction of FS Road 45 and Oregon Highway 372, where there are known noxious weed sites.

Control

Monitoring and treatment of noxious weeds and invasive plants will occur regularly beginning in 2004 and will continue through successful vegetation establishment. The monitoring and treatment plan will be cooperatively developed by WFLHD, FS, and County staff with the FS as lead agency. The plan is not a substitute for prevention, but rather directs and funds additional resources to monitor and treat noxious weeds and invasive plant species in, and adjacent to, the construction corridor during and after project implementation. Monitoring also includes haul roads and source and waste areas.

PROPOSED REVEGETATION SCHEDULE

PLANT MATERIALS

Locally-collected plant materials will be obtained under the guidance of the Forest Service district botanist through seed collection contracts. Seed increase will be accomplished over a 3- to 4-year period using the regional seed increase contract. The following table gives a general schedule and rough estimate of cost of plant production.

OVERALL MONITORING

Monitoring will be conducted during late spring to early summer of the field season following the initial seed application. Areas of unsatisfactory plant establishment will be evaluated for retreatment and will be re-seeded, if appropriate, the following fall. Shrubs and trees will be assessed for establishment rate, survival, animal damage and need for protection, and potential need for replacement with new plants. Monitoring will continue over a period of 3 years to evaluate success in establishment, species composition, and percentage of plant cover. Noxious weeds will also be monitored for a minimum of 3 years, and will be eradicated if found on the site. "Soil cover" and "species presence" monitoring protocols will be used.

REVEGETATION UNITS

Five revegetation units plus source and waste areas were delineated for this project based on vegetation and soil field surveys. Subunits within 4 of the 5 units were delineated based on special treatment needs. The revegetation plan was developed based on existing disturbed, disturbed and recovered, and undisturbed reference sites for plant communities.

Climate

The project crosses through several distinct climate zones, often defined by distinct plant communities:

Lower Elevations (Revegetation Units 1, 2, 3). The beginning of the project (1,290 to 1,440 m [4,235 to 4,730 ft] elevation) has a climate similar to the towns of Bend or Sisters. The data collected at the weather stations in these towns show scant precipitation distributed relatively evenly throughout the year (Figure 8.1) with total annual rainfall between 12 and 14 in (30.5 and 35.5 cm). Typically, the melting snowpack recharges the soil profile in the spring; once plants become active, this moisture can become depleted quickly. Soil moisture is a limiting factor and seedling establishment should be approached with several objectives: 1) minimize soil moisture losses from evaporation by using surface mulch where possible; 2) keep competing vegetation away from planted seedlings by using surface mulch; 3) use deep-rooted, large container stock; 4) utilize two potential planting windows – in the fall after significant rains, or in the spring immediately after snowmelt and the soils are thawed. (Do not wait for higher soil temperatures.)

Snowpack is often gone by late winter. Frozen soils can extend into early spring. Soils must not be frozen when seedlings are planted.

The lower elevations have distinctly warmer daily temperatures than higher elevations; minimum daily temperatures are very similar (Figure 8.2). Microclimates created by landforms can make some portions of the lower elevations as cold as, or colder than, the higher elevations. Revegetation Unit 2, for example, sits on a flat with poor air flow. Cold area settles into this area creating an inversion or frost pocket. Where lodgepole pine is the dominant or only tree species present in an area, it is often an indicator that the site is very cold. In areas where the road traverses cinder cones or on gently sloping terrain, the air flow is greater, and minimum air temperatures are not as cold, nor is duration as long.

Lack of a continuous snowpack and the very cold temperatures on some sites can create problems for fall-planted trees. Trees that are planted in the fall will be subjected to extremely cold temperatures if they are not covered by snow. This can be a problem with newly planted

***Figure 8.1** – Precipitation for areas surrounding revegetation sites.*

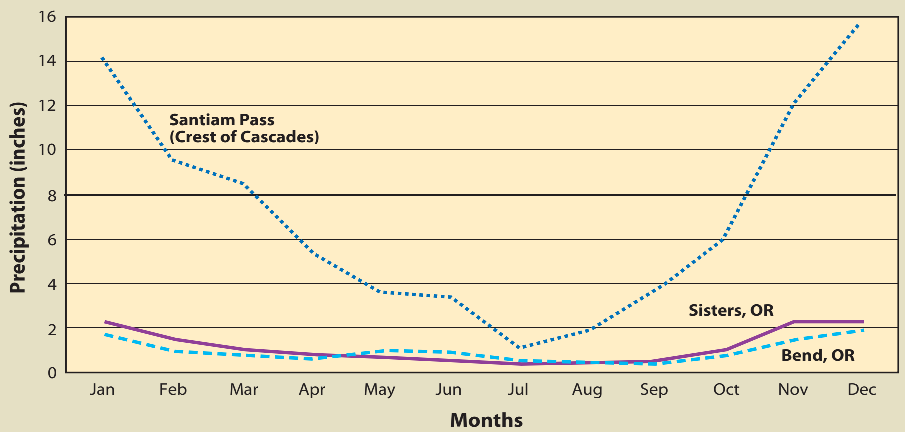
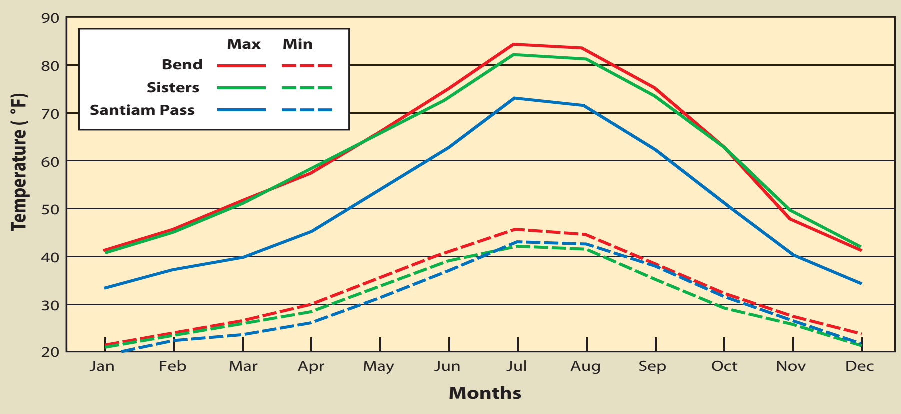


***Figure 8.2** – Minimum and maximum temperatures for areas surrounding revegetation sites.*



seedlings, especially during periods where soils are frozen and desiccating winds are high. Therefore, seedlings should be planted in late winter and early spring on these sites. Seeds can be sown either in the fall or early spring. If the seeds are sown in the early spring, they should be stratified for the required period before sowing and covered with a seedbed mulch or soil.

Higher Elevations (Revegetation Units 4 and 5). The revegetation units at the higher elevations (1,440 to 1,645 m [4,730 to 5,400 ft]) are greatly influenced by snowpacks. On typical years, snow has accumulated by November and can last into April or May. Snowpacks often insulate, or moderate, ground temperatures. Therefore seeds or seedlings placed in the fall can be protected from extreme temperatures and wind by a deep snowpack. Seeds that are sown in the fall and covered with a snowpack are protected, stratified, and ready to germinate as soon as the snowpack has melted. If conditions are right, soils might not freeze under a snowpack and seedlings can grow roots during late winter to early spring (observed at Chiloquin Highway). The preferred period for sowing seeds and planting seedlings at these higher elevations is in fall.

At higher elevations, high winds can restrict plant establishment, especially in Revegetation Unit 5. Without protection, tree establishment may be difficult. Planting seedlings behind down, woody material such as logs can help protect seedlings during establishment. Using tree shelters can also protect the seedlings from wind desiccation and should be considered on these sites.

Extreme surface temperatures are encountered on south slopes, especially in the spring. Temperature readings from iButton® data loggers (Maxim Integrated Products, Sunnyvale, CA) placed near the intersection of FS roads 45 and 46 showed daily temperatures close to 100 °F (38 °C). High temperatures can create very harsh conditions for seed germination. On these sites, mulch should be considered. Shredded wood fibers will have stability on south slopes and create favorable conditions for seed germination.

On steep north slopes, soils thaw much later than south slopes. Soil moisture is maintained longer on north slopes, so soils are more prone to the effects of freeze-thaw cycles or frost heaving. On steep slopes, this can make the surface soil very unstable. Seeds that are in the process of germinating on these sites will move downslope. One option is the application of surface mulch that would stabilize the surface so seeds can germinate in a more stable seedbed.

Soils

Soils are derived from pumice parent material. These soils are unique in that they have low bulk densities, are single-grained, and have low cohesion. Since these soils are derived from recent volcanic activity, they are young with very little development. Nutrient levels are in the lower ranges for plants. In many areas, the soils are deep, equating to a high moisture supply for seedlings with deep roots.

Soil Nutrients: Table 8.4 shows four sites where topsoil will be removed, stored, and reapplied. Samples were taken uniformly from the 1 to 23 cm (0.4 to 9.0 in) surface horizon and represent a composite sample of soils. These results show the soils have low coarse fragment composition with loamy sand texture, a mildly acid pH (6.1 to 6.4), and low salt levels. Organic matter is between 3% and 4%, which is acceptable; total N is low for forest lands. Calcium and boron are low, and fertilizers or soil amendments containing these elements could be beneficial to plant growth. Soil testing should be done in reference areas and during construction to determine soil amendment rates.

Fertilizing: Commercially available fertilizers (nitrogen, potassium, and phosphorus) are unnecessary on abandoned road sites where trees are planted. Species such as lodgepole pine require very little nitrogen. On sites where mulch is being applied, nutrients should be available as the mulch decomposes. Application of mycorrhizal fungi, either at the nursery or in the planting hole, will assure that the seedlings are well colonized with appropriate beneficial fungi. This will help increase seedling access to soil water and nutrients. If seedlings show nutrient deficiencies at a later point in their development, fertilizers can be surface-applied around each seedling instead of broadcast.

For sites to be seeded, fertilizers can be beneficial. However, high applications of fast-release fertilizer in the first year (e.g., ammonium nitrate) can encourage the establishment of weedy or undesirable plants. Therefore, seeds should be sown in the first year without fertilizers and allowed to become established. Slow-release fertilizers can be applied in spring of the following year based on soil analysis. Products such as Biosol® and Fertile Fiber are good products to use. Since the disturbed sites on this project will be low in nitrogen, applying as much nitrogen by the second or third years, in this form, could be beneficial to establishing long-term native plant communities. Higher application rates of slow-release fertilizers are possible on the low elevation sites because lower precipitation presents less likelihood of deep leaching of nitrogen. Also, cold soil temperatures throughout much of the year mean the slow-release fertilizers will not decompose as fast and release nutrients. As the slow-release fertilizers break down, nutrients are taken up by the well-established native plants that convert the readily available nutrients into biomass, boosting nutrient cycling.

Topsoil Storage: It will be necessary to ensure that topsoil is free of seeds from undesirable vegetation. When possible, schedule work to accommodate the following:

- Topsoils are stockpiled when dry;
- Storage periods are kept to a minimum;
- Stockpiles are protected from becoming wet in the winter; and
- Weed establishment around stockpiles is avoided.

Covering the piles with plastic will help keep piles from becoming wet, and also prevent weed establishment. When reapplying topsoil, avoid mixing the topsoil with any of the subsoil material.

Revegetation Unit 1

Description – This unit is 2,600 m (8,535 ft) in length – between stations 0+200 and 2+810 and located from 1,290 to 1,320 m (4,235 to 4,340 ft) elevation on a south aspect. Vegetation consists of ponderosa (*Pinus ponderosa*) and lodgepole pine (*P. contorta*) with a bitterbrush (*Purshia tridentata*) understory. The main revegetation unit consists entirely of minor cut and fill slopes, where the cuts predominately have slopes of 1V:3H and the fills have slopes of 1V:4H. The cut and fill slopes total approximately 16,700 m^2 (4.1 ac).

Site Limitations – Summer conditions are hot and dry, and evapotranspiration is high. The soil is loamy sand, which has low water-holding capacity, and can be hydrophobic in the summer. Gophers may be a problem.

Revegetation Objectives – Revegetation objectives are visual to blend with the surrounding forest stands and openings.

Treatments – This unit should become revegetated fairly quickly. A mix of species, including squirreltail (*Elymus elymoides*), western needlegrass (*Achnatherum occidentale*), Pacific lupine (*Lupinus lepidus*), silverleaf phacelia (*Phacelia hastata*), and rabbitbrush (*Ericameria bloomeri*) will be seeded. Scarlet gilia (*Ipomopsis aggregata*) and glaucous beardtongue (*Penstemon euglaucus*) may be added to the mix on the larger, more visible cut slopes. For gentle slopes (1V:5H or less), the seed mix will be applied with ground-based spreaders and covered with soil in late fall. The method to cover seeds will be determined later.

On all steep cut and fill slopes, hydroseeding (using the same seed mix) with 2,000 lb/ac mulch and tackifier will be applied in early fall.

This unit also contains 3 special subunits requiring additional treatments (Table 8.5).

Subunit 1.F.1. The majority of the fill will receive the same treatment as the overall Unit 1. The bottom of the fill, beginning 18 m (60 ft) from the road centerline, will be planted with Q-plug+1 ponderosa pine with a spacing of 3 x 3 m (10 x 10 ft) in a natural random pattern.

Subunit 1.A.1. This unit is a decommissioned road with only 1 entrance onto the main road. Once the road surface has been removed and subsoiled, planting islands will be established to blend with the surrounding forest type. Approximately 8 cm (3 in) of (contractor-supplied) mulch will be applied in 6 m (20 ft) diameter islands (approximately 14.5 m^3 [19 yd^3] of material per unit 1.A.1). Following mulch application, ponderosa pine will be planted into the established planting islands. The trees will be a combination of larger potted (4 l [1 gal]) trees at the entrance into the road, and smaller (Q-plug+1) trees throughout the rest of the unit.

Subunit 1.C.1. The majority of the cut will receive the same treatment as the overall Unit 1. Beginning 14 m (45 ft) from the road centerline, approximately 8 cm (3 in) of mulch will be applied to the cut slope (approximately 46 m^3 [60 yd^3] of material). Bitterbrush grown in

***Table 8.4** – Soil test results for four undisturbed sites that are proposed topsoil sources.*

Soil Parameter	Test	Units	20+960	18+800	18+640	14+620
Site Condition			Undisturbed	Undisturbed	Undisturbed	Undisturbed
Sampling Depth		cm	1-23	1-23	1-23	1-23
Texture	estimated	USDA	loamy sand	loamy sand	loamy sand	loamy sand
Rock Fragments	sieve	%	15	15	15	15
pH	saturated paste		6.4	6.1	6.4	6.2
Bulk Density	estimated	gr/cc	0.9	0.9	0.9	0.9
Salts (uS/cm)	saturated paste	uS/cm	0.75	0.74	0.66	0.6
C:N	calculated		20	26	23	21
Sol. Ca:Mg	calculated		0.86	1.49	0.00	0.76
Fe:Mn	calculated		11.50	7.66	4.30	8.24
Organic Matter		%	3	4.1	4.4	3.7
		lbs/ac	135,441	163,326	175,277	147,392
Total C	LECO	%	2	2.91	3.39	2.55
		lbs/ac	80,000	116,000	135,000	101,000
Total N	LECO	%	0.1	0.11	0.15	0.12
		lbs/ac	398	438	597	478
Available N (nitrate)	2N KCl extract	mg/kg	2.49	2.68	2.33	3.44
		lbs/ac	10	11	9	14
% Nitrate Release	calculated		2.513	2.511	1.508	2.929
Total P	Olsen $NaHCO_3$	mg/kg	5.3	5.1	9.8	5.5
		lbs/ac	21	20	39	22
Available K	saturated paste		2.9	1.96	4.9	4.9
		lbs/ac	12	8	20	20
Total K	Olsen $NaHCO_3$	mg/kg	58	47	105	96
		lbs/ac	231	187	418	382
Available Ca	saturated paste	mg/l	0.3	0.7	0	0.34
		lbs/ac	1.2	2.8	0	1.4
Available Mg	saturated paste	mg/l	0.35	0.47	0.45	0.45
		lbs/ac	1.4	1.9	1.8	1.8
Available Na	saturated paste	mg/l	8.77	11.4	8.46	9.76
		lbs/ac	35	45	34	39
Available S	saturated paste	mg/l	0.75	1.54	0.98	1.09
		lbs/ac	3	6.1	3.9	4.3
Sulfate S	Olsen $NaHCO_3$	mg/l	17.10	15.50	13.00	1.45
		lbs/ac	68	62	52	6
Available B	saturated paste	mg/l	0.02	0.02	0.01	0.02
		lbs/ac	0.10	0.10	0.00	0.10
Zinc	Olsen $NaHCO_3$	mg/l	0.31	0.36	0.81	0.41
		lbs/ac	1	1	3	2

D40 Deepot™ containers will be out-planted into this area with a 3 x 3 m (10 x 10 ft) spacing (avoiding grid planting).

Desired Future Condition – Native grass and forb species will occupy 15% of ground cover 12 months after seeding and over 40% after the second year. NPDES permit requires establishment of plant ground cover of at least 70% of the surrounding natural vegetative cover.

Approximately 12 months following road decommission, the conifer seedlings will have been planted on the abandoned road area at a rate of approximately 445 trees/ac (1,100 trees/ha), with heavier concentrations at the beginning of the decommissioned road. At the end of 5 years, this area should have an overall tree stocking at a minimum 250 trees/ac (620 trees/ha).

Monitoring Protocol – Photopoint monitoring will be conducted in the fall of the first and third years following seeding throughout the main unit.

Survival on the planted subunits will be monitored within planting islands. Ten percent of planting islands will be monitored in the first, third, and fifth years.

Noxious weeds will be monitored for a minimum of 3 years and will be eradicated if found on the site.

Data Gaps – Do we need mulch to germinate and establish seedlings? Test in 2004 did not show a difference.

Does wood straw or shredded wood fiber increase surface moisture during germination, therefore increasing germination and establishment?

Does time of sowing make a difference in germination and establishment? Current practice is fall sowing. Would stratified seeds hydroseeded in spring establish as well or better than fall?

Revegetation Unit 2

Description – This unit is 7,400 m (24,280 ft) in length – between 2+800 and 10+200, and located from 1,320 to 1,365 m (4,340 to 4,480 ft) elevation on a mostly flat gradient. The vegetation consists of lodge-pole pine and small amounts of ponderosa pine, with bitterbrush and glaucus penstemon predominating in the understory. The stands are mixes of regeneration cuts, openings, and islands of dense lodgepole pine. The main revegetation unit consists of minor cut and fill slopes, where the cuts have slopes of 1V:2H to 1V:3H and the fills have slopes of 1V:4H. The cut and fill slopes total approximately 35,040 m^2 (8.7 ac).

Site Limitations – The soil is loamy sand, which has low water-holding capacity and can be hydrophobic. Summer conditions are warm and dry. The unit has definite low-lying frost pockets. Gophers may be a minor problem.

Considering the high recreational use in this area, establishment of vegetation on the abandoned road areas may be difficult. Any forest opening on the Deschutes will become heavily used by off-highway vehicles (OHVs) and snowmobiles, which will impede survival and establishment of vegetation in these areas.

Revegetation Objectives – The Sunriver to Mt. Bachelor highway is used most heavily for recreational traffic during both the summer and winter seasons. Revegetation objectives are visual – that is, to maintain a grass and forb community to blend with the surrounding forest stands and openings. In addition, the reclaimed road bed should contain the same species mix (both overstory and understory) as the surrounding forest stands.

Desired Future Condition – Approximately 12 months following road reconstruction, a mix of low-growing grass and forb species will have begun to establish throughout the main unit. The same mix will be present at the end of 3 years. NPDES permit requires establishment of plant ground cover of at least 70% of the surrounding natural vegetative cover.

Approximately 12 months following road decommission, a mix of conifer and shrub species will have been planted on the abandoned road area at a rate of approximately 1,010 trees/ac (2,500 trees/ha) overall, with heavier concentrations of conifer species at each end of the decommissioned road. At the end of 5 years, this area should contain the same mix of species, with overall tree stocking at approximately 500 trees/ac (1,240 trees/ha).

Treatments – Due to the possibility of frost pockets and the hydrophobic soils, this area may be somewhat slower to revegetate than unit 1. Squirrel tail, western needlegrass, prairie lupine, glaucous penstemon, and golden rabbitbrush will be seeded onto this unit. Scarlet gilia, Oregon

Table 8.5 – *Special subunits for Revegetation Unit 1.*

Subunit #	Location	Predominant Landform	Approximate treatment area (m^2)	Approximate treatment area (ac)
1.F.1	0+280 to 0+360	Fill slope	400	0.10
1.A.1	0+580	Abandoned road	700	0.17
1.C.1	1+500 to 1+600	Cut slope	600	0.15

sunshine (*Eriophyllum lanatum*), and/or silvery lupine (*Lupinus argenteus*) may be added to the mix on the larger cut slopes. For all slopes less than 1V:3H slopes, the seed mix will be applied and harrowed in late fall. Shredded wood mulch without tackifier or compost may be used on some of the larger fill slopes.

On slopes greater than 1V:3H, hydroseeding (using the same seed mix) with 1,000 lb mulch and tackifier will be applied in late fall. Since wind is not a large factor in this area, some smaller cut slopes may be hydroseeded without mulch or tackifier.

This unit contains 1 special subunit requiring additional treatments (Table 8.6).

Unit 2.A.1. This unit is a large section of decommissioned road with 3 entrances onto the main road. Once the road surface has been removed and subsoiled, planting islands will be established to blend with the surrounding forest type. Approximately 8 cm (3 in) of (contractor-supplied) mulch will be applied in 6 m (20 ft) diameter islands (approximately 112 m^3 [146 yd^3] of material). Following mulch application, a mix of lodgepole and ponderosa pine will be planted into the unit. The trees will be a combination of larger container (4 l [1 gal]) trees at the entrance into the road, and smaller (Q-plug+1) trees throughout the rest of the unit. Heavier planting will occur at the beginning and end of the decommissioned areas. All planting will mimic the surrounding stand mosaic, and will not resemble a grid planting.

Monitoring Protocol – Photopoint monitoring will be conducted in the fall of the first and third years for cut and fill slopes. Survival on the planted subunits will be monitored within planting islands. Ten percent of planting islands will be monitored in the first, third, and fifth years.

Noxious weeds will be monitored for a minimum of 3 years and will be eradicated if found on the site.

Data Gaps – Effectiveness of using wood straw or mulch without tackifier with native species seeds on the east side of the Cascades is unknown. Effectiveness of hydroseeding without mulch with native species is unknown.

Revegetation Unit 3

Description – This unit is 2,900 m (9,510 ft) in length – between 10+200 and 12+100 and located from 1,365 and 1,440 m (4,480 to 4,730 ft) elevation on south- to southwest-facing slopes. This area is a warmer site than revegetation unit 1 or 2, with better air drainage, and is located at the base of a cinder cone. The overstory is ponderosa pine and small amounts of lodgepole pine, with bitterbrush, snowbrush ceanothus (*Ceanothus velutinus*), and greenleaf manzanita (*Arctostaphylos patula*) in the understory. The revegetation unit consists entirely of cut and fill slopes. The cuts have slopes of 1V:2H to 1V:3H and the fills have slopes of 1V:4H. The cut and fill slopes total approximately 8,260 m^2 (2 ac).

Site Limitations – Summer conditions are hot and dry, and evapotranspiration is high. This unit is located at the base of a cinder cone, and there are large outcroppings of lava rock.

Revegetation Objectives – The Sunriver to Mt. Bachelor highway is used most heavily for recreational traffic during both the summer and winter seasons. Revegetation objectives are visual – that is, to maintain a grass, forb, and shrub community to blend with the surrounding forest stands and openings.

Desired Future Condition – Approximately 12 months following road reconstruction, a mix of low-growing grass and forb species within 10 m (30 ft) of the road edge, and a mix of taller forbs and shrubs from 10 to 20 m (30 to 65 ft) from the road edge will have begun to establish throughout the unit. The same mix will be present at the end of 3 years. NPDES permit requires establishment of plant ground cover of at least 70% of the surrounding natural vegetative cover.

Treatments – None of the fill or cut slopes are particularly large, and the unit should be revegetated by the local seed bank fairly quickly. Hydroseeding will be minimal, and only a small number of species will be included in this mix. The mix should include squirrel tail, Idaho fescue (*Festuca idahoensis*), glaucous penstemon, and golden rabbitbrush for this unit. For fill slopes, the seed mix will be applied and harrowed in late fall. Hydroseeding will occur on cut slopes, but mulch or tackifier may not be necessary due to lack of wind through this area.

Monitoring Protocol – Photopoint monitoring for soil cover will be conducted in the fall of the first and third years for cut and fill slopes.

Noxious weeds will be monitored for a minimum of 3 years and will be eradicated if found on the site.

Data Gaps – Effectiveness of using hydroseeding without mulch or tackifier with native species seeds on the east side of the Cascades is unknown.

Revegetation Unit 4

Description – This unit is 4,200 m (13,780 ft) in length between stations 12+100 and 16+300, and located from 1,440 to 1,584 m (4,730 to 5,200 ft) elevation. The unit is somewhat colder than unit 3, with the overstory consisting of a mix of ponderosa and lodgepole pine, with bitterbrush, ceanothus, greenleaf manzanita, and wax currant (*Ribes cereum*) predominating in the understory. The revegetation unit consists cut and fill slopes and 3 sections of abandoned road. The cuts have slopes of 1V:2H to 1V:3H and the fills have slopes of 1V:4H. The cut and fill slopes total approximately 34,760 m^2 (8.6 ac).

Site Limitations – Summer conditions are hot and dry, and evapotranspiration is high. The topsoil is thin in many areas, with bedrock close to the surface and many lava outcrops.

Considering the high recreational use in this area, establishment of vegetation on the abandoned road areas may be difficult. Any forest opening on the Deschutes will become heavily used by OHVs and snowmobiles, which will impede survival and establishment of vegetation in these areas.

Revegetation Objectives – The Sunriver to Mt. Bachelor highway is used most heavily for recreational traffic during both the summer and winter seasons. In addition, this unit contains the area around Edison Butte Sno-Park, which is heavily used for hiking and cross-country skiing. Revegetation objectives are visual – that is, to maintain a grass, forb, and shrub community to blend with the surrounding forest stands and openings. The reclaimed road beds should contain the same species mix (both overstory and understory) as the surrounding forest stands.

Table 8.6 – *Special subunit for Revegetation Unit 2.*

Subunit #	Location	Predominant Landform	Approximate treatment area (m^2)	Approximate treatment area (ac)
2.A.1	3+300 to 3+550	Abandoned road	3,900	0.96

Desired Future Condition – Approximately 12 months following road reconstruction, a mix of low-growing grass and forb species will have begun to establish throughout the unit. The same mix will be present at the end of 3 years with better coverage. NPDES permit requires establishment of plant ground cover of at least 70% of the surrounding natural vegetative cover.

Within 12 to 18 months following road decommission, a mix of conifer and shrub species will have been planted on the abandoned road areas. Depending on the subunit, initial stocking will range from 445 to 1,010 trees/ac (1,100 to 2,500 trees/ha), with heavier concentrations of conifer species at each end of the decommissioned roads. At the end of 5 years, this area should contain the same mix of species, with overall tree stocking ranging from 250 to 500 trees/acre (620 to 1,240 trees/ha).

Treatments – This unit may require more time to regenerate because it is somewhat colder than the previous units, and contains a mix of plant associations. Both cut and fill slopes will be hydroseeded with 1,000 lb mulch and tackifier; wind is an issue in this area. Since this area includes the Sno-Park, which receives somewhat heavier use in the summer, the hydroseed mix will be slightly different than the other units – that is, it will include a few more forb species for visual enhancement. The seed mix will include squirreltail, western needlegrass, prairie lupine, silvery lupine, white leaf phacelia, glaucous penstemon, and Oregon sunshine. Hayblowing with squirrel tail may also be used on the fills.

This unit contains 7 special subunits requiring additional treatments (Table 8.7).

Unit 4.A.1. This unit is a decommissioned road that will run beside the main road. Once the road surface has been removed and subsoiled, planting islands will be established to blend with the surrounding forest type. Approximately 8 cm (3 in) of contractor-supplied mulch will be applied in 6 m (20 ft) diameter islands (approximately 21 m^3 [27 yd^3] of material). Following mulch application, ponderosa pine (Q-plug+1) will be planted into the unit.

Unit 4.A.2. This unit is a decommissioned road with 2 entrances onto the main road. Once the road surface has been removed and subsoiled, planting islands will be established to blend with the surrounding forest type. Approximately 8 cm (3 in) of (contractor-supplied) mulch will be applied in 6 m (20 ft) diameter islands (approximately 17.5 m^3 [23 yd^3] of material). Following mulch application, a combination of ponderosa pine (q-plug+1) and ceanothus (D60 Deepot™ plugs) will be planted into the unit.

Unit 4.A.3. This unit is a decommissioned road with 2 entrances onto the main road. Once the road surface has been removed and subsoiled, planting islands will be established to blend with the surrounding forest type. Approximately 8 cm (3 in) of contractor-supplied mulch will be applied in 6 m (20 ft) diameter islands (approximately 86 m^3 [112 yd^3] of material). Following mulch application, a combination of lodgepole and ponderosa pine and ceanothus will be planted into the unit. The trees will be a combination of larger potted (4 l [1 gal]) lodgepole pine trees at the entrance into the road, and smaller lodge-pole and ponderosa pine (Q-plug+1) trees and ceanothus (D60 Deepot™) throughout the rest of the unit with an approximate 3 x 3 m (10 x 10 ft) spacing for the trees and 2 x 2 m (6.6 x 6.6 ft) spacing for the ceanothus (avoiding grid planting).

Unit 4.C.1. This unit is a larger cut slope below a clearcut. The soil is shallow granitic, with bedrock close to the surface. The majority of the cut will receive the same treatment as the overall Unit 4. Beginning 18 m (60 ft) from the road centerline, ceanothus grown in D60 Deepot™ containers will be out-planted into this area on approximately 3 x 3 m (10 x 10 ft) spacing.

Unit 4.A.4. This unit is a decommissioned road with 2 minor entrances onto the main road (but with the reclaimed area running fairly close to the new road). Once the road surface has been removed and sub-soiled, planting islands will be established to blend with the surrounding forest type. Approximately 8 cm (3 in) of (contractor-supplied) mulch will be applied in 6 m (20 ft) diameter islands (approximately 21 m^3 [28 yd^3] of material). Following mulch application, a combination of ponderosa pine (Q-plug+1) trees and ceanothus (D60 Deepot™ plugs) will be planted throughout the unit.

Unit 4.F.1. This unit is a large fill section. The majority of the fill will receive the same treatment as the overall Unit 1. The bottom of the fill, beginning 18 m (60 ft) from the road centerline, will be planted with ceanothus (D60 Deepot™ plugs) on approximately 3 x 3 m (10 x 10 ft) spacing.

Unit 4.A.5. This unit is a visible decommissioned road with 2 highly visible entrances onto the main road. The small stand of lodgepole pine should be maintained between the new and old road. If possible, the stand should be thinned, mulched, and fertilized for the first 1 to 2 years to encourage growth for visuals. Once the road surface has been removed and subsoiled, planting islands will be established to blend with the surrounding forest type. Approximately 8 cm (3 in) of (contractor-supplied) mulch will be applied in 6 m (20 ft) diameter islands (approximately 97 m^3 [127 yd^3] of material). Following mulch application, a combination of lodgepole and ponderosa pine will be planted into the unit. The trees will be a combination of larger potted (4 l [1 gal]) lodgepole pine trees at the entrance into the road, and smaller lodgepole and ponderosa pine

(Q-plug+1) trees throughout the rest of the unit. Use of larger trees transplanted with a tree spade may be considered for the decommissioned "entrances" for this unit.

Monitoring Protocol – Photopoint monitoring will be conducted in the fall of the first and third years following seeding throughout the main unit. Survival on the planted subunits will be monitored within planting islands. Ten percent of planting islands will be monitored in the first, third, and fifth years.

Noxious weeds will be monitored for a minimum of 3 years and will be eradicated if found on the site.

Data Gaps – Effectiveness of using hydroseeding and mulch with native species seeds on the east side of the Cascades is unknown.

Revegetation Unit 5

Description – This unit is 5,423 m (17,800 ft) in length – between 16+300 and 21+723 and located from (1,585 to 1,645 m (5,200 to 5,400 ft) elevation. The overstory species in the unit grade from a mix of ponderosa and lodgepole pine, through an area containing ponderosa, lodgepole, western white (*Pinus monticola*), and whitebark (*P. albicaulis*) pines, mountain hemlock (*Tsuga mertensiana*), white fir (*Abies concolor*), and subalpine fir (*A. lasiocarpa*), to the higher elevation portion containing subalpine fir and lodgepole pine. The understory vegetation grades from ceanothus, greenleaf manzanita, and wax currant to pinemat manzanita (*Arctostaphylos nevadensis*), *Carex inops*, and bottlebrush squirreltail (*Elymus elymoides*). The revegetation unit consists of cut and fill slopes and 2 sections of abandoned road. The cuts predominately have slopes of 1V:2H to 1V:3H and the fills have slopes of 1V:4H. The cut and fill slopes total approximately 46,660 m^2 (11.5 ac).

Site Limitations – Summer conditions are hot and dry, and evapotranspiration is high. The topsoil is thin in many areas, with bedrock close to the surface. The higher elevation portions of the unit (close to the upper end of the project) are subject to wind damage.

Considering the high recreational use in this area, establishment of woody vegetation on the abandoned road areas may be difficult. Any forest opening on the Deschutes will become heavily used by OHVs and snowmobiles, which will impede survival and establishment of vegetation in these areas.

Revegetation Objectives – The Sunriver to Mt. Bachelor highway is used most heavily for recreational traffic during both the summer and winter seasons. Revegetation objectives are visual – that is, to maintain a grass and forb community to blend with the surrounding forest stands and openings. In addition, the reclaimed road bed should contain the same species mix (both overstory and understory) as the surrounding forest stands. NPDES permit requires establishment of plant ground cover of at least 70% of the surrounding natural vegetative cover.

***Table 8.7** – Special subunits for Revegetation Unit 4.*

Subunit #	Location	Predominant Landform	Approximate treatment area (m^2)	Approximate treatment area (ac)
4.A.1	14+260 to 14+350	Abandoned road	540	0.13
4.A.2	14+470 to 14+560	Abandoned road	720	0.18
4.A.3	14+600 to 14+860	Abandoned road	3,000	0.74
4.C.1	14+800 to 14+840	Cut slope	320	0.08
4.A.4	15+200 to 15+300	Abandoned road	1,000	0.25
4.F.1	15+700 to 15+840	Fill slope	840	0.21
4.A.5	16+150 to 16+420	Abandoned road	4,050	1.00

Desired Future Condition – Approximately 12 months following road reconstruction, a mix of low-growing grass and forb species will have begun to establish throughout the main unit. The same mix will be present at the end of 3 years at higher coverage.

Approximately 12 months following road decommission, a mix of conifer and shrub species will have been planted on the abandoned road area at a rate of approximately 445 trees/ac (1,100 trees/ha) overall, with heavier concentrations of conifer species at each end of the decommissioned roads. At the end of 5 years, this area should contain the same mix of species, with overall tree stocking at approximately 250 trees/ac (620 trees/ha).

Treatments – This unit may require a longer period to regenerate. It is colder than the previous units, and contains a mix of plant associations. Both cut and fill slopes will be hydroseeded with 1,000 lb/ac mulch and tackifier, since wind is an issue in this area. The hydroseed mix will be slightly different than the other units. The seed mix will include squirrel tail, mountain brome (*Bromus carinatus*), silvery lupine, glaucous beardtongue, and silverleaf phacelia. If it is possible to use chopped pieces of *Carex inops* roots, this species will be included in the hydroseeding mix. Hayblowing with squirrel tail may also be used on the fills.

Monitoring Protocol – Photopoint monitoring will be conducted in the fall of the first and third years following seeding throughout the main unit. Survival on the planted subunits will be monitored within planting islands. Ten percent of planting islands will be monitored in the first, third, and fifth years.

Noxious weeds will be monitored for a minimum of 3 years and will be eradicated if found on the site.

Data Gaps – Effectiveness of using hydroseeding and mulch with native species seeds on the east side of the Cascades is unknown. Effectiveness of spreading *Carex* spp. root systems via hydroseeding is unknown.

Note: The Forest Service is responsible for the revegetation of both source and waste areas associated with the project. Upon final selection of these areas, a revegetation plan will be formulated specifically for each selected site in accordance with environmental conditions.

***Table 8.9** – Revegetation cost estimates for Sunriver to Mt. Bachelor project.*

Project Phase	Sub-Phase	Cost Category	Person Days	Cost per Day	Total Cost
Planning	I.	Pre-field project orientation and planning: reviewing PIR, map-making, research & development contacts, project assignments	5	$300.00	$1,500.00
	II.	Field visits, scheduled meetings, Forest staff time, technology/product research. Travel, walk site, source and waste areas, locate reference sites develop species list, map noxious weeds, identify potential collection sites, water sources for hydroseeding.	20	$300.00	$6,000.00
	III.	Synthesize field data, develop site recommendations and draft revegetation prescriptions, develop timeline and make plans for seeds	10	$300.00	$3,000.00
	IV.	Arrange for seed collections and propagation	3	$300.00	$900.00
	V.	Finalize revegetation plan	8	$300.00	$2,400.00
Plant Materials	I.	Oversee seed collection/ procurement, seed increase and seedling production	8	$300.00	$2,400.00
	II.	Seed purchase (see plant material costs table)			$25,845.00
	III.	Seedling purchase (see plant material costs table)			$9,500.00
	IV.	Mulch purchase/application ($40/ application yd^3 x 863)			$34,520.00
Implementation/ Monitoring	I.	Final site assessment/evaluation	1	$300.00	$300.00
	II.	Storage, transport and staging of plant materials			$1,000.00
	III.	Application/planting costs			
		a) Hydroseeding ($3,000/ac x 35 ac)			$70,000.00
		b) Hand planting shrubs and trees ($2.00/plant x 4,860)			$9,720.00
		c) Field contract administration	30	$300.00	$9,000.00
	IV.	Monitoring			
		a) Establishment phase	10	$300.00	$3,000.00
		b) Effectiveness phase	10	$300.00	$3,000.00
		c) Noxious weeds	5	$300.00	$1,500.00
		d) Final report	3	$300.00	$900.00
	V.	Administrative oversight	6	$400.00	$2,400.00
Total Cost	I.	Total Days Budgeted	119		
	II.	Total Salary		**$36,300.00**	
	III.	Vehicle costs ($10/day + $0.445/mi)			$3,800.00
	IV.	Misc. materials and supplies			$1,500.00
	V.	Per Diem (70 days x $150)			$10,500.00
	VI.	Revegetation Cost			**$202,685.00**
	VII.	Total Revegetation Cost w/ overhead			**$205,077.00**

9 IMPLEMENTATION

9.1 INTRODUCTION

A successful revegetation project requires not only good planning, but effective implementation of the plan. The Initiation Phase of this report (Chapters 2 and 3) described the organizations, decision processes, and technical concepts involved in beginning a roadside revegetation project. The Planning Phase (Chapters 4 through 7) culminated in the Revegetation Plan, combining strategies for mitigating limiting factors, utilizing site resources, and revegetating the site. Now, in the Implementation Phase, the plan will unfold in the field.

The shift from the Planning Phase to the Implementation Phase involves a change in approach. The planning process tends to be orderly and systematic, with the planner able to take an idealized bird's eye perspective of how the project might best proceed. In contrast, implementation is approached from the ground up, and requires flexibility and adaptability in order to fulfill the objectives of the plan while working with the unpredictable realities of the field.

While the plan guides the project, few projects are implemented exactly as planned. Each project is unique, with its own set of issues and challenges. Schedules and supplies change, unforeseen circumstances intrude, and new opportunities emerge. Teamwork, cooperation, and effective communication with project managers and inspectors will enable the revegetation specialist to utilize all available resources to make the revegetation plan successful. Good planning and a systematic approach to implementation lay the groundwork to acquire necessary materials to revegetate the site, including services, seeds, topsoil, and nursery-grown plants. In the Implementation Phase, flexibility, adaptability, and creativity in obtaining and installing these materials will be important. For example, seed mixes, application rates, and installation methods might have to be modified due to new information or unforeseen circumstances. Lessons learned can lead to new and innovative approaches to revegetation.

The tasks for successfully implementing a revegetation plan are to:

1) Review plans with construction engineer,
2) Review revegetation treatment details and timelines,
3) Develop contracts,
4) Install treatments,
5) Keep good records,
6) Carry out quality control, and
7) Implement early maintenance and monitoring.

This chapter is a general overview of the implementation process. Following this chapter, Implementation Guides provide details on the key factors to consider, including soil and site treatments, obtaining plant materials, and installing and caring for plants.

9.2 REVIEW PLANS WITH CONSTRUCTION ENGINEER

The Initiation Phase highlighted the key working relationships for the revegetation specialist to develop during the revegetation process. For some projects, the same engineer will be the contact from project inception through its completion. For more complex projects, the design engineer may hand off the road plans for the construction engineer to implement. Regardless, the engineer who will be on-site during road construction is an essential relationship for implementing a successful revegetation plan. A relationship with both staffs is essential. The design engineer will assure that revegetation plans are designed into the construction plans, schedules, materials lists, and so on. The construction engineer, who will be on site during all phases of road construction, will interpret and implement designs with the input and interpretation of the revegetation specialist. Complex designs, such as soil-faced gabion walls, planting pockets, plantable rockeries, and so on, require more involvement from all participants.

The construction engineer can greatly facilitate all aspects of revegetation by providing construction timelines by road segment, modifications, updates, site specific information, and treatments by segment. The construction engineer can also help with techniques, experience, and equipment, and assure that any special contract requirements are upheld and implemented correctly. Remember that the Implementation Phase for revegetation begins prior to road construction and continues after construction is complete, so if there are two separate engineers, activities must be coordinated with both.

Before construction begins, a meeting should be scheduled with the construction engineer to discuss the Revegetation Plan. This meeting will cover the objectives for revegetation and the tasks that need to be coordinated with road construction activities. The revegetation plan should be taken to the project site and issues that might be associated with the various revegetation tasks should be discussed. The construction engineer needs to be aware of all details of the revegetation treatments and how they are to be implemented. Plan on-site project reviews early to discuss plans and allow ample time to overcome difficulties in integrating construction and revegetation design. Identify and assess potential areas of conflict between road construction activities and revegetation objectives. Review these potential conflicts one-by-one, and discuss ways to resolve them. Special contract requirements (discussed in Chapter 2) should also be reviewed. These may cover topics such as topsoil salvage, slope treatments, or other key practices. The construction engineers will also have ideas that can help translate revegetation plans to construction contractors.

Of course, it is best to minimize site disturbances in the first place. During the Planning Phase, collaboration with the design engineer is essential in potentially reducing the size of the construction footprint of the project. The construction engineer can often identify opportunities for reducing potential problems, in some cases, making changes that can modify or even eliminate certain construction or revegetation treatments.

During these meetings, it is critical to respect and learn from the experience and insights of the construction engineer. They may have worked with revegetation treatments on other road projects and could have ideas on installation methods on the current project. There are many ways to achieve revegetation objectives; collaboration between the construction engineer and the revegetation specialist will always create the best results. With your combined expertise, new and innovative approaches can also be created.

After the development of treatment details and timelines, another meeting should be scheduled to get the construction engineer's input and to double-check quantities, areas, supplies, and equipment for revegetation treatments. As road construction proceeds, periodic meetings should be scheduled to discuss conflicts and refine revegetation plans.

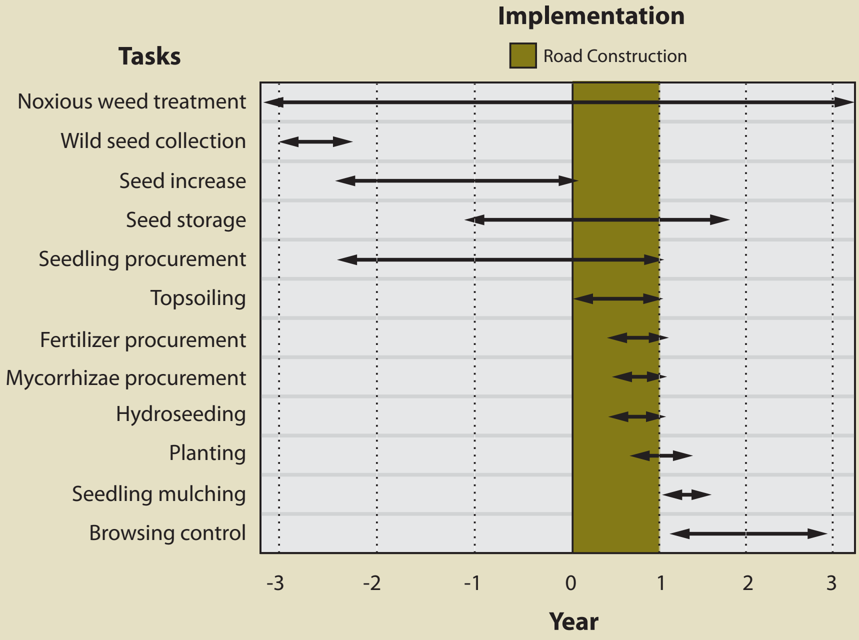
Before road construction begins, roles and responsibilities on the job site need to be clearly defined. Refer to procedural manuals for the agencies involved and make sure you follow their chain of authority. The revegetation specialist must coordinate directly with the construction engineer. The construction engineer will be directing all phases of road construction, and you must always ask permission to communicate directly with any of the contractors. Remember, your role as a revegetation specialist is not to direct the construction contractors, but to play an advisory role so that all contract requirements can be carried out effectively and on schedule.

The more that you are on site during all phases of construction, the stronger your relationships with the construction engineer and construction contractors will be. These strong working relationships will ensure that all revegetation plans will be implemented successfully. Sometimes, spur-of-the-moment meetings must be called to address immediate problems or to adapt to shifting tactics. You must understand that all road projects will not go exactly as planned, so be as responsive as possible.

9.3 REVIEW TREATMENT DETAILS AND TIMELINES

The Revegetation Plan will outline all of the treatment details, quantities, and schedules for the project. However, details often need to be revised or defined more specifically. Accurate and reasonable calculations and schedules will help the revegetation specialist collaborate more effectively with contractors and agency suppliers. At this stage of the process, you should refine calculations and timelines in sufficient detail to begin the contracting process. Calculating and rechecking areas to be treated, needed equipment and supplies, and schedules and budgets will ensure that contracted items are accurately identified and defined.

***Figure 9.1** – Example implementation timeline. Implementing the revegetation plan often requires separate schedules and different contractors, so coordination is essential.*



In general, four types of implementation activities take place in revegetation, and the Implementation Guides following this chapter give specific details and follow the same general organization:

1) Implementing Site and Soil Treatments: fertilizers, tillage, mulches, topsoil, organic matter amendments, lime amendments, beneficial soil microorganisms, and topographic enhancements.
2) Obtaining Plants: collecting wild seeds, collecting wild cuttings, collecting wild plants, nursery seed production, nursery cutting production, and nursery plant production.
3) Installing Plants: seeding, hydroseeding, installing cuttings, installing plants.
4) Caring for Plants: post installation care.

Advanced planning is essential. Many implementation tasks begin up to three years before road construction. Proper planning will ensure that all materials will be ready at the appropriate time during the construction phase. (Planting can occur as early as year one in a multi-year construction project.) Be aware that procuring plant materials and implementing mitigating treatments will involve separate schedules with different contractors. Therefore, developing an implementation timeline is essential in order to keep all scheduling details straight. An example of an implementation timeline is shown in Figure 9.1.

Most timelines have interdependent and time-linked tasks. In Figure 9.1, for instance, the hydroseeding contract is dependent on the success of the seed increase contract. Before that, the seed increase contract depends on the wildland seeds collected by agency personnel or contractors. The success of the hydroseeding contract rests on the successful execution of two tasks that must begin years before hydroseeding implementation. Detailed schedules and timelines are necessary to coordinate these activities. The Implementation Guides provide more detailed information on how to organize and schedule the various tasks.

When creating timelines for tasks, be sure to incorporate the advance time needed to issue contracts. This is especially crucial when ordering plant materials, which will require several years before needed species and quantities can be grown. However, even for routine procurement of equipment or supplies, nine to twelve months of advance notice will result in better prices, since suppliers will have more time to plan their orders. Reputable contractors have plenty of

Figure 9.2 – *How to calculate areas being treated.*

Station	Slope Length (m)	Distance between stations (m)	Area (m²)
20 + 1000	3	20	60
20 + 1020	4	20	80
20 + 1040	6	20	120
20 + 1060	7	20	140
20 + 1080	6	20	120
20 + 1100	4	20	80
20 + 1120	2	20	40
		Total (m²):	**640**
		Acres:	**0.16**

work and may not be available on short notice. Implementation Guides provide more detail on scheduling and contracting timelines for individual tasks.

Renting equipment and calculating quantities of materials is an essential part of implementation. In many cases, the construction engineer can provide you with information regarding cubic volumes, surface areas, and haul distances as they refer to plans and specifications. Accurate calculations are essential to develop contracts for various tasks. Figure 9.2 shows example calculations to determine areas being treated. Further details on developing quantity specifications for the various tasks of implementation can be found in the Implementation Guides following this chapter.

Once treatment details and timelines have been developed, meet with the construction engineer and review quantities, timing, materials, and equipment, as well as overall strategies. If areas are only estimates at this stage due to possible changes while the road is constructed, express them as ranges (e.g., 40 to 50 acres) when issuing contracts. After the site has been prepared, you can narrow these ranges down to exact numbers. Be sure to allow for contingencies, especially when ordering seeds. Once you feel confident about the details and timing, develop contracts to carry out the work.

9.4 DEVELOP CONTRACTS

A contract functions as a detailed plan for each task or set of tasks, communicating the desired outcome for the work. Contracts are essential tools for implementing revegetation treatments. Even if the work is to be carried out by personnel within the agency, approaching the tasks as if they were private contracts will facilitate clear communications and a high-quality job. (Check agency procedural manuals for how to create in-house agreements.) The Revegetation Plan and the treatment details (developed above) are used to create a contract. The contract details the implementation work to be done by the contractor or agency personnel for that task, with clear definitions of roles and schedules.

Depending on the complexity of the project, multiple contractors are usually involved. As emphasized previously, developing contracts well in advance of the work is necessary in order to ensure proper scheduling. Contracts vary by the type of work to be done and by the types of parties involved. In general a contract should define:

- Supplies/services to be provided;
- Scope of work (size, schedule, and so on);

- Project location;
- Contractor obligations;
- Revegetation specialist obligations;
- Delivery details (who, how, when, including timelines and deadlines);
- Quality standards;
- Contractor quality assurance plan (to be provided by contractor);
- Revegetation specialist quality assurance plan (to be provided by revegetation specialist who will be inspecting the contractor's work);
- Price;
- Payment method (submission of invoices, approval of work);
- Contractor's designated representative (so you only coordinate with one person);
- Safety plan; and
- Other terms and conditions (e.g., what to do in the event of changes).

Usually you will put out a call for proposals for a task with most of the above details included. Contractors will provide their offers for completing the work, including their plans for safety and quality control. For technical work, the contractor usually provides an explanation of the proposed technical approach for each task to be performed. The most suitable contractor is selected for the task and then the details are worked out in writing. Make sure that the contractor designates one representative to be your contact person for the project; having just one "point of contact" reduces confusion and makes communication easier. Also, when detailing "other terms and conditions," especially for plant materials, make sure there are clauses that cover possible variations in quantity or quality. For example, low quality seeds may still be usable, but perhaps a fair price reduction can be agreed upon if the germination is below the contract specifications.

Quality control is essential for every implementation task. Quality control plans assure that the contracted tasks were performed as planned. Usually the contractor provides a quality control plan describing how their organization will monitor their work and assure that the contract is efficiently fulfilled. The revegetation specialist must also define, in advance, the standards by which work will be assessed and detail how work will be inspected. Predefined quality standards are essential to assure that everyone is working towards the same clearly defined goal to achieve the DFCs for the project. More information on quality control is provided in the next section. An example contract (between the USDA Forest Service and a private contractor) is provided on the following pages.

9.5 INSTALL TREATMENTS

The Revegetation Plan, in part, is based on the construction plans and predicted post-construction outcomes. However, after road construction is complete, you will often find that the predictions do not exactly match the reality. In addition, materials available may change. To adapt to these unplanned changes, implementation tasks are updated during and after construction based on actual changes to the site or actual materials available at the time of implementation. A concise revegetation plan, combined with clear contract performance work statements and consistent communication, will provide an adaptive framework from which change can readily occur.

Prior to installation of treatments, several questions should be asked and evaluated. First, determine if there are any major unplanned construction changes that require new road plans and cross-sections. If so, these changes need to be documented on the revegetation map and a plan needs to be developed to revegetate them. Second, reassess the limiting factors to revegetation success as described in Chapter 5. For example, is the rooting depth as predicted? Is there fracturing in the bedrock? Are some slopes steeper than originally designed? Was ground water intercepted? Is there enough topsoil salvaged to reapply at the planned rates? Are there areas of instability? Did unexpected weeds show up? If any of the answers are different than planned, mitigation treatments should be reevaluated. Third, reevaluate the revegetation unit map. Are the units located on the map correctly? Are the descriptions still valid? If they are not, then make the changes so each management unit can be developed properly. Adaptive

Example Contract

Contract No.	53-04R3-4-045	**Project Name:**	Weston-Elgin Road Construction Project	**County:** Umatilla
Contractor:		**Issuing and Billing Office:** Umatilla National Forest 2517 SW Hailey Avenue Pendleton, OR 97801		

Item No.	Sub-item No.	Description	Quantity to Date	Quantity Ordered	Unit	Unit Price	Amount
1		Hydraulically apply permanent seeding* to newly finished cut and fill slopes.					
	1a.	Fall 2005		40	Acre	$3,000	**$120,000**
	1b.	Fall 2006		5	Acre	$3,300	**$16,500**
2		Hand plant shrubs*, and conifers*, over 2 seasons.					
	2a.	Fall 2005, shrubs only		5,600	Plant	$3.00	**$16,800**
	2b.	Fall 2006**, conifers and shrubs. 2,700 conifers. 2,400 shrubs.		5,100	Plant	$3.00	**$15,300**
3		Pneumatically install compost/ mulch erosion blanket w/ seed* onto two (2) fill slopes.		2 acres	Acre	$12,000	**$24,000**

Required Delivery Date: All work shall be completed by November 15, 2005. Work is estimated to begin October 15, 2005. All work shall be completed within 10 calendar days. Timing of current construction and access to work sites may necessitate work on weekends and short notifications to begin work.

All items will be awarded to one (1) contractor.

*** Government supplied materials**
**** Contractor to perform subitems 1b and 2b together during Oct.-Nov. of 2006.**

Total Price:

$192,600

Contractor: (Name and Signature)

Requested By: (Name and Signature)

Jim Scott, COTR

Fund Authorization: (Name and Signature)

Ordered By: (Name and Signature)
Contracting Officer

Order Date:	**Job Code: WGFCNA**

EXAMPLE STATEMENT OF WORK
Weston-Elgin Road Construction Project, HWY 204
M.P. 10.65 to M.P. 20.77
Walla Walla Ranger District, Umatilla National Forest
Umatilla County, Oregon
Elevation 3,800 to 5,000 ft

Location of work:

The project area is located in Umatilla County, near Tollgate, OR and east of Athena, OR on Highway 204. Project is located between MP 10.65 and MP 20.77. Athena is located midway between Pendleton, OR and Walla Walla, WA along Highway 11. See attached map.

Construction of the road will span two seasons and require seeding and planting work to be performed in both the fall of 2005 and 2006, with the majority of work completed in 2005.

Description of Work and Standards:

Item 1. Hydraulically apply seeds, mulch, fertilizer, and tackifier to finished cut and fill slopes associated with new road construction. Provide permanent seeding for up to 45 acres of cut, fill, and adjacent obliterated road surfaces. Government will furnish all seeds. The majority of slopes will average 1V:2H with a small amount of 1V:1.5H. Areas are adjacent to existing paved road and/or graveled surfaces. The majority of work (95%) can be performed from the tower; however, a hose lay (up to 100 ft) will be required for a single large fill. The permanent seeding work window for this project will be between October 1 and November 15, 2005–6, unless alternative dates are mutually agreed upon.

Hydraulically combine and apply EcoFibre® (http://www.canforpfd.com) @ 2,000 lb/acre, Biosol® (http://www.pawneebuttesseed.com) at 1,200 lb/acre and Super Tack® at manufacturer's recommended rate; add XL crosslinker at 40% the weight of Super Tack® (http://www.ranteccorp.com) for slopes 1V:2H or steeper (approximately 5 ac).

Equivalent products may be substituted at the discretion of the government.

Item 2. Hand-plant 1+0 container and bareroot hardwood nursery stock in fall 2005. Hand-plant 1+0 hardwood container nursery stock and 2+0 conifer container stock in fall 2006. Use hand tools to plant styro-15 plugs, styro-40 plugs, and bareroot plant materials. Plant spacing distances will be assigned by the COTR for each site. Plant up to 10,700 individuals (in total, 2 years) in cut and fill slopes, obliterated road surfaces, and a short segment of riparian zones. Areas are adjacent to existing paved road and/or graveled surfaces. Planting work window for this project will be between October 1 and November 15, 2005–6, unless alternative dates are mutually agreed upon.

Contractor will be responsible for loading, transporting, and care of all living plant material once in possession in both 2005 and 2006. Contractor is responsible for all scheduling and delivery of plant materials from a private nursery in Milton-Freewater, OR. The facility is located on HWY 11 and is approximately 40 to 45 minutes from the project. Upon award, location and contact information will be provided.

Planned Weston-Elgin Revegetation Project Plant Materials for Fall Planting of 2005 and 2006

Species	Stocktype and Quantity			Total by Species
	Bareroot	Styro-15	Styro-40	
Alnus viridis s. sinuata	0	30	0	30
Amelanchier alnifolia	0	0	720	720
Cornus sericea s. sericea	0	175	0	175
Holodiscus discolor	0	0	1,160	1,160
Physocarpus malvaceus	476	250	1,330	2,056
Populus trichocarpa	0	0	80	80
Rosa woodsii	0	0	263	263
Rubus parviflorus	0	0	204	204
Sambucus nigra s. cerulea	0	192	0	192
Sorbus scopulina	0	0	620	620
Spiraea splendens	0	0	100	100
Total 2005	**476**	**647**	**4,477**	**5,600**
1+0 *Symphoricarpos albus*	0	0	1,500	1,500
2+0 Conifers	0		2,700	2,700
1+0 Additional shrubs			900	900
Total 2006				**5,100**

Item 3. Pneumatically install compost/mulch erosion blanket w/tackifier and seeds. Apply an even coverage 2 inches in depth over 2 acres of slopes ranging from 1V:2H to 1V:1.5H. Access will be from existing roads. **Contractor must provide compost specifications to the COTR prior to start work date.** Compost must conform to U.S. composting council standards and be state certified in Oregon and Washington. See evaluating compost quality (http://www.compostingcouncil.org) for standards of acceptable compost. **An accessible compost storage site will be provided within one (1) mile of the installation site. Site is accessible to trucks and trailers.**

Contractor Quality Control Plan:

The Contractor shall prepare a brief Quality Assurance Plan and submit it with the completed bid.

Government Quality Assurance Plan:

A qualified USFS COTR will be on site during all phases of project fieldwork, providing technical support and ensuring that project objectives are met. The contractor is fully expected to take an active role in providing, sharing, and advising in technical aspects that may benefit the project outcome.

The following plan is to be used by the Government for quality assurance:

Item 1. Application. Hydroseeding slurry mixture, rate of application, uniformity, and coverage will be inspected. Apply hydroseeding mix so no holes exist. Apply so that no gaps exist between the matrix and the soil. Application is not allowed over frozen ground or snow or during periods of extended rainfall. A tracer (mulch or dye) sufficient to visibly measure coverage and progress is mandatory in each slurry unit. Follow-up monitoring to determine germination and survival will be carried out during May, July, and September 2006-7. Monitoring will be used to assess the effectiveness of treatment and determine whether follow-up treatments are needed to adequately stabilize seeded slopes. A follow-on contract may be issued for additional hydroseeding, if necessary, as determined by monitoring.

All equipment shall be free of weed seeds. Hydroseeding equipment shall be clean and free of all previous seeds, fertilizer, mulch, or any hydroseeding products used on prior jobs. Equipment will be inspected prior to initial applications. If equipment does not pass inspection, the contractor will be required to clean equipment off-site at an approved facility before returning to the project site. The Government may not be held liable for lost time due to re-cleaning of equipment.

Item2. Shrub and tree planting. Vertical planting depth, site selection, species appropriateness, handling, mechanical damage during planting, that is, excessive broken branches, tops, and roots, excessive damage to bark which exposes cambium, will be inspected. Due to the perishable nature of trees and shrubs, care and protection is considered critical and will be carefully monitored throughout the planting schedule to ensure proper care. The COTR will frequently observe planting in progress, dig trees and/or shrubs to check underground planting quality, and observe planting methods. Follow-up monitoring to determine survival and establishment will be carried out during May, July, and September 2006-7. Monitoring will be used to assess the effectiveness of plantings and determine whether follow-up treatments are needed to adequately stabilize selected slopes. A follow-on contract may be issued for additional planting, if necessary, as determined by monitoring.

Item 3. Pneumatically install compost/mulch erosion blanket with tackifier, fertilizer, and seeds. Evenness and consistency of application to slopes will be monitored. Ingredients, additives, and injection will be monitored as well. Application is not permitted over frozen ground or snow or during periods of extended rainfall. Contractor must provide compost specifications to the COTR prior to work start date. Standards must conform to U.S. Composting Council standards. See evaluating compost quality (http://www.compostingcouncil.org) for standards of acceptable compost. The COTR will evaluate test results for compost furnished by contractor and randomly inspect and/or take samples from material stored on site. Government will furnish seeds.

Measurement and Payment:

Payment for hydroseeding will be on a per acre basis. Additional acreage will be paid at the stated contract price and performed via a follow-on contract.
Payment for installed compost erosion blanket will be on a per acre basis.
Payment for hand shrub and tree planting will be on a per plant basis.

Government Furnished Material:

The government shall provide all seeds to the project site. The government shall produce all conifers and shrubs; contractor is responsible for pick-up, delivery, and care during the contract period.

Schedule:

Treatment/Year	2005 (Acres/Plants)	2006 (Acres/Plants)	Total (Acres/Plants)
1) Hydroseeding	40 ac	5 ac	45 ac
2) Hand-plant shrubs and conifers	5,100 plants	5,600 plants	10,700 plants
3) Install compost and seeds	2 ac		2 ac

management is ongoing throughout all phases. Change is a certainty, and preparedness provides options and allows the revegetation specialist to respond to these situations.

The status of available materials must be determined. The final inventories should be obtained from the agency staff and contractors. The inventories will include the quantities of each species for seeds and/or seedlings, topsoil supply, and so on. Producers may not be able to deliver the exact quantities ordered. Seed producers may have succeeded in growing more seeds for certain species while producing less of other species. The nursery may have been affected by frosts, insects, disease, or other events that reduced the inventory for some species but not others. Just as likely, the nursery could have extra seedlings available for some species that could make up the shortage of others. Guided by the objectives and DFCs of the Revegetation Plan, the revegetation specialist must adapt to these changes and carry out the implementation tasks to the best of your ability using the materials and resources at hand.

9.6 KEEP GOOD RECORDS

During the Implementation Phase, keeping records often seems like a low priority. The field work demands a high level of energy and attention, and time for keeping records may tend to fall by the wayside. However, records are invaluable, and recordkeeping is an essential part of implementation. Records are essential in the short-term for reporting and accountability, including communicating with contractors and agencies. In the long-term, records are needed to assess what was done, what worked, and what did not work as the project unfolded so that optimal results can be recreated and failures can be avoided on future projects. It is almost impossible to remember what was done on a project several weeks, months, or years after implementation. However, it will be necessary to know what happened. Without good records, there will be no way of piecing together the causes of failure or success and little ability to share “lessons learned” with peers. Record-keeping and daily diaries are very important from a contractual view as well. As part of doing business, there is always a chance of a dispute leading to a claim by a contractor. Good records provide the foundation the contracting officer will need to defend the contract administrator.

Keep a notebook or manila folder that contains the final revegetation plan, contracts, diaries, spread-sheets, receipts, maps, and correspondence. Since the majority of this information may be electronic, keep a folder on your computer that contains all e-mails, spreadsheets, budgets, plans, and contracts. E-mails and phone conversations can be stored in one spreadsheet for all projects. The process of photo documentation of project development (as described in Chapter 11) is also important.

Keeping a simple daily log (or diary) is also invaluable. Take a few moments to jot down what happened at the project site each day until implementation is complete. Include thoughts of how things are going, any anticipated changes, and challenges and opportunities. An example daily diary form and template is provided in Figure 9.3. While the example shows a diary for contract work, the same template can be utilized to keep records of your own work, that of other agencies, and overall project development.

Records are also used to develop reports when it is necessary to document accomplishments to date. Reporting requirements vary, but some type of accomplishment report is usually due quarterly or annually. Monitoring reports (discussed more in Chapters 11 and 12) are essential in order for environmental agencies to ensure that you fulfilled objectives and appropriately addressed environmental regulations. While putting these reports together, take a few hours to organize the files and summarize the information in them. At the completion of the entire project, a final report is assembled based on the records that were kept throughout the project. For this reason, good record-keeping is essential.

9.7 CARRY OUT QUALITY ASSURANCE

To evaluate the effectiveness of implementation work, quality assurance standards are set and quality is monitored until each task is complete. The standards for quality assurance are linked to the DFCs that were set in the Planning Phase. In other words, many of the quality assurance standards translate aspects of the DFCs (e.g., desired percent vegetative cover) into short-term standards for implementation work (e.g., quantity of seeds applied). Details for quality assurance standards are defined in the contract specifications. The contractor will provide monitoring and inspection of their own work to assure that tasks are carried out as

***Figure 9.3** – Example of contract daily diary (source: USDA Forest Service).*

Contract Daily Diary

(Reference FSH 6309.11)

1. PROJECT SITE: Upper Grange Road
2. CONTRACT NO.: 54-46-37

3. PROJECT: Upper Grange Road Revegetation (working on Reveg Units 1-3 today)

4. CONTRACTOR: Plant and Protect Inc.

5. CONTRACTOR REPRESENTATIVE ON SITE: Jane McLean

6. OFFICIALS ON SITE: Me (Davis Lee)

7. DATE	8. DAY OF WEEK	9. TIME ARRIVED	10. TIME DEPARTED	11. WEATHER
6/7/06	Wed.	07:30	16:00	Overcast, Thunderclouds west

12. TEMPERATURE °F	13. GROUND CONDITION	14. CONTRACT TIME	15. DAYS USED	16. COMPLETION DATE
Min. 45 | Max. 55	Moist, firm — good condition	6/7/06 to 6/14/06	1	

17. TIME USED (%)	18. WORK COMPLETED (%)	19. WORK ON SCHEDULE	20. CONTRACTOR'S WORK - (X Appropriate Box)
14%	20%	[X] YES [ ] NO	[X] Acceptable [ ] Unacceptable Explain In Narrative

21. CHANGE ORDERS/AMENDMENTS ISSUED: No changes yet, may reschedule tomorrow if heavy rain continues tonight.

22. WORK ORDERS ISSUED (Include SUSPEND/RESUME): Install hydromulch (blow on compost & seed mix)

23. MATERIALS FURNISHED TO JOB SITE (Furnished by G-Govt., C-Cont; S-Subcont.)

- Seed mix RRCA5, 50 lbs for use w/mulch (G)
- 537 yards of certified compost (for mulch) (C)

24. LIST EQUIPMENT ON SITE (Furnished by G-Govt., C-Cont; S-Subcont.)

Type	Contract Item Number and Location of Use	Hours Used
	Mack truck w/ lowboy (C)	
	Cat 9506 loader (C)	
	Kenworth truck with Finn blower	
	Jane's SUV (C)	
	Hydroseeder (C)	
	Trailer w/ mulch loads	

25. List Contract Payments, Reports, Correspondence, ETC.

Item	Prep	Submit

26. Workers On Site

Classification	Number PRIME	Number SUB
Harry Medford (truck)	1	
Julio Valdovinos (hydro)	1	
Lila Carev (mulch)	1	
Jane McLean	1	

27. Government Provided Services Adequately and Timely: [ ] YES [ ] NO - Explain in Narrative

28. NARRATIVE REPORT

Met with Jane and crew (Harry, Julio, Lila) from 07:30 - 08:15. Looked over project site and reviewed compost/seed installation strategy. Talked safety: traffic, orange vests, PPE, working around equipment, evacuation plan in case of injury, equipment, footing OK! I inspected compost, appears high quality (collected 6 samples to be combined for test later). 08:30 crew began to unload and stage equipment, loading compost into blower (25 yds) mounted on Mack truck. Jane and Davis inspect reveg units/areas and explored secondary source of water (east end) if needed, permit OK. 09:30 crew began blowing compost/seed mix onto Reveg Units 1 & 3. Good job with careful hose placement. 14:00, rain began, a sprinkle then a downpour. 16:00, stopped work for day, compost becoming heavy with too much water so not blowing as far. If dries out overnight, will resume application tomorrow. Otherwise will have to postpone until dry enough to blow. Looks like rate can be 7-8 loads/day possible in good conditions. No other issues.

29. SIGNATURE	30. TITLE	31. ADDTL SPACE NEEDED
Davis Lee 06/07/06	Reveg Specialist	(Continued on 6300-21)

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contracted. The revegetation specialist is responsible for assessing the quality of each task to assure all tasks were satisfactorily completed and all contract requirements have been met so the contractor can be released from further obligations and fully paid.

On revegetation contracts, project objectives or standards are typically referred to as contract specifications. For example, a hydroseeding contract has a specification to apply 30 lb of seeds, 1,000 lb of wood fiber mulch, and 50 lb of tackifier per ac to 20 ac of cut and fill slope. Quality control for this task might be to count the pounds of seeds, wood fiber, and tackifier going into the hydroseeder tank and measure the area to which the mix is applied. This assessment can assure that the rate of materials applied on a per-acre basis is appropriate. If the calculated amount of material per acre does not match the stated objective or contract specifications, the amount is adjusted to meet the specifications. Quality assessment not only assures that the contractor meets his or her obligations, but alerts them when specifications are not being met so that corrections can be made. For any task, quality assurance standards describe what form of measurements will be used to assess the work.

9.8 IMPLEMENT EARLY MAINTENANCE AND MONITORING

Just after implementation, short-term monitoring of the project begins. Short-term monitoring is necessary to confirm that efforts to establish vegetation on the site were effective, and to correct shortcomings to ensure project objectives are achieved. Quality assurance confirmed that the predetermined amounts of fertilizer, tackifier, hydromulch, and seeds were put into the hydroseeding tank as specified, and that the materials were placed in the correct areas at the correct density. Short-term monitoring then determines whether the revegetation objectives of the plan were met using these rates and materials. For example, were germination rates sufficient? Are the plants surviving and becoming established? Short-term monitoring assesses project development as it relates to the DFCs. If objectives are not being met, determining the reason(s) should become a priority before further revegetation work is proposed. Short-term monitoring and management of roadside revegetation projects is discussed in Chapters 11 and 12. The information from short-term monitoring determines the level of maintenance that will be carried out to keep the project developing as planned.

Timelines for roadside revegetation projects can span several seasons or even several years, which means that early maintenance of some road segments will be taking place at the same time that other segments are being implemented. Sometimes, maintenance work is built into the contract as part of implementation. Once contract work is completed and the contractor has been released (final satisfactory inspection), maintenance begins. Most maintenance tasks will have been planned in advance, such as applying fertilizers after three months, or passing through to control weeds. Early maintenance also includes identifying and correcting unforeseen problems quickly. Unforeseen events include weather problems (e.g., drought), an unexpected invasion of weeds, impacts of pests, vandalism, or other issues that might mean that the project will not develop as planned unless corrections are made. If corrective measures are needed, additional contracts may be issued to carry out the tasks. Road maintenance must also be coordinated with the revegetation plan. This could ensure that herbicide is not applied to the newly planted areas. Discussion of monitoring and management continues in Chapter 11.

9.9 CONCLUSION

The Implementation Phase calls for flexibility, adaptability, and opportunism. At times, the implementation work demands a willingness to travel to the construction site on short notice to assess issues as they arise. The process requires the vision to fulfill the overall project objectives while working with, and adapting to, the resources and conditions at hand. Keeping channels of communication open with the construction engineer and with the revegetation contractors is an essential aspect of effective implementation. Advanced scheduling and careful calculations of timing, supplies, and services needed are necessary. Issuing clear contracts for implementation work, regular evaluations and quality assurance as treatments are carried out, and good recordkeeping are necessary to ensure the revegetation is implemented effectively. Short-term maintenance and monitoring help to identify and correct any shortcomings quickly in order to fulfill project objectives. The Implementation Guides following this chapter provide further details about individual implementation tasks, including working with soil and site treatments, obtaining plant materials, installing and caring for plants.

10 IMPLEMENTATION GUIDES

Chapter 10 details the practices common to most revegetation projects. It is divided into 19 subchapters, called implementation guides, which summarize the important information needed to execute each practice.

Implementation guides are grouped into four subject areas:

- 10.1 Soil and Site Treatments,
- 10.2 Obtaining Plant Materials,
- 10.3 Installing Plant Materials, and
- 10.4 Post Installation Care of Plant Materials.

The eight guides in Section 10.1, Soil and Site Treatments, explain how to improve site and soil conditions prior to the installation of plant materials. These guides cover the mitigating measures most often referenced in Chapter 5.

Section 10.2, Obtaining Plant Materials, covers six implementation guides that pertain to collecting and propagating plant materials. These guides describe how to take the species lists developed in Chapter 6 and obtain the desired species in the wild as seed, cuttings, or seedlings. These guides also cover how to increase gathered wild collections at nurseries to ensure that the revegetation project has sufficient quantities of plant materials.

Once plant materials are obtained from the wild or from nurseries, they are installed on the project site. The four guides in Section 10.3, Installing Plant Materials, cover the techniques for sowing seed, installing cuttings, and planting seedlings. They also cover how to determine the quality of the plant materials and how to care for them during storage and transportation.

Section 10.4, Post Installation Care of Plant Materials, outlines those practices that take place after the installation of plant materials. These practices help ensure that plants will become established. Practices include protecting seedlings from animal browsing, installing shade cards, irrigating, and installing tree shelters.

10.1 SOIL AND SITE TREATMENTS

Most post-construction sites are in poor condition for plant growth and will require the implementation of mitigating measures if full or even partial revegetation is expected. The following set of implementation guides cover the common mitigating measures for improving site conditions after construction. The implementation guide to fertilizers, Section 10.1.1, covers how to determine the quantity, type, and application method of fertilizers. Tillage, Section 10.1.2, describes the common practices of tilling the soil to improve water infiltration and root growing environment. Improving seed germination and reducing surface erosion can be accomplished through the application of mulches, which is detailed in Section 10.1.3, Mulches.

Section 10.1.4, Topsoil, outlines the removal, storage, and application of topsoil to reconstruct soil on highly disturbed sites. For sites where topsoil is not available or in short supply, organic matter can be applied to improve post-construction soils. Section 10.1.5, Organic Matter Amendments, discusses the types of organic matter available, how to determine rates, and how it is applied. On some sites where the topsoil has been removed, pH levels will need to be raised to improve plant growth. Section 10.1.6, Lime Amendments, details the methods for determining liming rates, materials, and application methods. Many sites devoid of topsoil will require the introduction of mycorrhizae or nitrogen fixing plants. Section 10.1.7, Beneficial Soil Microorganisms, covers how to obtain and apply the appropriate sources of these important biological organisms. Revegetation projects can be enhanced by integrating plants into bioengineering structures, water capture features, or planting islands or pockets. These are discussed in Section 10.1.8, Topographic Enhancements.

10.1.1 FERTILIZERS

10.1.1.1 Introduction

Fertilizers are used to bring soil nutrients up to levels essential for establishing and maintaining a desired plant community. When applied within a soil fertility strategy, using fertilizer can be a great tool for revegetation. In recent years, however, the use of fertilizers on roadsides has come under greater public scrutiny and more restrictive water quality laws. Many roads are adjacent to streams, lakes, or residential areas which can be affected by runoff or leaching of inappropriately applied fertilizers. It is important for the revegetation specialist to learn how to develop fertilizer prescriptions that integrate short- and long-term site fertility goals with water quality objectives.

Use of commercial fertilizer is only one of many options to increase nutrient levels. A soil fertility strategy should also consider the application of topsoil, mulch, compost, wood waste, biosolids, and/or the planting of nitrogen-fixing species. This section will guide the revegetation specialist through the steps necessary to develop a site specific fertilizer prescription. The process for developing a fertilizer prescription follows these steps:

- Determine nutrient thresholds and deficits,
- Delineate areas to be fertilized,
- Select fertilizer analysis,
- Select fertilizer release rates,
- Determine application rates,
- Determine timing and frequency, and
- Select application method.

The fertilizer prescription is the basic instructions for ordering and applying fertilizers.

10.1.1.2 Develop Nutrient Thresholds and Determine Deficits

All sites have a minimum, or threshold, level of nutrients that must be met for each plant community to become functioning and self-sustaining (See Section 5.5). Threshold values can

Figure 10.1 *– Threshold values are determined from reference sites. In this example, the threshold was established at 1,100 lb/ac, which was between the total N of a disturbed reference site with "poor" revegetation (A) and one with "fair" revegetation (B). Total N in post-construction soils was 650 lb/ac (C), making these soils deficient by 450 lb/ac. The undisturbed topsoil of reference sites showed a total N of 2,430 lb/ac (D), which sets the target levels of nitrogen between 1,100 and 2,430 lb/ac.*

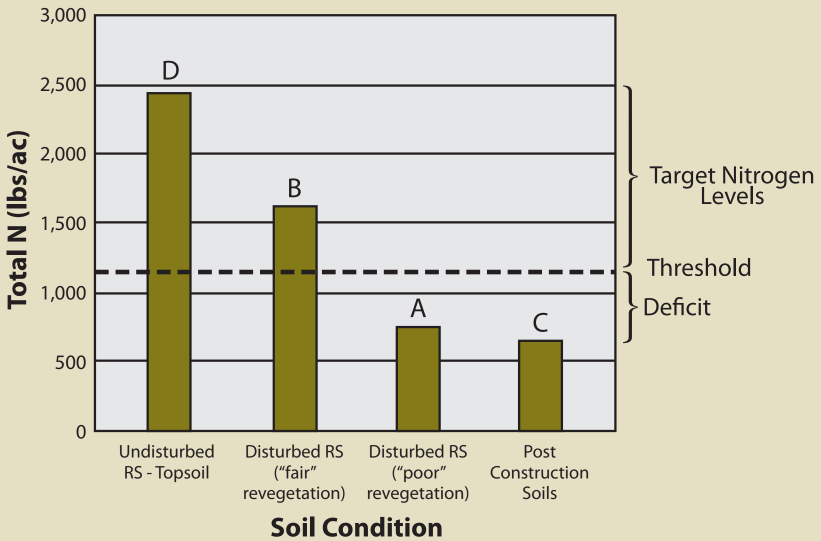


***Figure 10.2** – Determining the amount of nitrogen (N) needed to bring soils up to a nitrogen threshold can be calculated from equations shown in this spreadsheet.*

A	Total soil nitrogen (N)	0.025	%	From soil test of post construction soils – gr/l, ppm, mg/kg, ug/g divide by 10,000 for %
B	Thickness of soil layer	0.5	feet	The thickness of soil represented in (A)
C	Soil bulk density	1.4	gr/cc	Unless known, use 1.5 for compacted subsoils, 1.3 for undisturbed soils, 0.9 for light soils such as pumice
D	Fine soil fraction	70	%	100% minus the rock fragment content – from estimates made from sieved soil prior to sending to lab
E	N in soil layer: A * B * C * D * 270 =	331	lbs/ac	Calculated amount of total nitrogen in soil layer To convert to kg/ha: E * 1.12
F	Minimum or threshold N levels	1,100	lbs/ac	Determined from reference sites (see Figure 10.1)
G	N deficit: F - E =	769	lbs/ac	Minimum amount of N to apply to bring up to threshold

be determined by comparing soil tests from several disturbed and undisturbed reference sites (See Chapter 4). Disturbed reference sites should range from poor success to good. Based on nutrient values from good and poor revegetation sites, a target can be estimated between these values. Figure 10.1 gives an example of how a nitrogen threshold value was obtained by evaluating the total soil nitrogen levels from two disturbed reference sites, one considered "fair" revegetation and one considered "poor." The threshold was set between these two nitrogen levels. Threshold levels represent the minimum level of nutrients needed for a site. However, higher nutrient levels are more desirable. In fact, the target nitrogen levels in this example for establishing and maintaining the original plant community would be closer to the undisturbed reference site.

To determine whether any nutrient is deficient, post-construction soils must be collected and tested. The values obtained from these tests are compared against target values to determine if a deficiency exists. By comparing post-construction nutrient values against threshold values, the nutrient deficit can be estimated for each nutrient. Figure 10.2 shows an example of how nitrogen deficits are calculated based on post-construction soil tests and established threshold levels. In this example, total soil nitrogen is determined from soil tests. Since soil testing facilities report nutrients in a variety of rates, it is important to convert the rates to percentages. This is done by dividing values that come as gr/l, ppm, mg/kg, and ug/g by 10,000 to convert to a percentage. Converting percentage of nutrient in the lab sample to lb/ac of the nutrient requires multiplying % of nutrient, soil layer thickness, soil bulk density, and fine soil fraction together with a constant (line D). This is the pounds of nutrient in an acre of soil on the post-construction site. To determine the nutrient deficit, the pounds of nutrients per acre is subtracted from the threshold level. This value becomes the basis for determining fertilizer prescriptions.

The availability of many nutrients is regulated by soil pH. As discussed in Section 5.5.5, many nutrients are tied up in low pH and high pH soils. Calcium and magnesium are less available at low pH; phosphorus, iron, manganese, boron, zinc and copper become unavailable in high pH soils. It is important to compare the pH of post-construction soils with reference site soils to determine if the pH is substantially different between the two. If the pH of post-construction soils is different, then taking measures to bring the pH closer to pre-disturbance values should be considered when developing a nutrient strategy (See Sections 5.5.5.3, 5.5.5.4, 10.1.5, and 10.1.6).

10.1.1.3 Delineate Areas to be Fertilized

The post-construction project site should be delineated by distinct areas where fertilizer prescriptions differ. These differences are usually based on post-construction soil type changes, topsoil salvage, organic amendment additions, or the species and plant material being grown. Areas adjacent to, or that feed into, live water are often delineated and treated with lower rates of fertilizer. Note: If seedlings of shrubs and trees are being planted, spot fertilization should be considered in addition to, or in lieu of, fertilizing the entire area (See Inset 10.1, Spot-Fertilizing Seedlings).

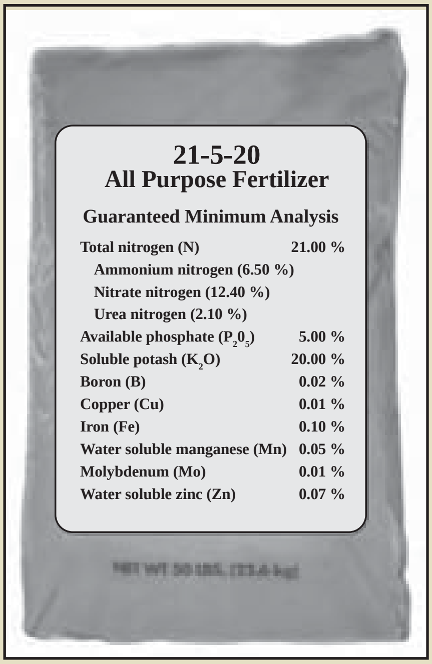


***Figure 10.3** – An example of a fertilizer label for an "all purpose" fertilizer. The top numbers (in bold) represent the percentage of nitrogen, phosphorus, and potassium respectively (21%N, 5% P_2O_5, and 20% K_2O). Multiplying these percentages by the pounds of bulk fertilizer applied per acre will give the quantity of each nutrient applied per acre. In this analysis, 500 pounds of fertilizer in this analysis would deliver 105 lbs N, 25 lbs P_2O_5, 100 lb K_2O, 0.1 lbs B, 0.05 lbs Cu, and so on.*

10.1.1.4 Select Fertilizer Analysis

There are a variety of commercially available fertilizers that can be used for fertilizing disturbed sites associated with road construction. The composition, or makeup, of the fertilizer is called the fertilizer analysis. Each container of fertilizer will have a label with a stated "guaranteed analysis" that indicates the percentage of each nutrient contained in the fertilizer (Figure 10.3). The label is your guide for determining which fertilizers to select and how much to apply. Tables 10.1 and 10.2 give analysis values for many common fertilizers. Labels can also be obtained from the manufacturer or fertilizer representatives.

The fertilizer label reports the nutrients as a percentage. The example label for a 50 lb bag of fertilizer in Figure 10.3 shows 21% nitrogen (N), which indicates that 10.5 lb of material in the bag is made up of nitrogen (50 * 21/100=10.5). The bag also contains 0.02 % boron (B), which indicates that there is 0.01 lb boron in the bag. Calculating the amount of phosphorous and potassium in the bag is a little trickier because the convention for reporting these nutrients is P_2O_5 and K_2O instead of elemental P and K. To convert P_2O_5 to P, the analysis for P is divided by 2.29. The percentage of P in the bag in Figure 10.3 is actually 2.2%, not 5% (5.0%/2.29=2.2). K_2O is divided by 1.21 to obtain 1.6% K.

Fertilizers are selected based on whether they contain the nutrients that are deficient on the project site. For example, if nitrogen, phosphorus, and boron are deficient, only fertilizers that contain these nutrients need be considered. Most fertilizers contain more than one nutrient. For instance, ammonium sulfate contains nitrogen and sulfur; triple superphosphate contains phosphorus, sulfur and calcium. Organic fertilizers often contain a range of macro and micronutrients. Fertilizers containing more than one nutrient should be considered if the nutrients contained in these fertilizers are deficient in post-construction soils. Table 10.1 and Table 10.2 show the combination of nutrients that are available in some commercially available fertilizers.

Fertilizer selection should focus first on the macronutrients (nitrogen, potassium, and phosphorus) that are deficient. These three nutrients are considered most important for long-term site recovery. If they are not deficient, chances are that the remaining nutrients are not either. On most highly disturbed sites, nitrogen is most likely to be deficient. This nutrient should be considered first when approaching fertilizer selection. Table 10.2 lists common nitrogen fertilizers with typical label analysis. Nutrients other than nitrogen can be supplied by fertilizers shown in Table 10.1. It is common to apply more than one fertilizer to meet the various nutrient requirements of the soil.

10.1.1.5 Select Fertilizer Release Rates

Fertilizers are grouped by how quickly they break down and release nutrients to the soil. They are either fast-release or slow-release. Release rates are important because they will determine the rates at which nutrients become available to plants during the year. If nutrients are released during periods when vegetation cannot use them, some will be lost from the site through soil leaching. This is not only a waste of fertilizer, but can be source of ground water pollution.

Fast-Release Fertilizers **–** Fast-release fertilizers are highly soluble fertilizer salts that dissolve rapidly and move quickly into the soil during rainstorms or snowmelt. The fertilizer label will give an indication of how quickly nutrients are released. Terms such as "soluble," "available," or "water soluble" indicate that these nutrients are released relatively quickly. "Ammonium" and "nitrate" forms of nitrogen are also indications of fast-release fertilizers. The fertilizer label shown in Figure 10.3 would indicate that this bag contains a fast-release fertilizer and most of the nitrogen would be relatively mobile and available to plant growth within the first growing season. Ammonium nitrate, ammonium sulfate, potassium nitrate, and urea are several examples of fast-release fertilizers.

***Table 10.1** – Analysis of some common fertilizers. Nitrogen fertilizers are shown in Table 10.2.*

	Source	Available Nutrients (typical values)													
		% N	% P_2O_5	% P	% K_2O	% K	% S	% Ca	% Cu	% Fe	% Mn	% Zn	% B	% Mo	% Mg
Phosphorus	Mono-ammonium phosphate	11	48	21			24								
	Ammonium phosphate	82													
	Diammonium phosphate	17	47	21				21							
	Single superphosphate	19					12	20							
	Triple superphosphate		45	20			1	13							
	Phosphoric acid		53	23											
	Dicalcium phosphate														
	Soluble potassium phosphate														
	Superphosphoric acid		80	35											
Potassium	Potassium chloride				61	50									
	Potassium nitrate	13			45	37									
	Potassium sulphate				51	42	18								
Micronutrients	EDTA								10	10	10	10			
	HEEDTA								6	7	7	9			
	NTA									8					
	DTPA									10					
	EDDHA									6					
	Granular borax												11.3		
	Copper sulfate								25						
	Ferrous sulfate									20					
	Sodium molybdate													40	
	Zinc sulfate											36			
	Zinc chelate											4			
Ca & Mg	Dolomitic limestone							21							11
	Magnesium sulfate														43
	Gypsum							23							
	Epsom salt (Epsogrow brand)						13								10

Introduction
Initiation
Planning
Implementation Guides
Monitoring & Management
Summary

***Table 10.2** – This table gives estimated nitrogen release rates for some commercially available fertilizers. Most release rates were obtained from lab testing. How they actually release on-site will vary from site to site, depending on temperature, moisture, and whether the fertilizer was placed on the surface or incorporated into the soil. If slow-release fertilizers are broadcast on the soil surface, release rates should be slower than if incorporated into the soil where the conditions are better for break down. Arid sites should have slower rates of release than sites with high moisture; cold sites should take longer to release nutrients than warm sites. First year nitrogen release rates for fertilizers are identified with an asterisk were adapted from Claassen and Hogan (1998). Non-asterisk fertilizers were based on best guess estimates.*

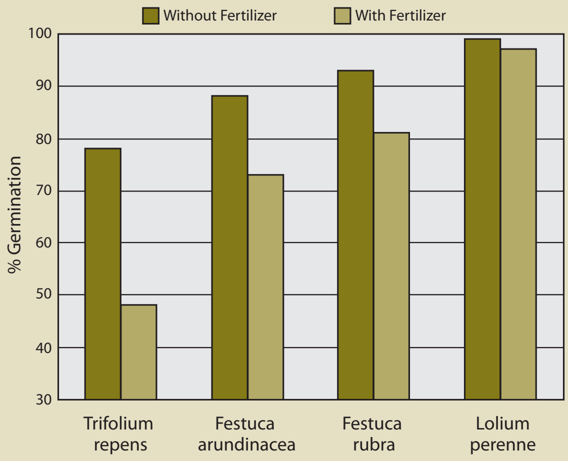
Source	Available Nutrients			
	N %	1st year N release (%)	% P_2O_5	% K_2O
Ammonium nitrate	34	99 to 100	0	0
Ammonium phosphate*	10	99 to 100	34	0
Ammonium sulfate	21	99 to 100	0	0
Anhydrous ammonia	82	99 to 100	0	0
Biosol® *	7	50 to 70	2	3
Calcium nitrate	15.5	99 to 100	0	0
Diammonium phosphate	18	99 to 100	46	0
Fertil-Fibers® *	6	50 to 70	4	1
Gro-Power® *	5	95 to 99	3	1
IBDU	29	95 to 99	3	10
Osmocote 18-6-12® *	18	95 to 99	16	12
Polyon PCU 40® *	30	99 to 100	0	0
Potassium nitrate	13	99 to 100	0	45
Ringer® *	5	50 to 70	10	5
Sustane® *	5	50 to 70	2	4
Urea	46	99 to 100	0	0

"Water soluble" or "available" nutrients do not always remain available or soluble after they are applied to the soil. Available forms of phosphorus, for instance, react in the soil to form less soluble compounds; potassium gets bound up in soils with moderate to high proportions of clay; and many of the micronutrients (e.g., zinc, copper, manganese) become unavailable when applied to soils with low pH (See Section 5.5.5). Unless soils are sandy or rocky, it can be assumed that many of the nutrients stated as "available," except for nitrogen and sulfur, will become somewhat immobile once they are applied. Over time, however, these nutrients will become available for plant uptake.

The advantages of fast-release fertilizers are they are relatively inexpensive, easy to handle, immediately available to the plant, and can be applied through a range of fertilizer spreading equipment. Disadvantages are that some nutrients, such as nitrogen, will leach through the soil profile if they are not first taken up by plants or captured by soil microorganisms in the break down of carbon. Nitrates from fast-release fertilizers have been found to leach through sandy soils to depths that are 4 times the rate of rainfall (Dancer 1975). For example, for sites with annual rainfalls of 12 inches, nitrate could move to a depth of four feet if it was not taken up by plants or soil organisms. At this depth, nitrogen would be out of range of most establishing root systems.

Since fast-release fertilizers are salts, they have a potential to burn foliage and roots, especially when fertilizers are applied at high concentrations or when applied during dry weather (See Section 5.5.5.2). High concentrations of fast-release fertilizers can also affect germination rates (Figure 10.4) because of the high soluble salt levels (Brooks and Blaser 1964; Carr and Ballard 1979). Salt damage can be reduced by mixing fast-release fertilizers at lower concentrations or by applying them during rainy weather.

Figure 10.4 – Germination of seeds for some species can be reduced following exposure to a 10-30-10 fertilizer solution at a rate of 750 lbs fertilizer per 1,000 gallon hydroseeder (after Carr and Ballard 1979).



Slow-Release Fertilizers – These fertilizers are designed to release nutrients at a much slower rate. To be labeled slow-release fertilizer, some states require a specific amount of nitrogen to be in a slow-release form. Forms of nitrogen shown on the label as "slowly-available" or "water-insoluble" are good indicators that a fertilizer is in a slow-release form. The advantages of using slow-release fertilizers are: 1) nutrients are supplied at a time when plants are potentially growing; 2) less frequent applications; 3) less potential for leaching into ground water; and 4) less potential to cause salt injury. The disadvantages are that many slow-release fertilizers are bulky, cost more to purchase and apply, and are limited by the type of fertilizer application equipment that can be used. On the whole, however, slow-release fertilizers have greater applicability for revegetating disturbed sites than fast-release fertilizers.

Slow-release fertilizers come in either organic or inorganic forms. Organic fertilizers include animal manures (including chicken, steer, cow), bone meal, fish emulsion, composted sewage sludge, and yard waste. Unprocessed organic fertilizers are hard to apply to roadside projects because they are bulky and high in moisture. Commercially available organic fertilizers, such as Fertil-Fiber™ and Biosol®, have been processed to remove most moisture, which makes them easier to apply through most fertilizer spreading equipment.

The agents responsible for release of nutrients from organic fertilizers are decomposing soil bacteria. When soil bacteria are active, the release of nutrients is high; when dormant, the rate is low. The release of nutrients is therefore a function of moisture and temperature, which governs the rate of bacterial growth. Warm temperatures and high moisture, conditions conducive to plant growth, are also favorable for the break down of organic fertilizers. Because of this, the release of nutrients from the decomposition of organic fertilizers often coincides with the period when plants are growing (spring and fall) and the need for nutrients is greatest. The nutrient release mechanism of slow-release organic fertilizers reduces the risk that highly mobile nutrients, such as nitrogen, will be released in the winter months when plants are incapable of absorbing them and the potential for leaching is greatest.

Inorganic forms of slow-release fertilizers were developed for the horticulture and landscape industries where they have become an effective method of fertilizing nursery plants. These are an expensive form of fertilizer and have not been tested on roadside revegetation conditions. Nevertheless, they should not be overlooked in their potential applicability for some native revegetation projects.

Inorganic slow-release fertilizers include ureaform, nitroform, IBDU (isobutylidene diurea), sulfur-coated urea, and polymer-coated nitrogen, phosphorus, and potassium. These fertilizers have varying mechanisms for nutrient release. Fertilizer granules coated with materials that release nutrients only during warm, moist conditions assure that nutrients are available during the period that plants are most likely to be growing. These coatings include sulfur (e.g., sulfur-coated urea) and polymers. Each fertilizer has its own formulated nutrient release rate, which varies from 3 months to 18 months. Release rates are available from the manufacturers for most inorganic, slow-release fertilizers. However, it should be noted that these rates were developed for 70 °F soil temperatures (Rose 2002), which are higher than soil temperatures in the western

***Figure 10.5** – An example of calculating fertilizer application rates to reduce nitrogen deficits.*

A	Nitrogen (N) deficit	769	lbs/ac	Calculated from example in Figure 10.2
B	N in fertilizer	8	%	From fertilizer label
C	Total bulk fertilizer needed: A * 100/B =	9,613	lbs/ac	To eliminate deficit
D	Est. first year N release rate of fertilizer	40	%	From Table 10.2 or obtain from manufacturers
E	Available N first year in fertilizer from 1st year application: B * C * D/10,000 =	308	lbs/ac	N available to plants and soil
F	Short-term N target (first year)	50	lbs/ac	Depends on C:N ratio, plant cover, and age (see text)
G	Excess nitrogen: E - F =	258	lbs/ac	Wasted N-could leach from soils into water
H	Adjusted rates of fertilizer to add: F * 100/D * 100/B =	1,563	lbs/ac	To assure that N released first year is not wasted
I	Remaining N deficit: A - (H * B/100) =	644	lbs/ac	Additional N needed as later applications of fertilizer

United States during the spring and fall when roots and foliage are growing. If roadside soils are colder than 70 °F, nutrient release will take longer than what the manufacturer states.

10.1.1.6 Determine Fertilizer Application Rates

Fertilizer rates are determined for each deficient nutrient as shown in Figure 10.5. The calculation in this example was done to eliminate a nitrogen deficit of 769 lb/ac. Using a slow-release fertilizer with 8% nitrogen, the amount of bulk fertilizer necessary to bring nitrogen levels to minimum targets is 9,613 lb/ac (769*100/8=9,613), which is an extremely high rate of fertilizer to apply. On the other hand, using a fast-release fertilizer with higher nitrogen analysis, such as ammonium nitrate (33% N), would reduce the amount of bulk fertilizer to 2,330 lb (769*100/33 = 2,330). While there would be less weight with this more concentrated fertilizer, this is considered a dangerous rate of fertilizer to apply. It would be risky and wasteful considering the potential for leaching high amounts of nitrate through soil into the ground water or the possibility of creating high salt levels toxic to plant growth. This example illustrates the difficulty in developing fertilizer prescriptions to meet long-term nutrient targets. How does the revegetation specialist develop a fertilizer strategy to meet short-term and long-term plant needs without over- or under-fertilizing?

The approach presented in this section is based on building long-term nutrient objectives around meeting short-term nutrient needs of the establishing plant community. For example, applying fertilizer at the time of sowing requires very low rates of available nitrogen to meet the first year needs of the establishing vegetation. Any extra fertilizer has the potential of being wasted. As the vegetation develops over the next few years, the ability of the plant community to take up more available nutrients increases and the fertilizer rates would be gradually increased. This practice, however, is seldom employed in roadside revegetation projects. In fact, the typical fertilizer practice does just the opposite – high rates of fertilizers are put on with seeds before there are even plants to utilize the available nutrients. In this practice, there is no return to the site in later years to assess whether additional applications of fertilizers might be essential for vegetation maintenance or growth. The approach we advocate is applying the appropriate mix of fertilizers to meet the annual needs of the vegetation while building long-term nutrient capital until the plant community is self-sustaining.

Since nitrogen is the key nutrient in establishing plant communities, this approach requires setting short-term and long-term nitrogen requirements of the plant community being established. Calculating long-term nitrogen targets is covered in Section 10.1.1.2. Short-term targets are more difficult to set because they change over time. They are governed by:

- Soil type,
- C:N,
- Climate,
- Amount of vegetative cover,

- Type of vegetation, and
- Age of vegetation.

Some general guides can be helpful in setting short-term nutrient targets for available nitrogen. Applying fertilizer at the time of sowing, for instance, will require very low rates of available nitrogen the first year since vegetation will not be established well enough to utilize it. Rates can be set below 25 lb/ac when applying fertilizer with seeds. When vegetation is becoming established, available N can range from 25 to 50 lb/ac (Munshower 1994: Claassen and Hogan 1998). After plant establishment, rates can be increased to account for increased plant utilization above this amount. These suggested rates should be adjusted upward on sites where high C:N soil amendments, such as shredded wood or straw, have been incorporated into the soil to compensate for nitrogen tie-up. Calculating precise rates of supplemental nitrogen for incorporated organic amendments is very difficult. In nursery settings, rates of over 100 lb of supplemental nitrogen have been recommended for incorporated straw, sawdust, and other high C:N materials (Rose and others 1995). However, applying supplemental rates in wildland settings should be done with caution, utilizing trials where possible to determine more precise fertilizer rates. Utilizing periodic soil analysis can give the revegetation specialist a better understanding of the soil nitrogen status. To keep testing costs low, only available nitrogen and total nitrogen need to be tested (See Section 5.5 for soil sampling and testing methods).

In determining how much fertilizer to apply, it is important to estimate how much nitrogen will be available the first year and the second year. Manufacturers have this information for most inorganic slow release fertilizers, and Claassen and Hogan (1998) performed tests on organic slow release fertilizers (shown in Figure 10.2). Release rate determinations are performed in the laboratory. How fertilizers actually release in the field will vary by the environment. In the example described in Figure 10.5, the first year release rate of nitrogen from the slow-release organic fertilizer was estimated at 40%. This was a guess based on the manufacturer's estimates of 55% release, but because it was being applied to a semi-arid site where decomposition of the fertilizer would be slow, the rate was dropped to 40% (Line D in 10.5). If 40% of the nitrogen became available the first year, 60% would remain for the following years (Line E). At this release rate, 308 lb/ac of nitrogen would become available the first year after application (Line F). While this is an extremely high rate, consider the application of ammonium nitrate at 100% first year release, which would supply 769 lb/ac (Line A) of immediately available nitrogen. Recalculating fertilizer rates using a more realistic rate of 50 lb/ac available nitrogen needed the first year after application (Line F), bulk fertilizer application rates would be 1,563 lb/ac (Line H). At this new rate, the site would have sufficient first- and second-year supplies of nitrogen, but lack adequate nitrogen the following years. The remaining deficit to meet long-term nitrogen targets would be approximately 644 lb/ac, which must be supplied through later applications of fertilizer or other carriers of nitrogen (topsoil, compost, biosolids, wood waste, mulch, and nitrogen-fixing plants). A nutrient strategy should be built around reducing nitrogen deficits over time.

The process outlined in Figure 10.5 can be used for other deficient nutrients. Understanding the availability of other nutrients is problematic. Many nutrients become fixed in the soils and their availability is dependent on highly variable factors such as soil texture, pH, and placement in the soil. It is a reasonable assumption that unless the soils are sandy or very rocky, that all nutrients, aside from nitrate or ammonium forms of nitrogen, are relatively unavailable the first year after application. With time, however, they will slowly become available.

10.1.1.7 Determine Timing and Frequency

The primary reason to fertilize is to supply nutrients during periods when plants can take them up for growth. The demand for nutrients changes throughout the year depending on the physiological state of each plant. In nursery settings, fertilizers are adjusted throughout the year at rates and formulations that correspond to the requirements of the plant. While we do not have that capability in wildland settings, we can use the fertilizers available to us more wisely by applying our understanding of how the assortment of fertilizers function in meeting the nutrient requirements of plant communities. At least two plant growth phases should be considered in the timing of fertilizer application – 1) seed germination, and plant establishment and 2) post plant establishment.

Seed Germination and Plant Establishment Phase – Traditionally, fast-release fertilizers have often been applied at high rates in the fall during the seed sowing operation. This practice is a quick and easy way to apply fertilizers. However, the timing can result in ineffective and wasteful use of fertilizers (Figure 10.6B) (Dancer 1975). In addition, application of fast-release fertilizers at this time can potentially pollute water sources. Slow-release fertilizers are more appropriate for seed sowing in the fall because much of the fertilizer should last through the winter, releasing nutrients in the spring (Figure 10.6D).

Perennial grasses and forbs do not require high levels of nitrogen for germination and early establishment (Reeder and Sabey 1987). In fact, elevated levels of available nitrogen can be a problem because it encourages the rapid establishment and growth of annual weed species over slower-growing perennial grass and forbs (McLendon and Redente 1992; Claassen and Marler 1998). Applying high rates of fertilizers during germination and early seedling establishment should be reconsidered in terms of how much fertilizer is actually needed in the establishment phase and how much will be available later for plant growth (See Section 10.1.1.6).

One strategy is to apply little or no fertilizer during sowing and wait until seeds have germinated and grown into small seedlings before fertilizers are applied (Figure 10.6C). This strategy assures that nutrients are available when the seedlings actually need them, not before. Fertilizers applied as slow-release form are preferred because they have less potential for causing salt damage when applied over emerging seedlings. Another strategy is to wait until the following fall (Figure 10.6E) or spring (Figure 10.6F) of the second year to fertilize.

Post-Establishment **–** Once vegetation is established (one or two years after sowing), fertilizers can be applied at higher rates with the assurance that nutrients will be taken up by the plants. Slow- and fast-release fertilizers can be combined to provide short- and long-term nutrient requirements (Figure 10.6 E and F). Spring applications of fast-release fertilizers are more effective than fall application because of the higher nutrient requirements of growing plants during that period (Figure 10.6F). Spring applications also have less risk of damaging vegetation through fertilizer salts because precipitation in the spring is typically frequent enough to wash fertilizers from the foliage. It is always prudent to check the conductivity of a fertilizer solution being applied over existing vegetation to avoid salt damage. A conductivity meter can be used to measure the conductivity of the solution (See Section 5.5.5). If rates exceed 3,500 mS/cm, then diluting the solution or applying the fertilizer during rainy weather is advised. Fall application of fertilizers should be done at lower rates and early enough for nutrients to be utilized by the growing vegetation. Fertilizer rates can be adjusted based on plant phenology or dormancy to minimize salt damage. Fertilizing dormant plants is also a possible way to minimize damage.

10.1.1.8 Select Fertilizer Application Method

Since nutrients have varying degrees of mobility (nitrogen is highly mobile; phosphorus and many micronutrients are relatively immobile), how fertilizers are applied will determine how accessible nutrients are to the root system. If nutrients are highly mobile, the easiest and least expensive method is to apply fertilizer to the soil surface, or broadcast, to allow rainfall or snowmelt to release and move nutrients into the soil. A more difficult, yet more effective application method for immobile nutrients is to incorporate, or mix, fertilizers into the soil surface so fertilizer granules are uniformly distributed within the soil and accessible by root systems.

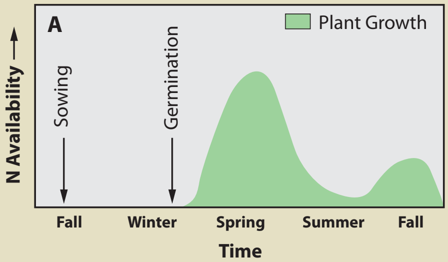
Broadcast Fertilizer Application **–** For fertilizers with highly mobile nutrients, such as nitrogen and sulfur, broadcast application on the soil surface is an appropriate practice. For immobile nutrients, broadcast fertilizer application can be relatively ineffective. These nutrients often become immobilized at the soil surface and are very slow to move into the rooting zone where they can be accessed. Depending on soil characteristics, such as pH and clay content, some immobile nutrients will take years to move only a few inches from the point of fertilizer placement.

There are a variety of dry fertilizer spreaders available, from hand-operated to tractor-mounted. Most equipment is limited to moderate slope gradients (less than 1V:2H). With all forms of spreaders, they must be calibrated before they are used to assure that the correct rates are being applied.

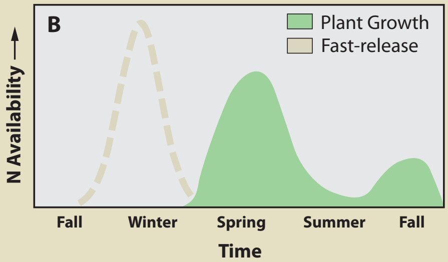
Hydroseeding equipment can be used to apply fertilizer in the same operation with seeds, tackifiers, and hydromulch (See Section 10.3.2, Hydroseeding). This equipment can also be used solely to apply fertilizers, especially after vegetation has become established. A great advantage to using hydroseeding equipment is that it can uniformly spread fertilizers on steep

Figure 10.6 – *Fertilizers should be applied during seasons, and at rates and formulations that release nutrients when native plants can efficiently draw them from the soil. The following are strategies for applying slow and fast release fertilizers.*

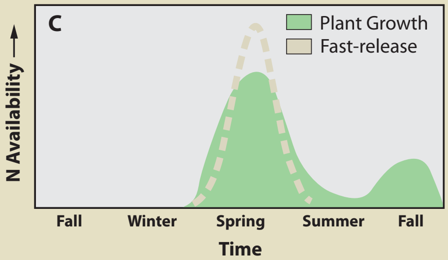
A. *When seeding occurs in the fall, seeds typically do not germinate until the following spring, at which time there is rapid growth. During the summer, growth rates slow. Growth rates accelerate again in the fall.*



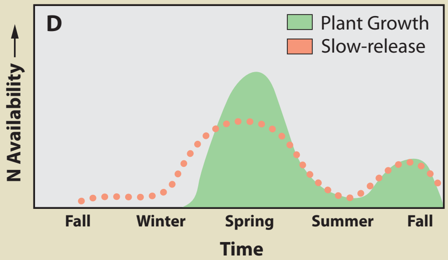
B. *When fast-release fertilizers (dashed line) are applied in the fall during seeding, fertilizers move into the soil with fall rains. However, there is no vegetation to take up the nutrients. Mobile nutrients, such as nitrogen, are leached and unavailable in the spring when the establishing plants require them.*



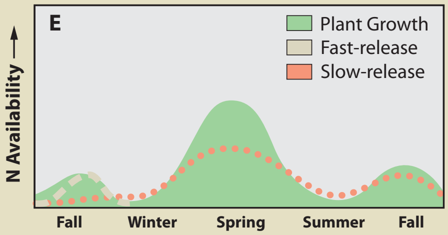
C. *Fast-release fertilizer applied in the spring after plants are established is more effective because plants are rapidly growing and can take up nutrients. There are fewer storms in the spring to leach nutrients from the soil.*



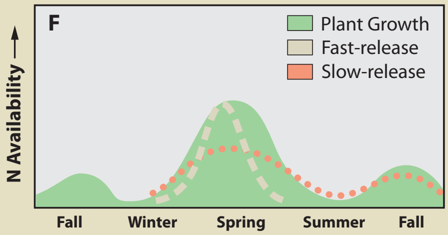
D. *Slow-release fertilizers (dotted line) release nutrients at a much slower rate. When they are applied in the fall, most of the nutrients should still be available in the following spring.*



E. *Once vegetation has become established, plant growth will take place in the fall. Fertilizers applied at this time will be taken up by growing vegetation. Since slow-release fertilizers might not be immediately available, small amounts of fast-release fertilizers can be added to give immediate release of nutrients.*



F. *Slow- and fast-release fertilizers can be applied in the early spring before rapid root and vegetative growth. Fast-release fertilizers can supplement slow-release fertilizers by supplying immediately available nutrients.*



Inset 10.1 – Spot-Fertilizing Seedlings

Fertilizing shrub or tree seedlings is done by placing fertilizer in each seedling hole or on the soil surface after each seedling has been planted. This practice has some risks, because fertilizers release salts which can damage roots. Studies have shown that placing fertilizers or liming materials in the planting hole or on the soil surface around seedlings at the time of planting can significantly decrease seedling survival, especially on droughty sites (Nursery Technical Cooperative 2004; Jacobs and others 2004; Walker 2002).

To reduce the likelihood of seedling damage, follow these practices:

- Assess the need for fertilizer (do not apply if nutrient levels are adequate).
- Use slow release fertilizers with low salt indexes.
- Use low rates of fertilizer if applying at the time of planting.
- If applying in seedling hole at planting, use low fertilizer rates and place fertilizer to the side at least 3 inches away from the root system.
- Preferably broadcast fertilizers on the soil surface after seedlings are well established.

When slow-release fertilizers are spread around well-established seedlings (several years after planting), seedlings often respond favorably, especially on highly disturbed sites. Walker (2005) showed that slow-release fertilizers broadcasted three years after seedlings were planted, increased stem diameter and shoot volume over the control seedlings by 143% and 104% respectively five years after the fertilizer was applied. In this study, rates of .05 grams of nitrogen per seedling showed the greatest response (at 8% nitrogen analysis, this would be over a half pound of bulk slow-release fertilizer per plant).

slopes and a variety of topographies. In addition, a combination of fertilizers can be easily mixed in the hydroseed tank and applied at relatively even proportions because they are in a solution. This is especially useful for applying small quantities of fertilizer, such as micronutrients, which are difficult to spread evenly over large areas.

Fertilizer Incorporation **–** It is important that nutrients that are deficient and have low mobility be incorporated into the soil prior to sowing or planting. Incorporation is possible on gentle slopes, but becomes very difficult with increasing slope gradients because of equipment limitations. On sites where fertilizers containing immobile nutrients cannot be incorporated, an alternative is to create roughened soil surfaces (See Section 10.1.2, Tillage) prior to fertilizer application. Broadcast fertilizers will accumulate in the depressions of the surface. As soil gradually moves into the depressions over time (through water erosion or surface ravel), the broadcast fertilizers will become covered with soil. When this happens, immobile nutrients are accessible by roots and nutrient uptake is possible. Surface roughening also reduces the potential for fertilizers to move off-slope through erosion.

Some agricultural spreaders, called fertilizer banders or injectors, are designed to place fertilizer, or other soil amendments including mycorrhizae, at varying depths in the soil. Usually this equipment has a ripping shank or tine that loosens the soil, followed by a tube that drops the fertilizer, and coulters or rollers that close up the furrow. As the bander is pulled through the soil, a line, or band, of fertilizer is created. Sowing and banding are often combined in one piece of equipment and applied at the same time. Fertilizer banders were developed for agricultural use and are limited by rock content and slope gradients. However, there are injectors that have been develop for wildland conditions (St John 1995).

The most common approach to incorporating fertilizer is accomplished in two operations, broadcasting fertilizer on the soil surface and tilling it into the soil. Hydroseeders and broadcast fertilizer spreaders, as discussed above, are means of applying the fertilizer evenly over the site, then the fertilizer is tilled into the soil using equipment outlined in Section 10.1.2, Tillage.

10.1.2 TILLAGE

10.1.2.1 Introduction

Tillage is defined in this section as any mechanical action applied to the soil for the purposes of long-term control of soil erosion and reestablishment of native plant communities. Tillage equipment was developed for agricultural soils and has limited applicability for steep, rocky sites typically encountered in wildland revegetation. This section will discuss the agricultural equipment that can be used for wildland revegetation as well as equipment specifically developed for these extreme conditions.

There are several reasons to use tillage in a revegetation project, including to:

- Shatter compacted soils,
- Incorporate soil amendments, and
- Roughen soil surfaces.

These objectives often overlap. For example, incorporating organic matter also loosens compacted soils and roughens soil surfaces. Identifying the objectives for the project will lead to selecting and effectively using the appropriate equipment to achieve the desired soil conditions (Table 10.3).

10.1.2.2 Shatter Compacted Soils

One of the primary purposes for tilling is to loosen compacted soils. When performed correctly, tillage can increase porosity in the rooting zone, increase infiltration rates, and increase surface roughness. For revegetation work associated with road construction and road obliteration, tillage to break up deep compaction is important for reestablishing plant communities. Shattering compaction at depths of at least 2 feet is essential for the healthy growth of most perennial plant species. Without this measure, it will take many decades for deep compaction to recover its original bulk density (Wert and Thomas 1981; Froehlich and others 1983). In a review of tillage projects on rangeland soils, Gifford (1975) found that deep tillage greatly reduced runoff, while shallow tillage had little effect.

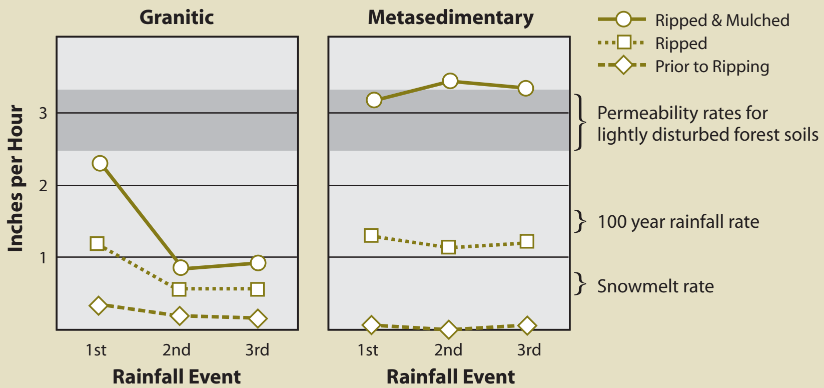
Tillage alone will not return a soil to its original bulk density or hydrologic function (Figure 10.7), nor will the effects of tillage last indefinitely, especially in non-cohesive soils (Onstad and others 1984). There are many factors that affect the return to bulk densities and infiltration rates typical of undisturbed reference sites. These include the type of tillage equipment used, penetration depth, soil moisture during tillage, soil texture, presence of topsoil, and organic matter content.

There are two fundamentally different equipment designs for reducing compaction. One design simply lifts and drops soil in place, shattering compacted soil in the process. This type of equipment includes rock rippers, subsoilers, and "winged" subsoilers. The second design churns and mixes the soil. Equipment that falls into this category includes disk harrows, plows, spaders, and attachments to excavators. This type of equipment can also incorporate soil amendments, like organic matter or fertilizers, in the same operation, and will be discussed in Section 10.1.2.3.

Table 10.3 *– The appropriate tillage equipment for the project depends on project objectives.*

OBJECTIVES	TYPE OF TILLAGE		
	Shattering	Mixing	Imprinting
	Rippers & subsoilers	Disks, plows, excavator attachments	Dixon imprinter, excavator attachments, trackwalking
Loosen compacted soil	Good	Good	Poor
Incorporate amendments	Poor	Good	Poor
Roughen surface	Good	Good	Good

***Figure 10.7** – Short-term benefits of ripping (using a winged subsoiler) and mulching road surfaces vary by soil type, as shown in rainfall simulation tests on sites in northern Idaho. Granitic soils responded to ripping and mulching with increased permeability during the first storm, but permeability rates returned to near pre-treatments rates with successive rainfall events. Metamorphic soils reacted positively to both treatments and maintained high permeability rates after three rainfall events. Mulching improved permeability in both soil types. In fact, for metamorphic soils, the combination of ripping and mulching increased permeability to rates that were typical of lightly disturbed forest soils (adapted from Luce 1997).*



The terms subsoiling and ripping are used interchangeably to describe soil shattering operations. Soil shattering involves pulling one tooth, or a set of teeth, at various depths through the soil to break up compaction created by equipment traffic. The rock ripper is a common tool found on most construction sites. When used to break up compaction, one or two large ripper tines are typically pulled behind a large bulldozer at 1 to 3 ft soil depths. While this equipment will break up compaction in portions of the soil where the ripper tines have been dragged, it does not effectively fracture the compacted soil between the ripper tine paths (Andrus and Froehlich 1983). The effectiveness of rippers can be increased by multiple passes through the soil or by adding tines to the toolbar. Even on small machines, up to 5 tines can be added to increase soil shatter.

Rippers have also been adapted to increase soil lift between tine paths by welding wide metal wings to the bottom of each tine. These wings are angled upwards so the soil between the tines has greater lift, and therefore greater shatter when the soil drops behind the wing. When two or more tines are placed together on a toolbar, they work in tandem to more effectively break up compaction. The resulting equipment is called the "winged" subsoiler (Figure 10.8). Andrus and Froehlich (1983) found that the winged subsoiler was a far more effective tool for breaking up compaction. This equipment fractured over 80% of the compaction in several operational tests, as compared to 18% to 43% for rock rippers and 38% for brush rakes. However, winged subsoilers are not practical in all soils, especially those with high rock fragments, buried wood, or slopes greater than 3H:1V gradients.

***Figure 10.8** – Soil shattering becomes more effective when wings are mounted on subsoil tines. This equipment is called a winged subsoiler. Photo courtesy Brent Roath.*

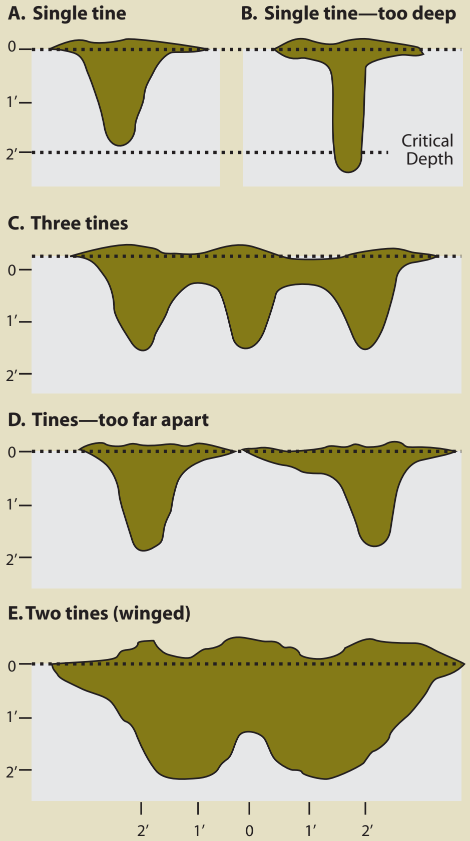
Achieving good shatter at deeper soil depths requires that tillage equipment be adjusted for site-specific soil conditions, especially soil texture, soil moisture, and large rock content. Soils should not be too moist during ripping because the tines will slice through the soil, causing very little soil shatter. Subsoiling when soils are extremely dry can bring up large blocks of soils, especially when the soils are high in clays (cohesive soils).

The winged subsoiler and rock ripper should be adjusted to meet the soil conditions of the site. Making the proper adjustments can lead to greater shatter and more efficient use of tractor equipment. These adjustments include:

- Tine depth,
- Tine spacing,
- Number of tines, and
- Wing width and angle (for winged subsoiler).

Tines should be set above the critical depth for the condition of the soil. If tines are set below this depth, the tines will not shatter the soil (Figure 10.9B). The critical depth changes for soil type and tine configuration. Soils high in clays with high soil moisture have shallower critical depths (Andrus and Froehlich 1983). The closer the spacing of tines, the greater the shattering. The more tines that are placed on a toolbar, the more area of soil can be shattered. However, where large rocks or large slash are present, closely spaced tines will drag these materials out of the ground. Three to five tines are typically used for most soil types. Wing size, angle, and shape of the tines all play a role in breaking up compaction (See Inset 10.2 for specifications for winged subsoiler).

***Figure 10.9 –** The effectiveness of subsoiling or ripping equipment to shatter compacted soil is a function of tine depth, number of tines, distance between tines, and wing configuration. Pulling a single tine (A) above a critical depth does some soil shattering as compared to a single tine ripping deeper than a critical depth (B). Placing 3 or more tines together (C) can be more effective than one tine, but tine spacing should not be too far apart or soils between the tines will not be shattered (D). Attaching wings to the tines is very effective in shattering compaction between the tines (E) (modified after Andrus and Froehlich 1983).*



Typical settings for rock ripper and winged subsoiler equipment configurations are shown in Table 10.4. These are suggested settings and should not be applied without first monitoring the results of the equipment on the project soils. The most direct method for monitoring soil shatter is to measure the depth to the compacted soil with a soil penetrometer or shovel (See Section 5.3.3.1). Immediately after a pass is made with the tillage equipment, the penetrometer is pushed into the soil and the depth to the compacted layer is recorded. Measurements are taken every 6 inches across a small transect perpendicular to the direction of the tractor and spanning the width of the tillage disturbance. Plotting the depths to compaction on graph paper gives a cross-section of the shattering pattern (Figure 10.9 is an example of plotting soil shatter). If the shattering pattern is inadequate, adjustments can be made to the tine depth, tine spacing, and angle of the wing. If these adjustments fail to increase soil shatter, a second and even third pass by the ripper or winged subsoiler should be

Table 10.4 – Recommended design features for some tillage equipment (modified after Andrus and Froehlich 1983; Froehlich and Miles 1984).

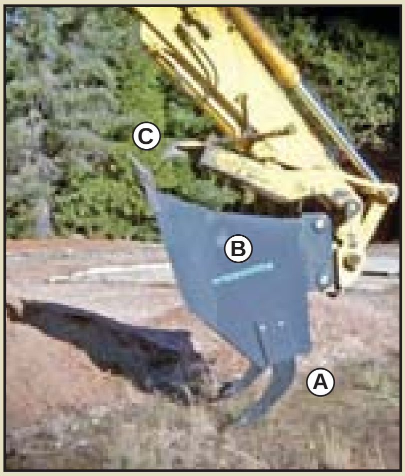
Item	Implement Feature	Recommended Design
Disk harrow	Disk diameter	40 - 50 in.
	Number of disks	6 -12
	Average disk weight	>1,800 lbs
	Disk arrangement	Offset gangs, independent disks
	Max slope (cross slope travel)	<5:1 H:V
	Max slope (down slope travel)	5:1 H:V
Brush blade	Tine spacing	22 - 26 in.
	Tine depth	<20 in.
	Max slope (cross slope travel)	>5:1 H:V
	Max slope (down slope travel)	3:1 H:V
Rock rippers	Tine spacing	24 - 30 in. (one pass)
		40 - 48 in. (two passes)
	Ripping depth	20 -24 in.
	Number of tines	5 (one pass)
		3 (two pass)
	Max slope (cross slope travel)	<5:1 H:V
	Max slope (down slope travel)	2.5:1 H:V
Wings of sub-soilers	Ripping depth	18 - 22 in.
	Number of tines	3 - 4
	Tine spacing	30 - 40 in.
	Wing width	12 - 24 in.
	Wing angle	10 - 60°
	Max slope (cross slope travel)	<5:1 H:V
	Max slope (down slope travel)	2.5:1 H:V

considered. Successive passes should be made at 45 to 90° angles from the first pass to achieve the greatest benefit.

A general rule for tillage work is to operate equipment on the contour to reduce the potential of water concentrating in the paths of the furrows and creating soil erosion problems. Operating equipment on the contour (cross slope) is limited to gentler slopes (Table 10.4). To optimize the use of equipment on steep slopes, down-slope operation of equipment must not create long, continuous furrows. It is also important to consider that if cuts and fills are left less compacted, there will be deeper rills and gullies created if concentrated flows of water are directed onto these slopes. These features are unsightly and can deliver high quantities of sediment to watercourses. Therefore, on slopes that have been tilled, it is important to redirect any concentrated flow of water that might enter the top of the cut to areas that are designed to handle this water. While it is not the job of the revegetation specialist to walk the tops of cuts and fills to determine whether concentrated water might flow into areas that are not designed for it, the success of the tillage project might depend on it.

Most soil shattering equipment is attached to a tractor toolbar and is limited to slope gradients of 3H:1V or less. Subsoilers and rippers are best used for projects that consist of gentle terrain or obliterated road sections. Newer equipment, such as the subsoiling grapple rake, has been developed to overcome these limitations. Attached to the arm of an excavator, this equipment can reach 35 feet up and down slope and specifically rip targeted areas of compacted soil (Figure 10.10).

***Figure 10.10** – The subsoiling grapple rake is a quick-mounting attachment to excavating machinery that combines several operations in one: (A) subsoiling with winged tines, (B) soil incorporation with bucket, and (C) removal of rock and slash with grapples (Photo courtesy of Mike Karr, Umpqua National Forest).*



10.1.2.3 Incorporate Soil Amendments

Tilling is used to incorporate fertilizers, organic matter, lime, and other amendments evenly throughout the soil, while loosening compacted soils. Tilling with these objectives requires equipment that mixes soil, such as plows, tillers, disks, chisels, and soil spaders. This equipment is tractor-drawn and limited to gentle slope gradients (5H:1V or greater) and soils low in rock fragments. These tools are not designed to break up deep compaction. Under most disturbed soil conditions, the best that can be expected this equipment is tillage to a depth of 8 to 12 inches.

Rippers and subsoilers are not very effective in incorporating materials such as fertilizers or organic matter into the soil. Nevertheless, spreading mulch on the soil surface prior to ripping or subsoiling usually incorporates enough organic matter into the soil surface to enhance infiltration rates (Luce 1997). In the same manner, fertilizers applied to the soil surface, especially those containing immobile nutrients, will be mixed into the top several inches of soil and made available to surface roots. On projects where topsoil has been salvaged and reapplied, subsoilers or rippers are the preferred equipment. Using equipment that mixes soils runs the risk of incorporating salvaged topsoil with the infertile subsoil.

A more recent set of specialized revegetation tools that mix and incorporate amendments have been developed for the tracked excavator. The arm of the excavator can reach 35 to 40 feet on steep cut and fill slopes and work soils that were previously inaccessible to most equipment. The simplest excavator attachment is the bucket which can be used to move topsoil or organic matter to concentrated locations and creating mounds or planting islands (See Section 10.1.8). When islands are created for deep-rooted species, such as shrubs and trees, soil can be excavated several feet deep with the excavator bucket and incorporated with organic matter amendments to create a deep rooting profile.

The subsoiler grapple rake (Figure 10.10) adds several design features to the excavator bucket. In addition to mixing organic amendments into the soil, the subsoiler grapple rake can remove large rock with the grapples and loosen soils with the winged subsoiling tines.

Inset 10.2 – Contract Specifications for a Winged Subsoiler

A winged subsoiler consists of a self-drafting, winged subsoiler on a dolly mount, sized for use with a D-7 tractor. The unit consists of three winged ripper tines capable of extending 12 to 34 inches below the draw bar. Wings shall be at least 20 inches wide with a 2 inch lift of the wings from horizontal. Tines shall have an individual tripping mechanism that automatically resets; tine spacing must be adjustable and individual tines must be removable. Various wing patterns must be available and easily interchangeable. Implement must be capable of achieving maximum fracture of compacted soils (minimum 24 inches) in one pass (Adapted from Wenatchee National Forest contract specifications).

10.1.2.4 Roughen Soil Surfaces

Tilling is often done to roughen the soil surface for erosion control and to create a more optimum seedbed (See Section 5.6.7). The micro-topography of a roughened surface consists of discontinuous ridges and valleys. The valleys become the catch basins for seeds and surface runoff. Seeds have greater opportunities to germinate and become established in the micro-valleys because of increased moisture, higher humidity, protection from the wind, and shelter from the sun. Surface roughening is a side benefit of the mixing and shattering operations discussed above in Section 10.1.2.2 and Section 10.1.2.3. Roughening is also accomplished by either scarifying or imprinting operations.

Scarification is the shallow loosening of the soil surface using brush blades, harrows, chains, disks, and chisels. Because it only loosens the soil surface several inches, the benefits for revegetation are only seen during seed germination and early seedling establishment. Once root systems hit the hard compacted layer several inches below the loosened surface, plant growth is curtailed.

Imprinting is a form of surface tillage that leaves the soil with a pattern of ridges and valleys. The equipment applies a downward compressive force to a metal mold, leaving an impression on the soil surface. The most basic type of imprinting is trackwalking (Figure 10.11). In this operation, tracked equipment are "walked" up and down cut and fill slopes, leaving a pattern of tractor cleat imprints on the soil surface no deeper than an inch or two deep. Imprinting methods that are tractor-based are restricted by slope gradients. Since heavy equipment is used, trackwalking can compact soils. Compaction is not often considered when selecting trackwalking practices because soils of most construction sites are already very compacted, and trackwalking is unlikely to significantly increase compaction. This is one reason why trackwalking has been considered beneficial for erosion control and revegetation because it does create a somewhat better "short-term" growing environment and reduces surface erosion and sedimentation on a very poor site.

An alternative to trackwalking is the use of the bucket of an excavator to pack and imprint the soil surface. Different patterns of steel "teeth" can be welded on the face of the bucket to achieve the desired surface micro-relief. Figure 10.12 shows a makeshift imprinter, which is simply 4 strips of angle iron welded to a bucket to create a pattern of 3-inch deep impressions. The excavator in this example can move topsoil in place, shape the cut and fill slopes, and imprint the surface, all with one operation.

If the last operation on a construction site is to subsoil or rip soils 1.5 to 2 ft deep and leave the soil surface in a roughened condition prior to revegetation, trackwalking would be more detrimental than beneficial on most soils. The tractor used to create imprints would compact the tilled soil leaving the surface smoother (less rough) than if left alone. If one of the construction objectives is to leave the construction soils in non-compacted condition,

Figure 10.11 *– Trackwalking creates imprints on the soil surface, but will also compact surface and subsurface soils.*

Figure 10.12 *– An alternative form of imprinting road cuts and fills that does not compact soils is welding angle iron onto the bucket of an excavator. As the excavator pulls topsoil into place and contours the slope, it presses the face of the bucket into the soil surface to form surface imprints.*

the use of trackwalking should be seriously weighed against the long-term impacts to plant establishment and growth. Compaction will affect surface infiltration and runoff, therefore, trackwalking should be critically evaluated for its potential increase in soil erosion. Rainfall simulation tests can be run on sites near the construction project that have been trackwalked and compared with those that have been left in an uncompacted state to determine the effects on runoff and soil erosion (Hogan and others 2007).

Specialized imprinters have been developed for rangeland restoration. For example, the "Dixon" imprinter was developed to restore perennial grasses for rangelands in Arizona and other arid states. It consists of a roller with large conical metal "teeth" that is pulled behind a tractor. The imprinter creates a pattern of V-shaped troughs, 4 to 7 inches deep, encompassing approximately 1 ft^2 area (Dixon and Carr 2001a, 2001b). These imprints are substantially larger and deeper than those created by trackwalking, with greater longevity. This equipment also has a set of ripping shanks attached to the tractor that shatters deeper compaction before imprinting.

10.1.3 MULCHES

10.1.3.1 Introduction

Mulch is defined as a protective material placed on the soil surface to prevent evaporation, moderate surface temperatures, prevent weed establishment, enrich the soil, and reduce erosion. Mulches therefore have many functions or roles in the recovery of native vegetation to a disturbed site. But confusion often arises around the use of mulches on revegetation projects unless the reasons for using them in a project are clearly defined. In this discussion, we have grouped mulches into four uses based on revegetation objectives:

- Seed Covering,
- Seedling Mulch,
- Soil Improvement, and
- Seed Supply.

For most projects, mulches are used to meet more than one objective. Problems arise when the methods for applying overlapping objectives are not compatible. For example, erosion control objectives and seed covering objectives go hand-in-hand because the soil surface needs to be stable for seeds to germinate and grow into young seedlings. In turn, the surface ultimately becomes stable through the establishment of young plants. Yet erosion control products and practices that are effective for controlling surface erosion are not always optimal for establishing vegetation. For this reason, it is important to understand the objectives for mulching and to integrate them into a comprehensive strategy when selecting mulch types and application methods.

This section discusses the objectives for applying mulches and the potential mulch sources. We have left the discussion of the effectiveness of mulches for erosion control and surface stabilization to the many publications and research devoted to this topic and focus primarily on the characteristics of mulches for plant establishment.

10.1.3.2 Seed Covering

One of the principal reasons for applying mulch is to enhance seed germination and early seedling establishment. During this critical period, desirable mulches will:

- Protect seeds and young seedlings from soil splash, sheet erosion, and freeze-thaw;
- Keep seeds moist during germination;
- Moderate surface temperatures during germination;
- Keep young seedlings from drying out; and
- Prevent salts from wicking to the surface and harming newly germinating seedlings.

The characteristics of mulch materials that make ideal seed coverings are those that protect seeds from drying winds, solar radiation, high evapotranspiration rates, and surface erosion while still allowing seeds to germinate and grow through the mulch into healthy seedlings. Long-fibered mulches, such as straw, wood strands, pine needles, and ground or chipped wood, placed at the appropriate thickness, usually meet these characteristics. When applied correctly, the strands of long-fibered mulch loosely bridge on top of each other, much like "pick-up-sticks," forming large air spaces or pores (Figure 10.13). Large pores function much like the air spaces in building insulation by moderating extreme temperatures.

***Figure 10.13** – Long-fibered mulches, like wood strands shown below, create a good growing environment because seeds and seedlings are protected from excessive drying during germination and early seedling establishment. On sites where freeze-thaw is prevalent, long-fibered mulches can insulate the soil and protect emerging seedlings.*

Compared to short-fibered mulches, such hydromulch, long-fibered mulches can be applied at greater thicknesses, which help maintain surface soil moisture and higher humidity around germinating seeds and emerging seedlings. In addition, long-fibered mulches can mitigate the effects of frost heaving at the soil surface (Kay 1978), significantly reduce high surface temperatures (Slick and Curtis 1985), and allow sunlight penetration, which enhances seed germination and seedling establishment. Large pores created by long-fibered mulches also allow better gas exchange between the soil and atmosphere (Borland 1990).

Short-fibered mulches, on the other hand, have smaller pores and form denser seed covers. These materials are typically applied thinly (Figure 10.14), so they offer less insulation than long-fibered mulches and therefore have less value as a seed covering. Some researchers suggest that very fine textured mulches can actually increase surface evaporation by wicking moisture from the soil to the surface of the mulch (Slick and Curtis 1985; Borland 1990; Bainbridge and others 2001). Short-fibered mulches are effective as an erosion control cover, but are considered inferior to long-fibered mulches for germination and early seedling establishment (Kill and Foote 1971; Meyer and others 1971; Kay 1974, 1978, 1983; Racey and Raitanen 1983; Dyer 1984; Wolf and others 1984; Norland 2000).

***Figure 10.14** – Hydromulch with tackifier can stabilize the soil surface for up to a year, but does not necessarily create an optimum environment for germinating seeds. The short-fibered textures typically form a covering that is too thin to maintain moisture around the seeds during germination when the weather is dry. The hydromulch (dyed with a green tracer) shown in this picture is applied at approximately 1,500 lb/ac.*

Erosion mats can perform well as seed covers (See Section 10.1.3.8). These materials come in rolls or sheets, which are laid out on disturbed soils and anchored in place after seeds have been sown. They are composed of such materials as polypropylene, straw, coconut, hay, wood excelsior, and jute. Good characteristics of erosion mats for seed germination and early seedling growth are those with enough loft, or porosity, to create a micro-environment for seed germination while allowing some sunlight to penetrate to the surface of the soil (Figure 10.15).

On sites where vegetation is expected to take several years to establish (e.g., arid, high elevation sites), it is important to apply a mulch with a longevity of more than one year. Materials with greatest longevity are most long-fibered wood mulches, as well as erosion mats made from polypropylene. Straw, hay, and short-fibered wood products are less likely to be present after the first year.

Mulching for seed covering is critical on sites that have: 1) high evapotranspiration rates during germination, 2) unstable soil surfaces, 3) susceptibility to freeze-thaw, and 4) high soil pH. It is less important on sites where soil surfaces do not dry out during seed germination or on projects where seeds have been covered by soil.

10.1.3.3 Seedling Mulch

Mulch is placed around newly planted or established plants to improve survival and growing conditions by:

- Reducing surface evaporation,
- Preventing the establishment of competing vegetation,
- Moderating surface temperatures, and
- Allowing water infiltration.

Studies have shown that survival and growth of young trees are significantly increased by applying mulches around seedlings at the time of planting (DeByle 1969; Lowenstein and Ptikin 1970; Davies 1988a, 1988b). Mulching around seedlings results in the greatest benefit on hot and dry sites (typically south and west aspects) and sites with aggressive competing vegetation. It is less important to mulch around seedlings on sites that have a low potential for establishing competing vegetation the first several years after planting. Mulching is also less critical on sites that have low evapotranspiration rates or high summer rainfall.

Seedling mulches are applied either as an organic aggregate or as sheets. Organic aggregate mulches consist of shredded or chipped wood derived from bark, wood, branches, sawdust, or lawn clippings applied deeply around seedlings. Sheet mulches are large pieces of non-permeable or slightly permeable materials made from translucent plastic, newspaper, or geotextiles (woven fabrics) that are anchored around planted seedlings (Figure 10.16).

Sheet Mulches – A variety of sheet mulches are available commercially. These mulches are popular because of the relative ease of transport and installation. The effectiveness of sheet mulches increases with the size of the sheets. For most hot, dry sites, a 2.5 by 2.5 ft sheet is considered to be the minimum dimension (Cleary and others 1988). On harsher sites, 3 by 3 ft or even 4 by 4 ft sheets are necessary to control competing vegetation. When purchasing and installing sheet mulches, the following should be considered (after Davies 1988a, 1988b):

1) **Select the right size.** The size of the mulch should be based on site conditions and the type and amount of competing vegetation. A hot, south-facing site with full cover of competing grasses will need a large sheet mulch; a north-facing slope with scattered forbs and grasses will suffice with the smallest size.

Figure 10.15 – *Erosion mats can be good seed covers. Mats with the highest loft create the best microenvironment for seed germination while allowing some sunlight to penetrate to the surface of the soil.*

Figure 10.16 – *Sheet mulches come in a variety of materials, such as the paper/ cardboard product shown in this picture. The size of the sheet mulch must be large enough to keep competing vegetation away from the seedling. The 3 by 3 ft sheet mulch shown around this Pacific madrone* (Arbutus menziesii*) seedling is the minimum size for this site.*

2) **Order only opaque materials.** Translucent materials should not be used as sheet mulches because weed seeds can germinate and grow under these materials. During the summer, surface temperatures under translucent materials can be lethal to seedling roots.

3) **Use sheet mulches with long life spans.** The durability of sheet mulch should be at least 3 years. It often takes 3 to 5 years for seedlings to become established on hot, dry sites (Cleary and others 1988).

4) **Weed or scalp around seedlings prior to installation.** Sheet mulch cannot be installed properly without competing vegetation being completely removed.

5) **Mulch immediately after planting.** Waiting until later in the spring to mulch runs the risk that competing vegetation will have depleted soil moisture, thereby making the mulch ineffective during the first growing season.

6) **Securely stake or anchor all corners of the mulch.** The sides of the mulch sheets can pull out easily by wind, animals, or competing vegetation growing under the mulch sheets. It is important that, at a minimum, the corners are staked. For greatest effectiveness, bury all edges of the sheets with soil.

7) **Consider visibility.** Sheet mulches can be very apparent in high visibility areas. Measures to reduce unsightliness of sheet mulches include covering with aggregate mulches such as hay, straw, or wood mulch, or selecting sheet mulch colors that blend into the area.

Figure 10.17 *– This photograph was taken in late summer, months after adjacent soils had dried out. The lack of competing vegetation and the low surface evaporation resulting from the placement of 3 to 4 inches of coarse sawdust resulted in very high soil moisture. The high C:N of the sawdust was believed to be a factor in inhibiting the establishment of weedy annuals.*

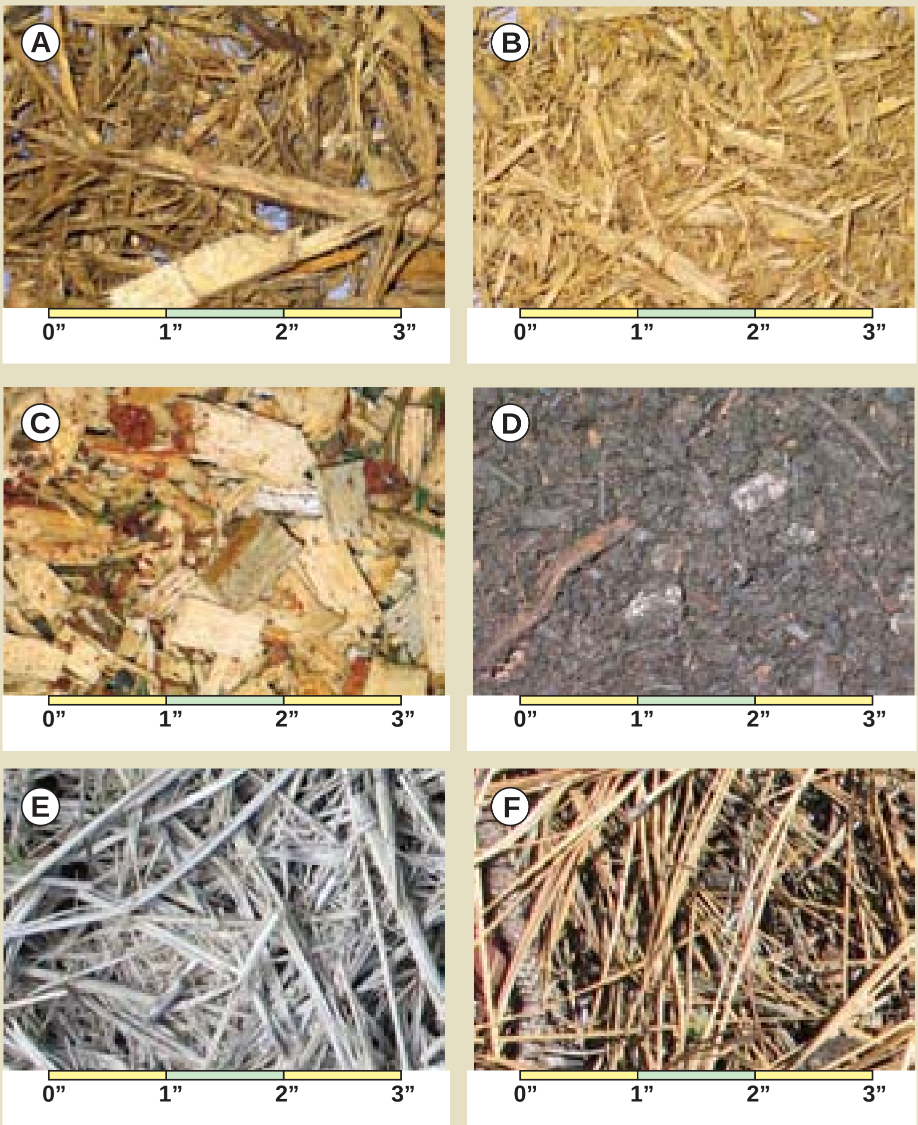
Organic Aggregate Mulch – Organic aggregates are another group of materials that, when placed thickly around installed plants, will control the establishment of competing vegetation and reduce surface evaporation (Figure 10.17). These aggregates include hay, straw, or chipped and shredded wood materials. Organic aggregates are often used in highly visible areas because they are more esthetic in appearance than sheet mulches. They are also used in planting islands for long-term control of competing vegetation.

The effectiveness of organic aggregate mulches on seedling survival and growth depends on the depth, total area covered, the control of seed germination of competing vegetation, and its longevity.

The longevity of organic aggregate mulches is a function of: 1) C:N, 2) texture, and 3) depth. High C:N materials, such as uncomposted, shredded wood, bark, or sawdust, will last longer than low C:N materials, such as composted yard materials, because these materials are in the initial stages of the decomposition cycle. Coarse-textured materials (Figure 10.18) have greater longevity than finer-textured materials because coarser materials have less surface area for microbial break down (Slick and Curtis 1985). Coarse-textured materials also tend to hold less moisture, which slows decomposition rates. The longevity of an organic aggregate mulch also depends on the application thickness – the thicker the layer of mulch, the longer it will last.

The same factors that affect longevity (e.g., texture, C:N, depth) also determine the effectiveness of aggregate mulches in deterring seed germination of unwanted vegetation around the seedling. Coarse-textured mulches are excellent mulches because they hold very little moisture at the mulch surface, and are therefore poor environments for seed germination of unwanted vegetation. Fine-textured mulches, on the other hand, create a more favorable environment for seed germination because they hold more moisture and are in closer contact with seeds. For this reason, many fine-textured materials, such as composts, are actually excellent growing media for weed seed germination and establishment. As discussed in Section 5.8.1.2, mulch materials with high C:N discourage growth of weedy annuals because high C:N materials remove available nitrogen that would otherwise give these species a competitive advantage. The effectiveness of a mulch in discouraging the establishment of competing vegetation generally increases with the thickness it is placed on the soil surface (Baskin and Baskin 1989). The most effective mulch thicknesses are between 3 to 4 inches (Pellett and Heleba 1995; Ozores-Hampton 1998), but thicknesses as low as 1.5 inches have been found to be effective for some small-seeded weed species that need sunlight for germination (Penny and Neal 2003).

Figure 10.18 *– Examples of different types and textures of mulches: (A) freshly ground coarse wood passing a 3 inch screen; (B) freshly ground coarse wood passing a 1.5 inch screen; (C) freshly chipped wood; (D) composted mixtures of ground wood, biosolids, and yard wastes passing a 1.5 inch screen; (E) weathered straw; (F) ponderosa pine needles.*



Organic aggregate mulches have several advantages over sheet mulches. First, organic mulches can be applied over a much larger area than sheet mulches. Some projects have organic mulches covering the entire site, while other projects concentrate it in strategic areas, such as planting islands. Second, organic aggregate mulches moderate surface soil temperatures, whereas sheet mulches can actually increase surface temperatures. Mulch thicknesses of 3 inches have been found to reduce soil temperatures below mulch layers by 8 to 10 °F (Slick and Curtis 1985; Steinfeld 2004), which can benefit the growth of seedlings on very hot sites. The insulative quality of mulches also affects the seasonal heating and cooling patterns in the soil. Soils under thick mulches take longer to warm in the spring, but in the fall, take longer to cool down. Depending on the temperature and rainfall patterns of a site, this could influence seedling establishment.

Mulch can create problems to planted seedlings if it is placed in contact with the plant stem. The high moisture around the stem can be conducive to pathogenic injury. On southern exposures, heat will build up at the surface of, and directly above, the mulch, creating extremely high temperatures on warm summer days. The high temperatures can cause heat damage to stems of young seedlings. It is important, therefore, to keep mulch several inches away from the stem of planted seedlings.

10.1.3.4 Soil Improvement

Mulches are sometimes used specifically to increase the nutrient and organic matter status of a soil. Composted organic materials are used for these purposes and are characterized by having low C:N, high nutrient levels, fine textures, and dark colors. While these materials are typically more effective when incorporated into the soil, they are sometimes applied to the surface of the soil where tillage is not feasible (steep and rocky) or tillage costs are unaffordable. Where composted organic materials are applied on the soil surface, the nutrient release rates will be much slower. See Section 10.1.5, Organic Matter Amendments, for more information on composts.

10.1.3.5 Seed Supply

The objectives for applying mulch on some projects are to spread materials that contain native seeds. There are several mulch materials that carry native seeds, including duff, litter, and straw from native seed production fields. When these materials are applied to the soil surface, seeds will germinate given favorable environmental conditions.

Duff and Litter – Duff and litter layers are organic mats that form under tree and shrub plant communities. These layers are accumulations of years of leaves and needles at varying degrees of decomposition. Included in these layers are dormant seeds, many of which are still viable. When the duff, litter, and seed bank is collected and spread on disturbed sites the environmental conditions for breaking seed dormancy of some species may be met and seeds will germinate.

Figure 10.19 – *Large mulching operations require access and working space. The operation shown in this photograph shows the wood waste material being dropped into a grinder with an excavator (left), and conveyed as mulch to the bucket of a front end loader (right).*

Duff and litter can be collected from adjacent forest- or shrub-dominated sites or salvaged prior to construction. Reapplying them to disturbed sites completes several operations at once: 1) adds seeds, 2) covers seeds, and 3) adds a supply of long-term nutrients. Although this practice might seem expensive or impractical, when compared with purchasing and applying seeds, fertilizer, and mulch separately, the costs might be comparable. See Section 10.1.3.11 for more information on litter and duff.

Native Hay From Seed Production Fields – One of the byproducts of native grass seed production is the stubble that remains in the fields after seed harvest. This stubble contains varying quantities of unharvested seeds, which eventually end up in bales. If bales are stored in dry conditions, seeds can remain viable for several years. When hay bales containing the native seeds are spread as a mulch on disturbed sites, seeds come into contact with soil and eventually germinate. See Section 10.1.3.9 for more information on straw and hay.

10.1.3.6 Selecting the Appropriate Mulch Materials

There are a variety of materials that can be used as mulches:

- Wood fiber,
- Erosion mats,
- Hay and straw,
- Manufactured wood strands,
- Duff and Litter,
- Composts (See Section 10.1.5), and
- Hydromulch (See Section 10.3.2).

The following sections describe these materials and how they are used in revegetation projects. Figure 10.18 gives examples of some of these mulches.

10.1.3.7 Wood Fiber

Mulches produced from woody materials are used primarily for seed covering and seedling mulching. There is usually a readily-available source of wood material from project sites situated in forested environments. Branches, stems, bark, and root wads are typical waste products from clearing and grubbing that can be chipped or mulched on site to produce various types of wood mulch. In the past, this material has been burned or hauled to waste areas for disposal. With greater burning restrictions and higher hauling costs, chipping these materials and returning them to disturbed sites as mulch are practices that are becoming more common.

Wood Fiber Mulch Production – Creating mulch from right-of-way clearing woody material requires planning and coordination. First the road contractor piles the woody right-of-way clearing debris into "slash piles." These piles include tree boles, bark, branches, and stumps, but must not contain large rocks or other inert materials that can cause wear or damage to the equipment. When clearing and piling is completed, a company that specializes in processing wood waste is contracted (typically by the road contractor). In this operation, equipment is brought to each slash pile and materials in these piles are processed into mulch. The resulting wood mulch is either placed in piles adjacent to the slash piles or transported to designated storage sites. The timing of these operations should consider the possibility of limited equipment use due to fire restrictions, which typically occurs in the western United States from mid summer through early fall.

If undesirable plant species are included in the slash piles, spread of these species is likely to occur when they are processed and applied as a mulch. This can be prevented by identifying these plant populations on site during the weed assessment (See Section 5.8.2.1) and avoiding placing them into slash piles.

It is important to define the desired mulch characteristics prior to processing the piles. This can be difficult since there are a variety of wood waste reduction equipment, producing different dimensions and fibrosity (the degree that wood fibers are separated). Specifying the particle size and shape by stating a screen size the material must pass does not always produce the desired material. Screens only sort for two dimensions, and not for length or fibrousness. Identifying the type of waste reduction equipment can narrow the type of mulch produced (Table 10.5). For example, mulch produced by shredders is long and fibrous (Figure 10.18 A and B), whereas

Table 10.5 – Table of general types of wood waste reduction equipment (modified from Re-Sourcing Associates and CPM Consultants 1997).

General Equipment Types	Examples	Feedstock	Particle Geometry
Chippers	Disc Chippers, Drum Chippers	whole logs, clean residuals	clean edge, two-sided
Hogs	Swing Hammer, Fixed Hammer, Punch & Die, Mass Rotor	wood waste, stumps, land clearing debris	coarse, multi-surfaced, fibrous
Shredders	Low Speed-High Torque, High Speed	wood waste, stumps, land clearing debris	coarse, multi-surfaced, fibrous
Hybrids	Knife Hogs, Pan & Disc	wood waste, stumps, land clearing debris	semi-coarse

mulch produced from chippers has close to equal length sides, with fibers still intact (Figure 10.18 C). Visiting with mulch company representatives and viewing the type of products they produce is a good way to determine the types of products you can expect to receive. If this is not possible, have them send you samples of different mulch products. Typically, the coarser the size of the mulch, the cheaper will be production costs since more mulch of coarser size can be produced in a given time frame than smaller textured mulch. Other factors, such as tree species, moisture content, and portion of tree processed, will affect the characteristics of the mulch. If the wood is wet during processing, it is more likely to be shredded; if it is dry, it will be more chip-like. There is also variation in mulches based on species of origin. For example, ponderosa pine (*Pinus ponderosa*) and western juniper (*Juniperus occidentalis*) tend to create more fibrous mulch than lodgepole pine (*Pinus contorta*). Processed root wads tend to be more fibrous than boles of trees.

Purchasing Wood Fiber Mulches – On projects where waste materials are not available for mulching, the purchase of wood fiber mulches should be considered. Overall costs are much higher because of the added expenses of transporting these materials to the site. If commercial mulch sources are nearby, this can be an economically viable option. It is very important to be sure of the quality of the material. Testing methods and specifications can be developed that are similar to those given in Section 10.1.5.

Applying Wood Fiber Mulch – Wood fiber mulch is typically applied with mulch-blowing equipment. This equipment has varying transport capacities, ranging from 25 to 100 yards of material (Figure 10.20). An application hose is positioned where mulch is to be applied and is pneumatically delivered from the mulch bins to the site. The amount of mulch applied depends on the objective. For seeding, application rates range from 100 yd^3/ac (0.75-inch thickness) to 135 yd^3/ac (1.0-inch thickness). For seedlings, mulch application ranges from 400 yd^3/ac (3 inch-thickness) to 540 yd^3/ac (4-inch thickness). Note: The higher rates used for mulching seedlings are only used in close proximity to the plants. The remaining areas are mulched at a lower rate.

Application rates depend on factors such as length and diameter of hose, blowing equipment, elevation rise, and dimension of the area being covered. Rates of application typically range from 25 to 35 yd^3/hr. If mulch is applied at a 1-inch depth (134 yd^3/ac), it would take between 4 to 5 hours to cover an acre. These are optimum rates because they do not account for the time it takes to travel to the mulch source, load the mulch bin, and travel back to the application site. The time required to make these trips can sometimes be longer than the actual application of the mulch. Using larger transport capacities is one way to significantly cut the time associated with refilling mulch bins.

Mulch blowing equipment can be used on any slope gradient that can be accessed by foot. By using ropes, slope gradients of up 1H:1V can be accessed. Hose lengths can be attached to extend the delivery of mulch up to 400 ft. Since mulch is delivered through hoses, the system will plug if the size of the wood fibers exceeds the tube size. It is therefore important that mulch be free of large pieces of wood. Using a mulch blower is an excellent method for evenly applying wood fiber, but frequent monitoring by inspectors is important to assure that the specified amount of mulch is being applied.

Where slopes gradients are gentle and free of rock and debris, wood fiber mulch can be evenly applied with a manure spreader. Mulch can also be moved to the site in tractor buckets and spread across the soil surface with the blade or bucket of the tractor. Obtaining an even mulch depth is extremely difficult using this method, and requires many passes of the equipment that invariably compacts the soil. An alternative is to deliver several yards of mulch to a planting island in the bucket or shovel of a tractor or excavator. After the seedlings are planted, mulch can be hand raked at the specified thickness to cover the island.

***Mulch Storage* –** If wood fiber is stored for long periods of time, the materials should not be placed in piles taller than 10 ft. Fresh piles of wood fiber have the potential to spontaneously ignite in larger piles, creating a fire hazard and potential loss of material. Consider placing a plastic covering over the piles to keep moisture out during the winter because wet mulch is harder to apply through a mulch blower than drier mulch.

***Seed Placement During Mulching* –** Seeds can be sown prior to or during mulch operation. Sowing that is done before mulching can be accomplished through dryland sowing methods or through hydroseeding. Applying seeds during the mulching operation is accomplished by placing seeds in a "seed metering bin" attached to most mulch-blowing equipment. This equipment meters seeds into the mulch as it is being applied. The rate at which the metering system delivers seeds can be adjusted and must be calibrated prior to mulching to obtain the desired seed density (See Section 10.3.1, Seeding, for seed calibration methods). Recalibration should be done when seed rates or mulching rates have been changed.

***Fertilizers* –** It is difficult to evenly apply fertilizers through a mulch blower system. Outside of mixing fertilizers in the mulch prior to placing it into the mulch bins, fertilizing must be done in a separate operation, either before or after mulching. Applying fertilizer through a hydroseeding system after seedling establishment is one strategy for increasing available nutrients on the site. As discussed in Section 10.1.1, Fertilizers, the delayed timing of fertilization reduces the

***Figure 10.20* –** *Wood fiber mulch is applied on steeper slopes with mulch blowing equipment. Large trucks can hold between 75 and 100 yards of mulch (A) while smaller trucks can hold up to 25 yards (C). Mulch is pneumatically delivered to the site through an application hose which can reach several hundred feet up steep slopes (A) with still enough force for ample delivery of mulch (B).*

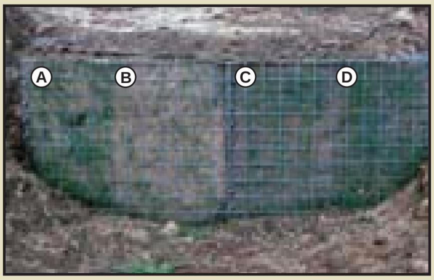
risk of nutrient leaching and increases the probability that nutrients will be available at the levels needed for established plants.

10.1.3.8 Erosion Mats

Erosion mats are manufactured blankets or mats designed to increase surface stability and control erosion. They are available in strips or rolls with a minimum thickness of 0.75 inch. Erosion control revegetative mats (ECRM) or rolled erosion controlled products (RECP) are applied directly to the soil surface for control of sheet erosion and to aid the establishment of vegetation. Turf reinforcement mats (TRM) are materials that are filled with soil when installed to increase surface soil strength (Kemp 2006).

There are a multitude of products on the market, with a range in design and costs. Figuring out which products will serve your project needs at the right price can be challenging. Several state departments of transportation periodically evaluate and compare the shear stress, soil erosion protection, longevity, and other characteristics for these products (Caltrans 2003; Kemp 2006) and these documents are usually available on the internet. Since the installed costs of erosion mats can be very expensive, it is important that the job is done right. Taking the time to select the appropriate erosion mats, native species mix, and seed placement techniques is essential for assuring that revegetation is successful. Small field trials using different species and erosion mats can help in these decisions (Figure 10.21).

***Figure 10.21** – Small field trials can help select the most appropriate species and materials for a project. The trial shown in this picture compared straw mat (A and B) with a polywoven mat (C and D). It also compared the growth of blue wild rye* (Elymus glaucus) *and California fescue* (Festuca californica) *(A and C). The first year results indicated that there was much better establishment of grasses on the polywoven erosion mat than the straw mat, yet no difference in species growth. Maintaining the trial for two years showed that California fescue outperformed blue wild rye. These results led to using California fescue and polywoven erosion mat for the project described in Inset 10.3.*



The same characteristics that create an optimum environment for seed germination in other mulches are also important to consider when selecting erosion mats. Typically, those materials that protect the seeds from drying out but allow light and space for germinating seeds to grow into seedlings will perform the best for revegetation establishment. The thicker erosion mats with the most loft should have better conditions for seedling establishment than thinner materials.

The drawbacks to erosion mats are generally not in the product itself, but in how it gets applied to the site. Poorly applied erosion mats can result in sheet and rill erosion under the fabric. To avoid this problem, several important measures should be taken when installing erosion mats. First, the surface of the soil must be smoothed to a uniform elevation before the mat is placed. This will assure that when the mat is pinned to the soil, it is in intimate contact with the soil surface. Second, the materials must be trenched or keyed into the soil at the upper reaches of the fabric. This will assure that the material does not move downslope. Third, as with all slopes being revegetated, concentrated water should be kept off these slopes.

Seeds must be sown on the site prior to installing erosion mats. This can be done using any type of seeding method (e.g., hydroseed, drill, or hand broadcast). Care must be taken during and after mat installation to avoid disruption to the seedbed. Unless the seeds are extremely small, sowing seeds over installed erosion mats is not recommended because larger seeds will hang up in the fabric. Small seeds can be applied over erosion mats if tackifiers are not used and if the timing is correct so sufficient rain will move it through the erosion mat to the soil surface.

Some manufacturers offer erosion mats that are impregnated with seeds, eliminating the need for sowing. This method is advantageous on steep slopes or soil-faced gabion walls (Inset 10.3) where placing seed prior to mat installation is very difficult. It is important to work directly with companies that provide these products by supplying them with source specific seeds and specifying appropriate sowing rates. For successful germination, seeded erosion mats must be installed so that the seeds and fabric are in direct contact with the soil.

10.1.3.9 Straw and Hay

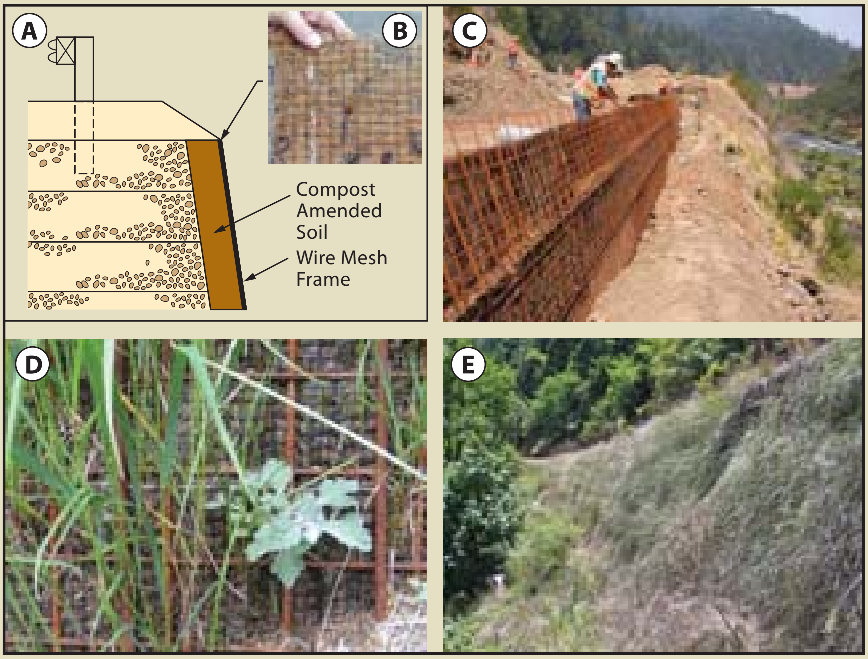
Straw and hay are long-fibered mulches used on many revegetation projects for seed cover and erosion control (Figure 10.18E). The terms straw and hay are often used interchangeably. However, straw is the stubble left over after seeds have been harvested from commercial seed or grain crops; hay comes from grass/legume fields usually grown for feed. When hay is harvested, it usually contains seeds from a variety of pasture species.

Inset 10.3 – Case Study: Erosion Mats with Native Grasses and Forbs

Reconstruction of the Agness-Illahe Highway required the construction of long sections of gabion walls. Since this highway is visible from the Rogue River (a designated "wild and scenic" river in southwestern Oregon) and is heavily traveled for recreational purposes, it was important that the gabion walls be visually screened using native plants. Gabions were designed to hold 12 inches of compost-amended soil (topsoil was not available) on the face of the walls by wire mesh frames (Figure A). Placement of seeds at the surface of the gabion wall was problematic. Several small plots using different erosion mats, seed mixes, seed rates and seed-attaching methods were tested to determine how to best meet the revegetation objectives (Figure 10.21).

The results from these trials indicated that we could attach native grass and forb seeds to erosion mats using a tackifier (B). In 2003, we applied our findings to the construction project. Needing approximately 33,000 ft^2 of gabion wall facing, we prepared the erosion mats by rolling them out on a road surface, applying California fescue (*Festuca californica*), gluing the seeds to the mat, and re-rolling the erosion mats.

The seeds held tightly to the fabric during transportation and handling. At the construction site, seeded mats were attached to the wire mesh at the face of the wall (C) and compost-amended soil was placed behind the screen and lightly tamped. The gabion walls were built in the summer of 2003, but the seeds did not germinate until late fall after several rainstorms. Figure D shows a close up section of wall with newly germinating seedlings coming through the erosion mat in late 2003, four months after wall construction. Figure E shows 20 to 30 ft high walls in July 2006, three years later, fully vegetated and effectively screening the walls from the road and river (Photo C courtesy of Scott Blower).



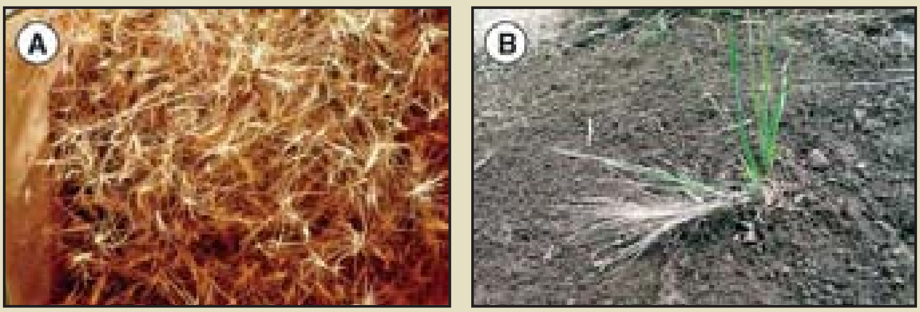
Straw and hay are often used on revegetation projects because they are available, comparatively inexpensive, and generally successful in establishing grass and forb plants from seeds. The long stems of these materials create loft, or high porosity, that keeps moisture near the soil surface where seeds are germinating. This creates a favorable environment for young seedlings by allowing sunlight to penetrate and protecting the young seedlings during the early stages of establishment.

Straw is often preferred over hay because it generally contains fewer undesirable seeds. The seeds that are contained in the straw may not always be considered inappropriate for use in revegetation projects. For example, straw from some grain production fields (e.g., rice straw) has seeds of species that are not adapted to wildland environments and therefore will not become established. Straw produced from native seed production fields, on the other hand, is desirable if the fields are grown from identified genetic sources and used for projects within the seed transfer zones. Not only does source-identified straw act as a mulch, but it also supplies extra native seeds to the site. Some native grass species grown for seed production are very difficult to harvest and clean. For these species, the seeds are not harvested, but baled together with the grass stems. The seeded bales are applied directly to the site through straw blowing equipment, accomplishing seeding and mulching in one operation (Figures 10.22 and 10.23). This method offers a practical alternative to species such as bottlebrush squirreltail (*Elymus elymoides*) or western needlegrass (*Achnatherum occidentale*) which can be difficult to harvest and clean.

Purchasing Straw and Hay – The drawbacks to using straw and hay are that these materials can contain seeds from undesirable species, are susceptible to wind movement, have limited application distance, and decompose in a relatively short time compared to other mulches. Introducing seeds of undesirable species from straw and hay sources is an important consideration when choosing a source. There are many examples where, in the urgency of erosion control, straw or hay from unknown sources was applied, resulting in the introduction of weed species. The assumption in most of these cases was that short-term control of soil erosion and sediment production outweighed the long-term introduction of undesirable plant species. The potential disastrous results from these assumptions need to be understood and agreed upon prior to applying hay or straw from unknown sources. Good integration of erosion control and revegetation planning can eliminate the need for last minute purchase and application of unknown or undesirable hay or straw sources.

A good source of straw is native seed production fields. Seed growers identify straw bales by genetic source, so it is important to be sure that the source-identified bales are appropriate for the geographic area of the project site. Because of the potential for introducing weeds to your project site, you must be very certain of the species present in the hay or straw you are applying to your site. Many states have certification programs that inspect fields and certify that the bales are "weed free." Be clear what "weed free" means when you purchase these materials. There can be other seeds in the bales that, while not considered weeds by the certifying state, might nevertheless be unwanted on your site. A conservative approach for non-certified seeds is to examine the fields that will be producing your bales and observe which species are present before they are harvested. It must be assumed that if a species of grass or forb is present in a

Figure 10.22 – *Seeds of some species are baled with straw because of the difficulty of seed harvesting and cleaning. The long awns of the squirreltail seeds (A) show how difficult collecting and handling these seeds can be. The squirreltail seeds are germinating from the heads of the seeds that came in the bales (B).*



hay field, seeds from these plants will show up in the bales.

Some species grown for native seed production are difficult to harvest and clean because of long awns (Figure 10.22). An alternative method of seed harvest for these species is to allow the seeds to ripen in the fields and bale the seeds and grass stems together. The seed bales are applied to the site through hay blowing equipment. The seeds are detached from the stem as it is blown through the equipment, falling to the surface of the soil and covered by the grass stems. This is an effective means of applying seeds and seed covering in one operation.

***Figure 10.23** – Straw blowers range in size from machines which can apply 30 to 60 bales per hour (shown here) to very large straw blowers that can shoot up to 20 tons per hour.*

Some things to require when purchasing straw or hay are:

- Source must meet or exceed State Certification Standards for "weed free." Many states have straw certification programs. Where no standards programs exist, acceptance should be based on seed crop inspection reports and/or visual field inspections by the COTR prior to harvest. Standards may also be set by the Government and listed on individual task orders.
- Straw or hay must be baled and secured according to specifications listed on the Task Order. Generally, bales should be less than 100 lbs.
- Bales should not be allowed to become wet after harvest or during storage prior to delivery.

The quality of straw and hay varies between grass species. Rice straw, for instance, is wiry and does not readily shatter, which makes it more difficult to apply as compared to wheat, barley, or oats (Kay 1983; Jackson and others 1988). Native straw is generally longer and stronger than grain straw (Norland 2000). Yet within native grasses, some species have better properties as mulches than others. Larger stemmed grasses, such as blue wildrye (*Elymus glaucus*), mountain brome (*Bromus marginatus*), and bluebunch wheatgrass (*Pseudoroegneria spicata*) make good mulches because of the large leaves and stems.

Application – Straw and hay can be spread by hand or with a straw blower. For large jobs, using a straw blower is the most practical application method. There are many types of straw blowers available on the market, ranging from very small systems (Figure 10.23) that deliver from 30 to 180 bales per hour to large straw blowers that operate at rates up to 20 tons per hour. The distance that straw or hay can be blown depends on the hay blowing equipment, wind conditions during application, straw characteristics, and whether the material is being applied upslope or downslope (cuts or fills). When wind is favorable, straw can be shot up to 100 ft. However, when wind is blowing against the direction mulch is being applied, the distance is reduced. Because of the limited application range, this equipment is limited to sites adjacent to roads. The upper portions of steep, extensive slopes are typically not reachable by straw blowers.

When straw is used as a seed mulch, it is important that the application rates are not too deep that a physical barrier is formed. A minimum depth that has been shown to control evaporation is one inch (Slick and Curtis 1985). Applying too much straw will restrict sunlight and growing space for establishing seedlings. A rule of thumb is that some surface soil (15% to 20%) should be visible through the straw after application (Kay 1972, 1983; Jackson and others 1988). This equates to 1.5 to 2 tons per acre, depending on the type of straw and its moisture content.

Straw is susceptible to movement with moderate to high winds. Tackifiers are often applied over the straw to keep it in place (Kay 1978). Products such as guar and plantago are used with low quantities of hydromulch to bind straw together (Manufacturers have stated application rates for this purpose).Straw can also be crimped, rolled, or punched into the soil. These measures will stabilize the straw by burying portions of the stems into the soil and can increase erosion protection because of the more intimate contact of straw with the soil surface. The potential for compaction is increased with these treatments and the tradeoffs of offsetting surface stability with long-term soil productivity should be weighed.

10.1.3.10 Wood Strands

Wood strands are long, thin pieces of wood, produced from wood waste veneer. This product was developed as an effective erosion control alternative to straw and hay (Foltz and Dooley 2003). The advantages of wood strands over straw are that it is free of seeds, has a longer life, and is more resistant to wind.

Wood strands, like straw, form a stable cover with high porosity or loft, characteristics which are important for controlling soil moisture and temperature around the germinating seeds. The large spaces or pores created by the wood strands allow space, light, and protection for young emerging seedlings (Figure 10.13). Unlike straw, these materials keep their structure or porosity over time, and do not compress with snow or lose fiber strength through decomposition. While the performance of this new product as a seed cover has not been tested, it has all the characteristics of being an excellent seed cover. The application rates for wood strands are likely to follow the guides for straw – at least 15% to 20% of the soil surface should be visible. This is likely to be greater than the recommended rates for erosion control. Installing small test plots of varying thicknesses of mulch would be a good means to determine the appropriate thickness for optimum seed germination. Wood strands are delivered in different size bales and applied by hand or through straw blowing equipment (Figure 10.23). As with straw, this product is limited by the accessibility of the site by hay transportation and blowing equipment.

10.1.3.11 Litter and Duff

Litter is the layer of fresh and partially decomposed needles and leaves that cover the surface of most forest and shrub plant community soils. Duff is the dark, decomposed layer directly below the litter layer (leaves and needles are not identifiable in the duff layer) that is high in nutrients and humus. In addition to providing soil protection and nutrients, litter and duff can also contain dormant, yet viable, seeds from species that make up the forest or shrub plant communities. When litter and duff are collected, they should be matched to the appropriate revegetation site. For example, litter and duff collected from cool, moist sites should not be applied on hot, dry sites.

The depth that litter and duff accumulates will vary by species composition, age, and productivity of the plant community. Dense stands of ponderosa pine can produce thick layers of litter. More open forest stands on dry, less productive sites will have thinner layers of duff and litter (often less than an inch deep). The quality of the litter for erosion control and longevity varies by the dominant forest or shrub species. Pine needles provide the greatest benefit because the long needles interlock, reducing the potential of movement from rain or wind erosion (Figure 10.18F). Needles from species such as Douglas-fir are shorter and tend to compact, providing less surface stability. Litter from shrub plant communities provides less protection because the leaves are less interlocking. Nevertheless, these materials should not be overlooked because they can be a source for seeds and nutrients.

The collection of litter in the western states has typically been done manually by raking. Mechanizing the collection of litter has been done in the southern United States. The pine straw industry is well developed in this part of the country. Baling equipment has been developed for this industry and might be applicable to the western United States. Collection of needles and duff should be done during the summer and fall, when the litter and duff are completely dry. If these materials are not used immediately, they should be placed in small piles and completely covered by plastic to keep the materials dry. Excessive moisture can turn the piles into compost and possibly affect seed viability.

Inset 10.4 – Pine Straw Industry

Using forest litter as a mulch is not a new concept – pine needles have been a popular landscaping mulch in the southern United States for the past 25 years. The "pine straw" industry, as it is referred to, has been established to harvest needles in a sustainable manner from young plantations of southern pine species to meet this demand.

Litter and duff can be applied manually to disturbed sites. If viable seed rates are high in the litter and duff, and it does not contain large material, it can be applied in a variety of ways (e.g., hydroseeder, mulch blowing equipment).

One method for determining the amount of viable seeds in a litter layer is to actually conduct a germination test at the project site over a several year period by obtaining litter and duff from several potential collection areas and testing them on nearby sites. Like soil sampling, samples should be collected by obtaining a composite of subsamples of an area. Collect samples from each of the plant communities that are considered for litter collection and keep these samples separate. Establish test plots at sites that are representative of each revegetation unit (these can be reference sites). Each plot should be well marked (each corner identified with stakes and permanent labels identifying the litter source) and located where it will not be disturbed. Plots must be free of vegetation and top several inches of soil should be removed to eliminate potential seed sources. A known amount of litter (either by dry weight or by volume) should be spread across each plot. Visit the plots during the spring and count the number of seeds that are germinating. During the summer or fall, identify plant species and count individual plants in the plots. At the end of the assessment, calculate the number of seedlings per known volume or weight of litter material. These figures can then be used to determine the rate of litter to be applied.

10.1.4 TOPSOIL

10.1.4.1 Introduction

Topsoiling is the salvage, storage, and application of topsoil material to provide a suitable growing medium for vegetation and to enhance soil infiltration (Rauzi and Tresler 1978; Woodmansee and others 1978; NRCS 1994). Topsoiling has been found to increase plant cover and biomass through an increase in nutrient availability, water-holding capacity, and microbial activity, including mycorrhizae (Claassen and Zasoski 1994). It has also been found to increase the number of plant species native to the area. Bailey (2004) found that the application of 3 inches of topsoil over subsoil in eastern Washington increased the presence of native species by a factor of four and increased vegetative ground cover the first and second year by 20%.

While topsoiling has many beneficial effects for revegetation, topsoiling cannot recreate the original undisturbed soil. In the process of removing and reapplying topsoil, soils undergo a loss of 1) soil aggregation, 2) organic nitrogen, 3) arbuscular mycorrhizal fungi (AMF) inoculum, and 4) microbial biomass carbon (Visser and others 1984). Minimizing topsoil disturbance is preferred to topsoiling, especially on sensitive soils, such as those derived from granitic and serpentine bedrock (Claassen and others 1995).

10.1.4.2 Salvaging Topsoil

The removal of topsoil should only be done in areas that will be excavated, severely compacted, or buried with excavated material, such as fill slopes. These areas are usually identified early in the planning stages. During the assessment phase of the revegetation plan, a topsoil survey should be conducted to determine the depth and quality of the topsoil that will be excavated (See Section 5.5.1). Ideally, only the topsoil is removed in the excavation process. Mixing topsoil and subsoil together will dilute microbial biomass and mycorrhizal inoculum of the topsoil, which will decrease their effectiveness in reestablishing nutrient cycling.

Topsoil quality should be determined from laboratory tests and field surveys. Topsoils with high sodium, high salinity, very high or very low pH, or any other condition that may be toxic to plant growth should be avoided (Rauzi and Tresler 1978). If weeds are observed during the field survey, it should be assumed that the seeds of these species are present in the topsoil and these areas should be avoided. During topsoil excavation, the litter and duff layers are usually removed with the topsoil. These layers are sources of decomposed and partially decomposed organic matter. Under topsoil storage conditions, this material will undergo some decomposition, releasing nutrients. Separation of duff and litter from the topsoil prior to topsoil excavation should be considered when the duff and litter are to be used as a native seed source or soil cover.

It is best to excavate topsoil when soils are relatively dry. Under dry conditions, there is less potential to compact the soil or destroy soil aggregation. Dry topsoil should also store longer and maintain better viability than moist topsoil (Visser, Fujikawa, and others 1984). The period when topsoils are dry is generally limited to the beginning of the summer through the middle of fall, which may not always lend itself to construction schedules. Restricting topsoil excavation operations to dry periods should be considered for large topsoil piles or if topsoil will remain in piles for greater than one year.

Topsoil layers are typically removed with either the blade of a tractor or excavator bucket. Soil compaction should be minimized prior to removal, which requires keeping large equipment travel to a minimum. Topsoil is typically placed into berms at the bottom of fill slopes or top of cut slopes and stored there until it is reapplied. If salvaged in this manner, small piles are created and soil is minimally handled. Minimum berm dimensions are approximately 6 ft wide by 3 ft high, which is often not large enough for the amount of topsoil that needs to be stored. When this is the case, topsoil is trucked offsite to larger storage piles. Because of the potential for weed invasion, potential offsite topsoil storage areas should have a weed assessment conducted prior to selection of the site.

10.1.4.3 Storing Topsoil

The question often raised around storing topsoil is how long it can remain piled before it loses its viability. Studies have shown that stored topsoil can remain viable from 6 months (Claassen and Zasoski 1994) to several years (Miller and May 1979; Visser, Fujikawa, and others 1984; Visser, Griffiths, and others 1984,) but will decrease in viability after 5 years (Miller and May 1979; Ross and Cairns 1981).

Viability of stored topsoil is a function of moisture, temperature, oxygen, nitrogen, and time. Stockpiled topsoil has been compared to "diffuse composting systems" (Visser, Fujikawa, and others 1984) because, under optimum conditions, organic material in the topsoil will compost. Decomposition of organic matter in stored topsoil will reduce microbial biomass essential for nitrogen cycling (Ross and Cairns 1981) and fine roots that store mycorrhizal inoculum (Miller and May 1979; Miller and Jastrow 1992). Optimum environments for decomposition include high moisture, warm temperatures, and available nutrients, all conditions present in most topsoil piles. Climates with lower moisture and temperatures can be more favorable to long-term storage. A study in Alberta, Canada, for instance, revealed that topsoil had very little respiration or organic decomposition after three years in a stockpile due to the influence of the cold, dry climate (Visser, Fujikawa, and others 1984). Dry topsoils store longer and maintain greater populations of viable mycorrhizal fungi (Miller and Jastrow 1992). If a topsoil pile is to be held over winter in areas of moderate to high rainfall, it should be kept dry by covering with plastic (which will also keep the piles protected from erosion and weed establishment).

The size of the pile can also affect the viability of the topsoil. The interior of large piles maintain higher temperatures and are usually anaerobic, which can be detrimental to soil microorganisms. Microbial biomass levels and mycorrhizal fungi have been found to be very

***Figure 10.24** – Soil testing of salvaged topsoil can be used to calculate the thickness to apply in order to meet minimum nitrogen levels.*

A	Total soil nitrogen (or other nutrient of interest) in salvaged topsoil	0.14	%	From soil test of post construction soils - reported in gr/l, ppm, mg/kg, ug/g divide by 10,000 for %
B	Soil bulk density	1.1	gr/cc	Unless known, use 1.5 for compacted subsoils, 1.3 for undisturbed soils, 0.9 for light soils such as pumice
C	Fine soil fraction	70	%	100% minus the rock fragment content - from estimates made from sieved soil prior to sending to lab
D	Nitrogen for soil layer (A * B * C * 270) =	2,911	lbs/ac ft	Calculated amount of total nitrogen in 1 acre feet of soil
E	Minimum or threshold N levels	1,100	lbs/ac	Determined from reference sites or minimum thresholds from literature
F	Minimum topsoil application: E/D * 12 =	4.5	inches	The minimum thickness of topsoil to apply to meet minimum thresholds of nitrogen

low in the bottom of large stockpiles (Ross and Cairns 1981; Miller and Jastrow 1992). Most projects limit topsoil piles to 3 to 6 ft in height. This is not always possible, especially when topsoil storage space is limited. Under these circumstances, the size of the topsoil pile can be quite large. To reduce the negative effects associated with very large piles, topsoils should be salvaged dry and kept dry during storage. Large piles should be stored for as short a time as possible.

Standard specifications often call for temporary seeding of topsoil piles. The benefits of this practice are erosion control and maintenance of mycorrhizae inoculum through the presence of live roots. This practice should be evaluated for each project to avoid the introduction of undesirable plant species in the seeding mix if non-native species are used. Alternatives to this practice include hydromulching without seeds or covering with plastic.

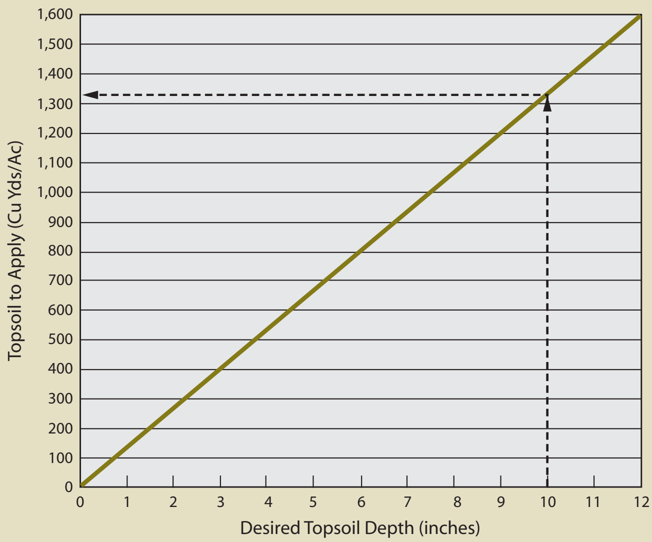
10.1.4.4 Reapplying Topsoil

The depth of topsoil application is generally based on the amount of topsoil available and the desired productivity of the site after application. As a rule, the deeper topsoil is applied, the higher the site productivity will be. If the objective is to restore a site to its original productivity, the placement of topsoil should be at a depth equal to or greater than the topsoil horizon of undisturbed reference sites. Sufficient topsoil quantities however, are rarely available in the quantities needed to restore disturbed sites to their original topsoil depths. This often leads to applying topsoil too thinly across a project site. There may be a minimum topsoil depth below which the application of topsoil is not effective. Research on a northern California road construction site (Claassen and Zasoski 1994) suggests that a depth of 4 to 8 inches was required for an effective use of topsoil. On sites where the subsoil is unfavorable for plant establishment (e.g., very high or low pH, high sodium, high salinity), minimum depths of greater than 12 inches of topsoil should be considered (Bradshaw and others 1982).

Determining minimum topsoil application depths can be based on the minimum amount of nitrogen required to establish a self-maintaining plant community. A threshold of approximately 700 kg/ha (625 lb/ac) of total nitrogen in the topsoil has been suggested for sustaining a self-maintaining plant community in a temperate climate (Bradshaw and others 1982). Claassen and Hogan (1998) suggest higher rates, especially on granitic soils, of 1,100 lb/ac total nitrogen. Using total nitrogen levels from soil tests of topsoil, the application thickness of topsoil can be determined using the calculations presented in Figure 10.24.

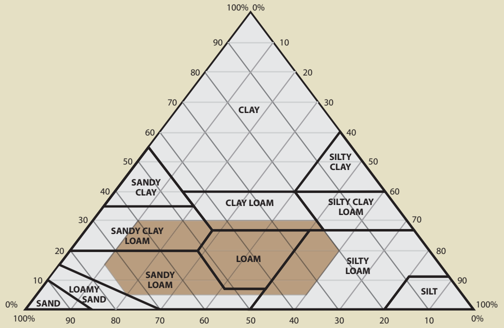
Once the desired topsoil depth has been established, it must be determined whether there is enough stored topsoil available to meet these standards. The quantity of cubic yards of topsoil required per acre can be determined based on the depth of topsoil from Figure 10.25. For example, if an average of 10 inches of topsoil is required on a project, approximately 1,350 yd^3/ac topsoil would be needed. If there is not enough topsoil to meet this depth, then less than full coverage of the site should be considered over reducing the desired thickness of the topsoil.

***Figure 10.25** – The quantity of topsoil to apply to achieve a specified topsoil thickness can be estimated by finding the desired depth of topsoil. For example, a 10-inch depth of topsoil would require 1,350 yd^3 of topsoil.*



Where topsoil quantities are limiting, it is important to develop a strategy that addresses the location the topsoil will be spread and the depth at which it will be applied. The strategy might concentrate topsoil in areas such as planting islands, planting pockets, or in a mosaic pattern that blends with the natural vegetative community. The non-topsoiled areas could be treated with other mitigating measures, such as organic matter incorporation or mulching.

***Figure 10.26** – Soil textures that are suitable as "loam borrow" are shown in light brown on the USDA textural triangle.*



10.1.4.5 Manufactured Topsoil

The term manufactured topsoil (also termed "engineered topsoil") is used to define a soil created to perform like, or develop into, topsoil. It is usually manufactured offsite and transported to the area where it will be applied. Manufactured topsoil is used in gabion walls, crib walls, or other bioengineered structures. It can also be used in planting pockets and planting islands.

Selecting the appropriate organic matter, soil texture, and soil amendments for manufactured topsoil will increase the success of the project. The basic components of a manufactured topsoil are the loam borrow, compost, and soil amendments (e.g., fertilizer or lime amendment).

***Loam Borrow* –** Loam borrow is any material that is composed of mineral particles meeting a suitable texture class (Figure 10.26). Loam borrow should have low coarse fragment content, not restrict plant growth, and be weed-free. This material can come from many sources, such as subsoils, river sands, and terrace deposits. Loam borrow must be tested and meet the general specifications shown in Table 10.6. If the loam borrow comes from subsoils or parent material, it should be assumed that beneficial soil microorganisms are not present and should be added when the soil is manufactured.

***Compost* –** The organic component of manufactured topsoil (See Section 10.1.5) is composted materials from of a variety of materials including yard waste materials (grass clippings, leaves, and ground wood of trees and shrubs), sawdust, and biosolids. The heat generated during composting effectively reduces pathogens, weeds, and insects that may be hazardous to humans and detrimental to reestablishing vegetation. Compost must be free of weed seeds and vegetative material that propagate weedy plants (e.g., blackberry canes). The material must be well-composted, or stable, which can be indirectly determined by a respirometry test or calculated using C:N obtained from laboratory testing of nitrogen and organic matter. A stable compost will have a low respirometry rate (<8 mg CO_2-C per g organic matter per day)

***Table 10.6** – General specification ranges for loam borrow used in manufactured topsoil. These can be modified depending on the soil characteristics of the compost and other soil amendments (modified after Alexander 2003b; CCREF and USCC 2006).*

Test Parameters	Test Methods	Loam Borrow
Physical Contaminates (man-made inerts)	Man-made inert removal and classification (TMECC 03.08-C)	<1%
Trace Contaminants	Arsenic, Cadmium, Copper, Mercury, Manganese, Molybdenum, Nickel, Lead (TMECC 04.06)	Meets US EPA, 40 CFR 503 regulations
pH	1:5 slurry pH (TMECC 04.11-A)	5.0 -7.5
Soluble Salts	Electrical conductivity using 1:5 Slurry Method (dS/m)	<5
Bioassay	% seedling emergence and relative seedling vigor (TMECC 05.05-A)	>80% of control
C:N Ratio	(TMECC 05.02-A)	<25

and low C:N (<25:1). A bioassay test which compares the rate of seedling emergence and seeds sown in compost to seeds sown in a control growing medium would be useful. Table 10.7 lists specified values for a series of tests that should be performed on composted materials used in manufactured topsoils.

To assure the delivery of high quality organic materials, compost should be obtained from a facility that participates in the Seal of Testing Assurance (STA) program (discussed in Section 10.1.5). These compost facilities will send the latest lab results of the material of interest. A listing of STA compost facilities can be found at http://www.compostingcouncil.org. If a STA composting facility is not close enough to the project, other sources will have to be considered and testing the compost will rest on you. This will involve sampling the compost piles and sending the samples to an STA lab (a listing can be found at the Composting Council's website). It is important that the compost piles be visually inspected prior to purchase to assure that noxious weeds are not present on or near the composting facility.

The compost application rates range from 10 to 30% by volume of the loam borrow. Section 10.1.5 discusses how to determine specific organic matter rates.

Other Amendments – Soil amendments, such as fertilizers, lime, and beneficial microorganisms, can be applied to the compost and loam borrow to bring the manufactured soil into acceptable ranges for pH, nutrients, and microbiological parameters. The type and amount of amendments to apply can be determined by conducting a lab analysis on a sample of the manufactured topsoil. The sample must be from a combination of loam borrow and compost at the expected mixing ratio. From the results of the soil analysis, a determination for the rates fertilizers (See Section 10.1.1), lime amendments (See Section 10.1.6), and beneficial organisms (See Section 10.1.7) can be made.

Large quantities of manufactured topsoil can be mixed in a staging area. Using the bucket of a front end loader, the compost and loam borrow can be measured out by volume. For instance, using a 5 yd^3 bucket, manufactured topsoil with a ratio of 25% compost and 75% loam borrow would have one scoop of compost applied to 3 scoops of loam borrow to produce 20 yd^3 of material. Additional amendments, such as fertilizers or lime materials, would be applied based on calculations for a 20 yd^3 pile. Once all the materials have been placed in the pile, it is thoroughly mixed using the front end loader.

Table 10.7 – *General specification ranges for composted materials for manufactured topsoil. These are generalized specifications that can be broadened depending on the soil characteristics of the loam borrow and site conditions (modified after Alexander 2003b; CCREF and USCC 2006).*

Test Parameters	Test Methods	Composted Material
Physical Contaminates (man-made inerts)	Man-made inert removal and classification (TMECC 03.08-C)	<1%
Trace Contaminants	Arsenic, Cadmium, Copper, Mercury, Manganese, Molybdenum, Nickel, Lead (TMECC 04.06)	Meets US EPA, 40 CFR 503 regulations
pH	1:5 slurry pH (TMECC 04.11-A)	5.0 -8.5
Soluble Salts	Electrical conductivity using 1:5 Slurry Method (dS/m)	<5
Bioassay	% seedling emergence and relative seedling vigor (TMECC 05.05-A)	>80% of control
% Moisture Content	% wet weight (TMECC 03.09-A)	30 - 60
Total Organic Matter	% by dry weight, loss on ignition (TMECC 05.07A)	25 to 60%
Stability	Respirometry. Carbon dioxide evolution rate - mg CO_2-C per g OM per day (TMECC 05.08B)	<8
C:N Ratio	(TMECC 05.02-A)	<25
Particle Size	% of compost by dry weight passing a selected mesh size, dry weight (TMECC 02.12-B)	* 3" (75 mm) 100% * 1" (25 mm), 90 -100% * 3/4" (19 mm), 65 -100% * 1/4" (6.4 mm), 0 -75% * Maximum particle length of 6" (152 mm)

Introduction
Initiation
Planning
Implementation Guides
Monitoring & Management
Summary

Purchasing loam borrow, compost and topsoil requires a set of contract specifications that assure product quality. The specifications in Tables 10.6 and 10.7 were developed for the DOT by the Composting Council Research and Education Foundation (Alexander 1993b). The tests are based on Test Method for the Examination of Composting and Composts (TMECC) protocols. These are general quality guidelines and can be broadened or made more constraining depending on the specifics of the project. When considering purchasing these products from a manufacturer, it is important to request the latest lab analysis. An STA facility (See Inset 10.7 in Section 10.1.5) will have these reports available while others might not. It is important that these tests be run by STA laboratories. It is also good to visit the location of the loam borrow, compost, or topsoil sources to determine whether there are undesirable or noxious weeds on or nearby the piles. If undesirable or noxious weeds are present, do not purchase the materials.

10.1.5 ORGANIC MATTER AMENDMENTS

10.1.5.1 Background

High quality topsoil is not always available in the quantities needed to meet the objectives of a revegetation project. In such cases, infertile subsoils can be augmented by the incorporation of organic matter and other soil amendments. This practice can be an important tool to begin the process of rebuilding a soil and reestablishing native vegetation.

One immediate effect of incorporating organic matter into infertile subsoils is increased infiltration. Water that would typically run off the soil surface during rainstorms now enters the soil. Amended subsoils also have greater permeability, and often increased water storage. Changes in these factors can improve the overall hydrology of the site, making soil less susceptible to runoff and erosion.

Incorporation of organic matter can often improve plant establishment and growth rates, especially if composted organic matter is used. Composted organic materials increase soil nutrients and rooting depth, which can create better growing conditions for native plant establishment. The use of non-composted organic materials, such as ground wood residues, can restrict plant establishment for the first several years after incorporation because of the immobilization of nitrogen. In this section, we will discuss the substitution of non-composted organic matter when composted materials are not available, are too expensive, or are excessive distances from the project site. Sources of non-composted organic materials are almost always available on construction sites as a result of the clearing and grubbing of trees and shrubs, and can be made available through grinding or chipping operations.

Incorporated organic matter becomes the primary source of energy for soil organisms and, whether fresh or composted, is the driving force behind soil development. In the process of decomposition, soil organisms turn cellulose into complex organic compounds, while slowly releasing nutrients for plant growth. Some of the complex compounds act similarly to glues, sticking soil particles together into aggregates, which ultimately create soil structure. The slow decomposition of organic matter delivers a steady supply of nutrients to the establishing plant community for many years.

The strategy behind many current revegetation projects is to obtain immediate cover with the use of seeds, fertilizers, and other amendments, without considering what is needed for long-term site recovery. It is not uncommon to find good establishment of vegetative cover immediately (within a year) after revegetation work, but several years later find that it was not sustainable. Life expectancy of many revegetation projects has often been found to be very short (Claassen and Hogan 1998). Incorporating organic matter takes a different approach. This strategy puts more emphasis on the development of the soils and less on the quick establishment of vegetation. It is based on the premise that reestablishing native vegetation will create healthy, functioning soils on highly disturbed sites over time. This cannot happen without basic minimum soil components, such as an organic source, nutrients, and good soil porosity. These components of a soil must be in place if plant communities are to become sustainable. Incorporating organic matter into the soils of highly disturbed sites is an important component of meeting long-range revegetation objectives.

10.1.5.2 Set Objectives

Section 10.1.3 discussed the use of organic matter as seedbed or seedling mulch. When used as mulch, organic matter protects the soil surface from erosion, enhances seed germination, and, with time, breaks down and improves the surface soil properties. Applying organic matter on the soil surface is far easier and more practical than incorporating it into the soil. Why, then, incorporate organic matter?

- Improve soils of "difficult" parent materials,
- Increase water-holding capacity,
- Improve rooting depth,
- Improve infiltration and drainage, and
- Encourage quicker release and availability of nutrients and carbon.

Setting objectives clarify why this mitigating measure is being considered and helps define the appropriate sources and application rates for incorporated organic matter.

"Difficult" Parent Material **–** The parent material from which soils are derived often plays an important role in how soils will respond to disturbances. Soils originating from granitic rock respond poorly to the removal of topsoil. Subsoils from this parent material have very high bulk densities and low permeability rates. They can "hardset" when dry, restricting root growth

Inset 10.5 – How Much is Soil Water-Holding Capacity Increased by Incorporating Organic Matter?

To determine whether there will be an immediate increase in the water-holding capacity of a soil as a result of organic matter incorporation, a test can be performed using readily available supplies (Note: This should be considered a "relative" test for available moisture, since wilting point is not determined).In the field, collect a large amount of soil (at least several quart bags). Obtain samples of the organic matter amendment under consideration. Make 6 or more containers out of 3-inch PVC pipe by cutting them into 4-inch lengths. Secure cheese cloth with duct tape around the bottom of one tube. Make a flat "end" piece for the tubes by cutting a plastic sheet (or using an old CD) and secure it to the bottom as well.

In a bowl, mix several samples of organic matter to sieved soil (a mixing rate of 4.5 cups soil to 0.5 cups organic matter = 10% organic matter; 4 cups soil to 1 cup organic matter = 20%; 3.5 cups soil to 1.5 cups organic matter = 30%). Place each mix in a PVC tube and fill to the top (the soil should be held in the tube by the cheese cloth and plastic). Lightly tamp the container against a surface and fill to the top of the tube. Identify the mix of soil and organic matter. As a control, or comparison, one tube must have no organic matter in the sample. Place each container in a 5-gallon bucket or plastic trash can (which must be taller than the length of the tubes). Fill the bucket with water just to the tops of the tubes (you might have to fill the bucket up to the top a few times) and keep them in the bucket for at least 30 minutes, or as long as it takes to see thoroughly moistened soils.

Remove the tubes from the water and let them drain. After several hours, detach the plastic bottoms (the soil should be held together by the cheese cloth) and place the ends of the tubes on a large stack of newspapers or paper towels. The paper will remove the excess water held at the bottom of the tube. Replace paper towels as they become saturated (Note: Place the plastic bottoms over the top of the tubes to prevent the soil at the surface from drying).

After 24 hours, record the weight of each tube. Remove the soil from the tube and weigh the tube. Dry soil at 221 °F (105 °C) in a drying oven. Unless a drying oven is available, purchasing one can be expensive. An alternative is drying each sample in a crockpot. These inexpensive appliances can reach temperatures of approximately 200 °F and it is possible to dry several samples in a day. When the sample is dry, weigh the sample. Calculate the percentage of soil moisture for each soil mix using the following equations (be sure to subtract the tube weights from the soil):

% soil moisture = (wet soil weight – dry soil weight) / dry soil weight * 100

If there is no increase in % soil moisture with the additions of organic matter over the soil with no organic matter additions, it means that in the short term, applying organic matter will not improve water-holding capacity. For a more accurate assessment, contact analytical laboratories that perform soil moisture tests.

and increasing runoff (Claassen and Zasoski 1998). Any positive effects of deep tillage are often short-lived on granitic subsoils (Luce 1997) because they quickly return to high bulk densities and soil strengths. Granitic soils can benefit from the incorporation of organic matter, not only because of increased nutrients, but because soil physical properties are improved. Organic amendments lower bulk densities and help to form pathways for water entry, soil drainage, and root growth. Organic matter can also increase the water-holding capacity of these soils.

Soils derived from serpentine rock have also been identified as difficult to revegetate because of heavy metals, low water-holding capacity, low nutrient levels, and low calcium to magnesium ratio. When disturbed, these sites can take decades to revegetate, producing a continual output of sediments. Incorporating compost into serpentine soils can greatly improve revegetation success by increasing water-holding capacity (Curtis and Claassen 2005).

Water-Holding Capacity **–** The incorporation of organic matter can increase water-holding capacity of soils with less than 9% available water capacity (Claassen 2006). These include soils with sand, loamy sand, and some sandy loam textures, as well as soils high in rock fragments. Incorporating organic matter to increase water-holding capacity can be critical on arid or semi-arid sites, or sites with very little summer rainfall. The increase in moisture-holding capacity depends on the type of organic matter and the degree of decomposition. Non-decomposed (fresh) organic sources, such as large wood chips and shredded wood fiber, can actually decrease soil water-holding capacity because these large materials hold very little water (These materials can act similarly to gravels).A test for determining how much soil moisture will be increased or decreased by the incorporation of organic matter is described in Inset 10.5. From these results, the source and quantity of organic matter to incorporate can be determined.

Rooting Depth **–** For species that have deep rooting requirements, such as trees and some shrubs, incorporating organic matter into the subsoil can increase rooting depth. This can be beneficial for plant establishment and long-term site recovery, especially when applied to soils derived from "difficult" parent materials. Soils that are compacted can also benefit from deep incorporation of organic matter. The incorporation of organic matter to deeper levels is often accomplished by applying a thick layer of organic matter to the surface, and then incorporating it to the desired depths with an excavator or backhoe. It is important that the organic matter is thoroughly mixed through the soil profile during incorporation.

Infiltration and Drainage **–** The hydrology of most disturbed soils is improved with organic matter incorporation. The degree to which infiltration and permeability is improved depends on the size and shape of the organic source and application rates (see following sections). Finer textured soils lacking structure (e.g., clay loams, silty clay loams, and sandy loams) should have better infiltration and permeability when organic matter is uniformly applied. This objective is applied in areas where water quality issues are high.

Nutrients and Carbon **–** Applying organic matter can assure that nutrients and carbon are available to decomposing soil microorganisms, which are essential for rebuilding a healthy soil. Typically this objective is applied to soils that are low in nutrients and carbon (e.g., sites lacking topsoil).

10.1.5.3 Select Organic Materials

There is a range of organic material sources to consider. Developing a selection criteria based on the following characteristics can be helpful:

- Source of organic matter,
- Level of decomposition,
- Carbon-to-nitrogen ratio (C:N), and
- Size and shape of material.

Recognizing how these characteristics will help achieve the objectives for incorporating organic matter should guide the revegetation specialist in making the appropriate decision for each project.

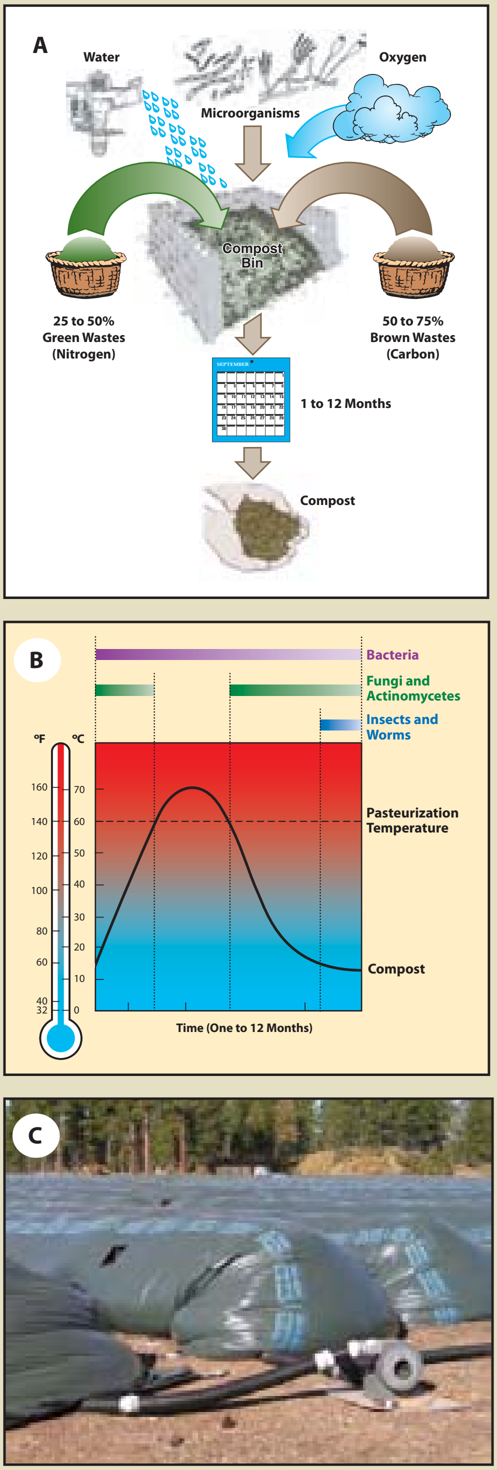
Organic Sources **–** Most available organic sources originate from waste byproducts of agriculture, forestry, and landscape maintenance. They include yard waste (lawn clippings, leaves), wood residues (sawdust, bark, branches, needles, roots, and boles of trees and shrubs from landscape maintenance, land clearing, logging operations, or mills), manures (poultry or

Inset 10.6 – Compost Production

The production and use of compost in the United States has flourished in the last 20 to 30 years as a result of a ban in many of states on yard wastes in landfills. Since 1988, the number of yard waste composting facilities in the United States has expanded from less than 1,000 in 1988 to over 3,500 in 1994. With the formation of the Composting Council in 1989, research in compost manufacturing has increased significantly.

Composting is the biological decomposition of organic matter under controlled aerobic conditions. To start the composting process, there must be organic matter, water, microorganisms, and oxygen (A). Heat is also needed, but is created by the microorganisms as they proliferate. Temperatures exceed levels necessary to kill most pathogens and weed species (B). With time, in a controlled composting environment, microorganisms release carbon dioxide and water from the organic matter. The rate at which these are released, and ultimately the composting time, is a function of the type of material being composted and the composting method.

A variety of composting methods have been developed over the years. State-of-the-art facilities and equipment that control and monitor oxygen, moisture, CO_2, and temperature levels throughout the composting process can produce relatively uniform products. The picture shown in (C) is of a composting system that pumps oxygen through a pipe centered in the wrapped piles of compost. Temperature and carbon dioxide are controlled through a venting system (adapted from Epstein 1997).



cattle), agricultural waste products (fruits and vegetables) and biosolids (treated sewage sludge meeting EPA regulations). In the composting process, usually more than one source is used. A compost from one facility might include lawn clippings, leaves, yard waste, poultry manure, and ground wood fiber, while another facility might use yard waste, ground wood fiber, and biosolids. When biosolids are used in the composting process, the resulting material is referred to as co-compost.

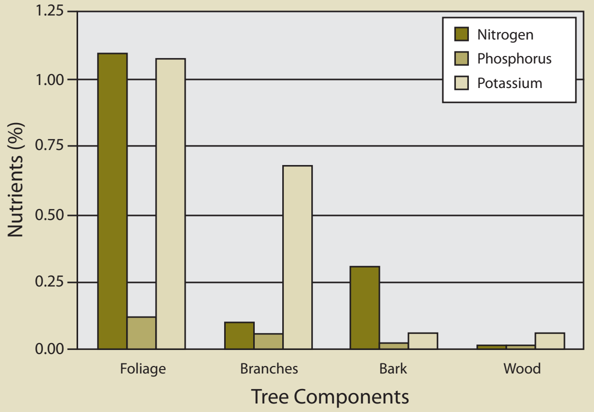


***Figure 10.27** – Nutrients are held in different portions of the forest biomass, as shown for old growth Pacific silver fir. On a percentage basis, tree foliage is the storehouse for nutrients. Mulch derived from branches and foliage will have far greater nutrient content than mulch from bark and wood (adapted from Cole and Johnson 1981).*

Each organic source has a unique nutrient composition. Green alfalfa, for example, has a very different nutrient makeup than organic matter derived from wood residues of cleared right-of-way. Even within sources, there are very different nutrient compositions (Figure 10.27). For example, most of the nutrients of trees are concentrated in the foliage and branches, and very little in the bole of the tree. A chipped slash pile composed of higher proportions of branches and foliage will contain far greater nutrients than a pile composed primarily of tree boles and, as such, would probably be a more preferred organic source.

As organic sources decompose, they contribute their combination of nutrients to the fertility of the soil. Knowing the source from which the organic matter was derived will give some indication of the amount of nutrients that might be supplied to the soil (Table 10.8). This information is important to determine whether target long-term nutrient levels will be achieved. Nutrient analysis reports should be obtained from facilities supplying the compost. Other sources of organic matter can be collected and sent to labs specializing in this type of testing (Inset 10.7).

Knowing the source of the organic matter might also identify contaminants that could potentially be harmful to plant growth. Additions of waste products, such as fly ash and municipal and factory waste products can potentially decrease the quality of an organic source. Testing these materials for contaminants, pH, soluble salts, and bioassay (Table 10.9) will identify potential problems with materials.

Level of Decomposition – Organic matter can be in various stages of decomposition; from fresh organic matter with minimal decomposition to compost that has undergone extensive decomposition. The level of decomposition is an important consideration when selecting an organic amendment. Additions of relatively undecomposed organic matter to the soil can have negative short-term effects on plant establishment and growth.

"Fresh" organic matter is recently ground or chipped material that has undergone very little decomposition. These materials usually have very high C:N and will immobilize soil nitrogen for months to several years after incorporation, depending on the characteristics of the organic source. Very slow establishment of plants

***Table 10.8** – C:N for common sources of organic matter (from Rose and Boyer 1995; Epstein 1997; Claassen and Carey 2004; Claassen 2006).*

Materials	C:N Ratio
Wood - Ponderosa pine and Douglas-fir	1,200:1 to 1,300:1
Bark - Ponderosa pine and Douglas-fir	400:1 to 500:1
Wood - Red alder	377:1
Paper	170:1
Pine needles	110:1
Wheat straw	80:1
Bark - Red alder	71:1
Dry leaves	60:1
Dry hay	40:1
Leaves	40:1 to 80:1
Yard compost	25:1 to 30:1
Oat straw	24:1
Rotted manure	20:1
Alfalfa hay	13:1
Top soil	10:1 to 12:1

Inset 10.7 – The Seal of Testing Assurance (STA) Program

Just as many products at the local market have seals of approval (e.g., "Approved by the FDA" or "USDA Inspected"), the United States Composting Council operates an approval system for composting facilities. The Seal of Testing Assurance (STA) is a voluntary program that requires compost manufacturers to regularly test their composts using an approved third-party testing facility. The procedures for sampling and testing are outlined in the Test Methods for the Examination of Composting and Compost (TMECC) protocols. The STA program takes the worry out of purchasing compost because you know that you can be assured that the company is reputable. You can purchase compost from companies that do not participate in the STA program (when the job site is in the back country you might have to do this), but this leaves the sampling and testing up to you. This involves traveling to the compost piles, systematically collecting samples from the compost piles, sending them to a qualified lab to run TMECC tests, and interpreting the results when you get them back. STA laboratories can be found at <http://www.compostingcouncil.org> (after Alexander 2003).

should be expected when incorporating fresh organic matter unless a continuous source of supplemental nitrogen is applied (e.g., applications of slow release fertilizers, growing nitrogen fixing plants). Nevertheless, applying fresh organic matter to highly disturbed soils can have a positive effect on slope hydrology and surface erosion. Fresh organic matter can increase infiltration and permeability in poorly structured soils by creating pathways for water-flow.

Incorporating fresh organic matter is not generally practiced in wildland revegetation. However, considering the expense of purchasing and transporting composted materials to remote sites, as well as the availability and abundance of road right-of-way material that is typically burned for disposal, this is an option that should be considered. If shredded or chipped road right-of-way material is to be incorporated into the soil, it should be allowed to age as long as possible in piles. To increase the rate of decomposition, the piles should be moved several times a year to add oxygen.

Some organic sources have been stored in piles for long periods of time and are partially decomposed. They are darker in appearance than fresh sources, but the appearance of the original organic source can still be discerned (e.g., needles or leaves are still identifiable).

***Table 10.9** – General specification ranges for composted materials for manufactured topsoil (modified after Alexander 2003; CCREF and USCC 2006).*

Test Parameters	Test Methods	Composted Material
Physical Contaminates (man-made inerts)	Man-made inert removal and classification (TMECC 03.08-C)	<1%
Trace Contaminants	Arsenic, Cadmium, Copper, Mercury, Manganese, Molybdenum, Nickel, Lead (TMECC 04.06)	Meets US EPA, 40 CFR 503 regulations
pH	1:5 slurry pH (TMECC 04.11-A)	5.0 -8.5
Soluble Salts	Electrical conductivity using 1:5 Slurry Method (dS/m)	<5
Bioassay	% seedling emergence and relative seedling vigor (TMECC 05.05-A)	>80% of control
% Moisture Content	% wet weight (TMECC 03.09-A)	30 - 60
Total Organic Matter	% by dry weight, loss on ignition (TMECC 05.07A)	25 to 60%
Stability	Respirometry. Carbon dioxide evolution rate - mg CO_2-C per g OM per day (TMECC 05.08B)	<8
C:N Ratio	(TMECC 05.02-A)	<25
Particle Size	% of compost by dry weight passing a selected mesh size, dry weight (TMECC 02.12-B)	* 3" (75 mm) 100% * 1" (25 mm), 90 -100% * 3/4" (19 mm), 65 -100% * 1/4" (6.4 mm), 0 -75% * Maximum particle length of 6" (152 mm)

These materials are sometimes referred to as "aged." Because only partial decomposition has occurred, C:N is lower than fresh organic matter. Nitrogen immobilization, however, should still be expected for a significant period of time after incorporation. Aged organic sources have not typically undergone extensive heating, like composts, and they can contain seeds of undesirable weeds.

Compost results from the controlled biological decomposition of organic material. The resulting heat generated in the process sanitizes the material. The end product is stabilized to the point that it is beneficial to plant growth (Alexander 2003a, 2003b). During the early stages of composting, heat is generated at temperatures that are lethal to weed seeds, insects, and pathogens (Inset 10.6). Fresh, moist compost piles will usually generate heat in the first few days of composting, reaching 140 to 160 °F, which will kill most pathogens and weed seeds (Epstein 1997; Daugovish and others 2006). The resulting material is a relatively stable, sanitized product that is very dark brown to black in color. Composts are very suitable materials for increasing the water-holding capacity of sandy soils, increasing nutrient supply, and enhancing soil infiltration and permeability rates.

Carbon-to-Nitrogen Ratio **–** The carbon-to-nitrogen ratio (C:N) is one of the most important characteristics to consider when selecting a source of organic matter. It is an indicator of whether nitrogen will be limiting or surplus (See Section 5.5.3.1). The higher the C:N, the greater the likelihood that nitrogen will be unavailable for plant uptake. When an organic source with high C:N is incorporated into the soil, carbon becomes available as an energy source for decomposing soil organisms. Soil microorganisms need available nitrogen to utilize the carbon source. Not only do microorganisms compete with plants for nitrogen, they store it in their cell walls, making it unavailable for plant growth for long periods of time. As the carbon sources become depleted, the high populations of soil microorganisms die and nitrogen is released for plant growth.

When C:N is greater than 15:1, available nitrogen is immobilized. As ratios dip below 15:1, nitrogen becomes available for plant uptake. Most fresh and aged organic sources have C:N greater than 15:1 (Table 10.8) and will immobilize nitrogen for some period of time when incorporated into the soil. When these same materials are composted, C:N approaches or even falls below 15:1. These materials will then provide a source of nitrogen to the soil. Co-composts, for instance, can have ratios between 9:1 and 11:1, indicating they are a ready source of available soil nitrogen. Since these materials provide nitrogen, they are often considered fertilizers (Ratios below 10:1 are typically labeled as fertilizers).

The period of time that nitrogen remains immobilized in the soil is dependent on several factors:

- ***Climate.*** High moisture and warm temperatures are important for accelerating decomposition rates. For example, organic matter will decompose faster in the coast range of Oregon than in the mountains of Idaho.
- ***Quantity of incorporated organic matter.*** The more organic matter that is applied, the longer the immobilization. A small amount of incorporated sawdust will immobilize very little nitrogen as compared to several inches of the same material.
- ***C:N of organic amended soil.*** The combined C:N of soil and incorporated organic matter gives an indication of how the type and rate of incorporated organic matter will affect the soil C:N. An amended soil with a high C:N will have a longer immobilization period than a soil with a lower C:N.
- ***Size and shape of organic matter.*** The more surface area of the organic source, the faster decomposition will take place. A fine compost will decompose faster than a coarse, screened compost.
- ***Nitrogen fertilization or fixation.*** Nitrogen supplied from fertilizers or nitrogen-fixing plants will speed up decomposition rates.

It is not easy to predict how long nitrogen will be immobilized in a soil. The variety of available organic sources, unique soil types, and range of climates of the western United States make this difficult. For practical purposes, it should be assumed that without supplemental additions of nitrogen (from fertilizers or nitrogen-fixing plants), the immobilization of nitrogen in soils with high C:N will be in the order of months, if not years. To give some idea of decomposition rates, Claassen and Carey (2004) found that partially composted yard waste with a C:N of 18:1 took over a year for nitrogen to become available under aerobic incubation testing conditions.

A high C:N might be beneficial to soil aeration and water movement because it does not break down as fast as material with lower C:N. For example, the incorporation of alfalfa hay (C:N =13:1) will decompose quickly, and the effects on soil structure might be short-lived. On the other hand, wheat straw (C:N = 80:1) or pine needles (C:N = 110:1) can be effective for several years. High C:N materials are also a longer-term energy source to soil organisms that help create a stable soil structure.

Nitrogen based fertilizers can be applied to offset higher soil C:N and make soil nitrogen available for plant growth. Section 10.1.1 discusses fertilizer strategies for reducing the effects of high C:N soils.

Size and Shape – The range in sizes and shapes of organic matter plays a role in how quickly organic matter breaks down in the soil. Particles with greater surface area to volume ratios should decompose faster than particles with less surface area to volume. Chipped wood, for instance, has a low surface area to volume ratio and would take longer to break down than long strands of ground wood or fine screened sawdust, which have greater surfaces areas.

The particle size and shape of the organic source can also be important in slope hydrology by increasing infiltration and permeability rates. Long, shredded wood fiber, for example, can create long passageways for water. If applied at high enough rates, long fibers can overlap, creating continuous pores that will increase drainage rates. Wood chips applied at the same rates are less likely to form continuous routes for water drainage because of their shape.

Large undecomposed wood can significantly reduce soil water storage due to low water-holding capacity of the material. Incorporating large, undecomposed woody organic matter into soils with low water-holding capacities should be tested first to determine its effect (See Section 10.1.5.1).

10.1.5.4 Determine Application Rate

The rates for applying organic matter should be based on the objectives for organic matter incorporation. Each objective discussed in Section 10.1.5.2 will yield different application rates. For example, a project objective to increase permeability would require the addition of 6 inches of compost mixed into 24 inches of soil. This is a far greater quantity than if the objective was to increase nutrient supply, which would require 2 inches of compost added to the top 12 inches of soil.

Determining rates of organic matter needed to improve nutrient status can follow the process outlined for calculating fertilizer rates in Section 10.1.1.2. If a nutrient, specifically nitrogen, is found to be deficient, the amount of organic material to apply must be determined. A nutrient analysis is necessary to make these determinations. Figure 10.28 gives an example of how to calculate the amount of organic matter to incorporate to meet minimum levels of nitrogen.

When organic matter is used to increase infiltration and permeability of a soil, a rate of 25% organic matter (by volume) to 75% soil (by volume) has been suggested by several researchers (Claassen 2006). This would require 4 inches of organic matter be incorporated for every 9 inches of soil. Actual field trials could be installed prior to construction to measure the effects

Figure 10.28 – *The following calculations can be used to determine the amount of compost to apply to a site. They are based on laboratory test results of the compost and threshold nitrogen levels obtained from reference sites.*

A	Total nitrogen (or other nutrient of interest) in compost	10	lbs/cu yd	From laboratory report — most labs will report out nutrients in lbs/cu yd of material
B	Nitrogen deficit	769	lbs/ac	Determine from reference sites or minimum thresholds from literature (See Figures 10.1 and 10.2)
C	Minimum application rates: B/A =	77	cu yd/ac	**Volume** of compost to apply to the site to meet minimum thresholds
D	Minimum application depth: C/135 =	0.6	in	**Thickness** of compost to apply to the site to meet minimum thresholds

of soil amendments on infiltration. By incorporating several rates of organic matter on plots in disturbed reference sites near the project, the infiltration rates of each treatment could be determined using rainfall simulation equipment.

If the objective for incorporating organic matter is to increase the soil's available water-holding capacity, the rate of organic matter application should be based on achieving a total available water-holding capacity for the desired vegetation of the project area (Setting these targets is discussed in Section 5.3).Inset 10.5 shows one method of determining relative water-holding capacity of amended soils.

10.1.5.5 Assure Product Quality

Purchasing compost requires a set of contract specifications that assure product quality. Table 10.9 is a "model specification" developed for the Department of Transportation (DOT) by the Composting Council Research and Education Foundation (Alexander 1993b) for composts used as soil amendments on roadways. The tests are based on the Test Method for the Examination of Composting and Composts (TMECC) protocols. These are general quality guidelines and can be broadened or made more constraining depending on the specifics of the project. When considering purchasing compost or any other type of organic matter from a manufacturer, it is important to request the latest lab analysis. A Seal of Testing Assurance (STA) facility (Inset 10.7) will have these reports available while others might not. It is important that these tests be run by STA laboratories. It is a good practice to visit the location of the organic sources to determine whether there are undesirable or noxious weeds on or nearby the piles. If these species are present, materials should not be purchased.

10.1.6 LIME AMENDMENTS

10.1.6.1 Introduction

Agricultural lime is used when soil pH of a disturbed site needs to be raised to improve plant survival and establishment (See Section 5.5.5, pH and Salts). Liming low pH soils improves plant growth by 1) reducing aluminum toxicity, 2) increasing phosphorus and micronutrient availability, 3) favoring symbiotic and non-symbiotic nitrogen fixation, 4) improving soil structure, and 5) enhancing nitrification (Havlin and others 1999).

Each plant community has an optimal pH range. Plant communities dominated by conifers, for instance, function well between pH 5.0 to 6.5, whereas grass-dominated plant communities in arid climates perform well between pH 6.5 and 8.0. Liming is not an easy operation on drastically disturbed lands. Liming materials must be incorporated into the soil profile for maximum effectiveness. This application is very difficult on steep rocky slopes, which are typical of road construction in mountainous terrain.

10.1.6.2 Set pH Targets

It is important to set a realistic post-construction target pH when considering liming because large quantities of lime are needed for even small changes in soil pH. For example, raising an existing soil pH of 5.5 to pH 6.5 takes nearly twice the amount of lime necessary to raise it to pH 6.0. A half point pH difference in this case can result in an increase of over 1,000 lb/ac in application rates.

***Table 10.10 –** Liming materials are rated by how well they neutralize the soil using pure limestone as the baseline of 100%. The rating system is called calcium carbonate equivalents (CCE). Values for some commercially available products are shown below (Campbell and others 1980; Havlin and others 1999).*

Material	Chemical Formula	CCE
Slag	$CaSiO_3$	60-90
Agricultural limestones	$CaCO_3$	70-90
Marl	$CaCO_3$	70-90
Pure limestone	$CaCO_3$	100
Pure dolomite	$CaMg(CO_3)_2$	110
Hydrated lime, slaked lime, builders' lime	$Ca(OH)_2$	120-135
Burned lime, unslaked lime, quicklime	CaO	150-175

As discussed in previous sections, it is important to understand the characteristics of the reference site topsoils and try to recreate these conditions after construction. If the post-construction surface soils have a lower pH than the reference site topsoils, then liming can be used to raise pH. On a project where topsoil is removed and not replaced, the difference between the pH of the topsoil and the subsoil should be determined. When the pH of the subsoil is significantly lower than the topsoil, liming to raise soil pH to reference topsoil levels (target levels) should be considered. Although it might not always be practical to raise pH of post-construction soils to reference topsoil values, a minimum pH target of 5.5 should be considered for most sites. This minimum standard would make most soils below pH 5.5 good candidates for liming.

10.1.6.3 Select Liming Materials

There are several types of liming materials commercially available (Table 10.10) and selection should be based on costs, reactivity, effects on seed germination, and composition of the material. All liming materials will raise soil pH, but not at the same level as pure limestone. To account for this, all commercially available liming materials are rated against pure limestone for neutralizing effects. The rating system is called calcium carbonate equivalent (CCE). Burnt lime (CaO) for instance, might have a CCE of 150, which means that it has a 50% greater neutralizing capacity than pure limestone and much less of this material needs to be applied to increase pH. A low CCE material, such as slag, might have a CCE of 60, which means that it has 40% less neutralizing capacity. Liming materials with high CCE, like $Ca(OH)_2$ (slaked lime, hydrated lime, or builders lime) and CaO (unslaked lime, burned lime, or quicklime), can be caustic to germinating seeds and, if used, should be applied several months before sowing (Havlin and others 1999).

The particle size of the liming material determines how quickly the pH of a soil will increase. The finer the material, the faster soil pH will increase. For instance, a lime material passing a 100-mesh screen reacts faster and takes less quantity than material passing a 50-mesh screen. Finer lime materials are more expensive to purchase. If very fine lime is to be used in surface application, it should meet the following size requirements: 100% passing a 100-mesh sieve and 80% to 90% passing a 200-mesh sieve.

10.1.6.4 Determine Liming Rates

Determining how much liming material to apply is based on these factors:

- ***Soil texture.*** Soil texture plays an important role in lime requirements because the higher the clay content, the more lime must be added to the soil. A soil with a clay loam texture requires over 3 times more lime to raise the pH from 5.0 to 6.0 than a sandy soil. This is because finer textured soils and organic matter have a higher propensity to attract and store bases released from liming materials (Inset 10.8).
- ***Soil organic matter.*** Soil organic matter (in humus form) has a high CEC and requires more lime material to raise the pH.
- ***Percentage of rock fragments.*** Rock fragments have little to no CEC because they are massive and typically unweathered. Rocky soils will require less lime materials to raise pH.
- ***Depth of liming material.*** Lime materials are relatively insoluble and only change the pH of the soil around where they were placed. Liming rates are adjusted based on the soil depth to which the lime material is mixed.

Inset 10.8 – Cation Exchange Capacity (CEC)

The capacity of a soil to hold positive ions (referred to as bases or cations) is called the cation exchange capacity (CEC). A soil with a high CEC holds a much greater amount of cations, such as calcium and magnesium, than a soil with low CEC. For this reason, a high CEC soil requires more liming material to raise it to the same pH level. Cation exchange capacity is directly related to the amount of clay and organic matter present in the soil – the higher the clay or organic matter content, the higher the CEC. Rock fragments have little or no CEC, since they are massive in structure. Rates of liming on high coarse fragment soils must be reduced proportionally.

__Figure 10.29 –__ This spreadsheet, along with Figure 10.30, provide the steps necessary for determining the approximate amount of liming material to apply.

A	pH of disturbed soil:	5		From pH test of disturbed soils
B	Target pH:	6		Target pH of reference site topsoil
C	Soil texture:	sandy loam		From field surveys of disturbed soils
D	Rock fragments:	35	%	From field surveys of disturbed soils
E	Incorporation depth:	0.3	feet	The depth the lime material will be incorporated
F	Limestone equivalent for disturbed soil pH	900	lbs/ac	From Figure 10.30 (C)
G	Limestone equivalent	2,800	lbs/ac	From Figure 10.30 (D)
H	(G - F) * (E /0.58) * (100 - D) / 100	639	lbs/ac	Amount of limestone to raise soil to target pH
I	Type of liming material:	dolomite		Based on availability and cost of material
J	CCE of liming material:	110		From Table 10.10
K	H / (J /100) =	581	lbs/ac	Total amount of material to apply

- ***Lime material composition.*** Each liming material is rated by how well it neutralizes the soil. Less materials with high CCE (See Section 10.1.6.3) are required as compared to low CCE materials.
- ***Fineness of liming material.*** The fineness of the liming material determines how quickly the pH will change. Very fine materials change pH quicker than coarse materials. Therefore, less quantity of finer grade materials will be required for immediate pH soil change.

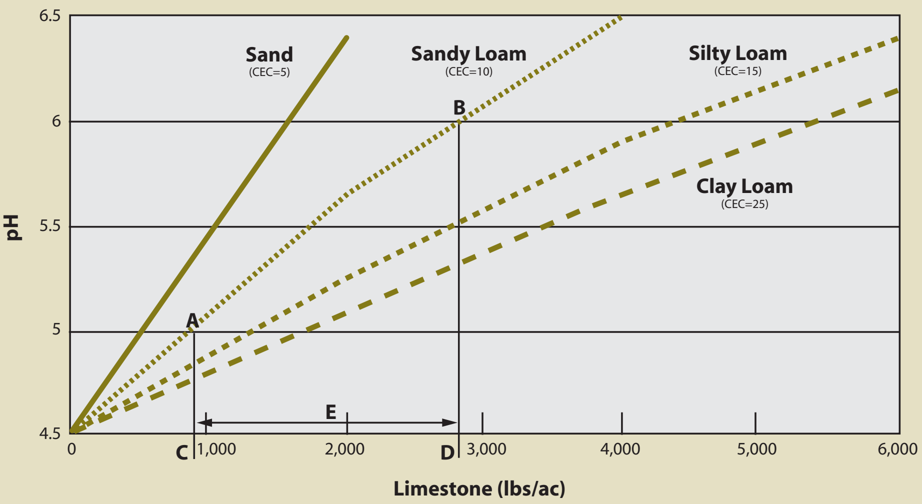
There are two methods for determining liming application rates: approximation and SMP (Shoemaker-McLean-Pratt) Buffer methods. For an initial estimate of how much liming material might be needed to raise soil pH to target levels, the approximation method can be employed. However, if liming will actually be done on a revegetation project, the SMP Buffer method should be used for calculations.

Approximation Method – For a quick approximation of lime application rates, the calculations shown in Figure 10.29 and Figure 10.30 are used. In the examples shown in these two figures, the topsoil was removed, leaving a gravelly, sandy loam subsoil at the surface. This material had a pH of 5.0. The target pH, based on the reference site for this area, was 6.0. The site was on a very steep slope where incorporating the limestone was not feasible (See Section 10.1.6.5). It was therefore decided to place the lime on the surface of the soil through hydroseeding operations. The surface had been left rough so that, over time, some of the liming materials would naturally become incorporated into the surface through soil movement. The incorporation depth was set between 3 to 4 inches (0.3 ft) based on this assumption.

Generalized curves shown in Figure 10.30 were used to determine the amount of limestone to add to raise the pH. On the baseline of the graph, rates of limestone in lb/ac that correspond to the surface soil pH (C = 900) and the target pH (D = 2,800) were determined from pH levels located on the sandy loam curve. The rate of limestone for the surface soil was subtracted from the target rate to give the quantity of limestone to add to 7 inches of soil (the depth of incorporation upon which these graphs were based). In this example 1,900 lb/ac of limestone was needed to achieve the target pH (2,800 less 900). This rate was subsequently reduced to 639 lb/ac to compensate for the volume of rock fragments and the shallow incorporation depth (3 inches instead of 7 inches). Since dolomite, which has a higher CCE value, would be applied, there would be less of this material needed (581 lb/ac).

SMP Buffer Method – For much greater accuracy, lab testing facilities offer the SMP Buffer Method for determining the lime requirement for a disturbed soil. The results from this test are reported in a table that includes the quantity of lime needed to raise the soil sample to pH 7.

Figure 10.30 – This chart can be used to approximate the liming application rates for disturbed soils. The chart is based on measuring pH changes of four soil textural classes as limestone is incorporated into the surface 7 inches of soil (chart modified from Havlin and others 1999). For example, a sandy loam soil has an existing pH of 5.0 (A) and a target pH after liming of pH 6.0 (B). The amount of limestone to apply (E) is 1,900 lb/ac, which is calculated by subtracting 900 (C) from 2,800 (D). More accurate lab results obtained from the SMP Buffer method for determining lime requirements can be substituted for values obtained in this graph.



The information can be graphed and used in a similar fashion to the example in Figure 10.30. The SMP test is well adapted for soils with pH values below 5.8 and containing less than 10% organic matter (McLean 1973).

10.1.6.5 Apply Liming Materials

Limestone materials are commonly applied in powder form through fertilizer spreaders or hydroseeding equipment. Fine limestone materials can be difficult to apply in dry form through fertilizer spreaders. Pelletized limestone, which is very finely ground material that has been processed into shot-sized particles, is easy to handle and can be used in fertilizer spreaders. Hydroseeding equipment, however, is probably the best method for spreading liming materials, especially very fine liming materials.

Since liming materials are relatively insoluble in water, surface applications of lime, without some degree of soil mixing, renders the lime ineffective for immediate correction of subsoil acidity. Several studies have indicated that it can take more than a decade for surface-applied lime (not incorporated) to raise soil pH to a depth of 6 inches (Havlin and others 1999). It is important, therefore, to incorporate liming materials into the soil at the depth where the pH change is desired.

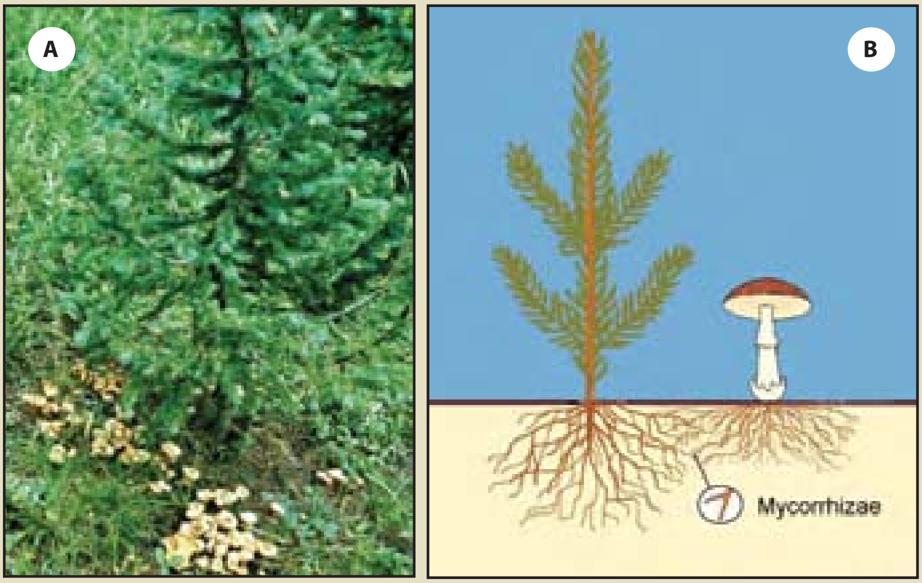
Incorporation can be accomplished on gentle slope gradients using tillage equipment, such as disks and harrows (See Section 10.1.2, Tillage). Liming materials can be mixed on steep slopes using an excavator. However, if equipment is not available for mixing on steep sites, applying very fine liming materials through hydroseeding equipment is a possible way of raising pH. This method requires the use of very finely ground limestone (Havlin and others 1999). This product raises pH faster, and depending on the soil type, can move a short distance into the soil surface. Nevertheless, with surface-applied limestone, it should be assumed that soil pH will not change much deeper than 3 inches below the soil surface.

10.1.7 BENEFICIAL SOIL MICROORGANISMS

10.1.7.1 Background

Beneficial microorganisms are naturally occurring bacteria, fungi, and other microbes that play a crucial role in plant productivity and health. Some types of beneficial microorganisms

Figure 10.31 – Many plants rely on symbiotic relationships to survive and grow in nature (A). The mushrooms under this spruce are the fruiting bodies of a beneficial fungus that has formed mycorrhizae on the roots (B).



are called "microsymbionts" because they form a symbiotic (mutually beneficial) relationship with plants. In natural ecosystems, the root systems of successful plants have several microbial partnerships that allow them to survive and grow even in harsh conditions (Figure 10.31). Without their microsymbiont partners, plants become stunted and often die. Frequently, these failures are attributed to poor nursery stock or fertilization, when the real problem was the absence of the proper microorganism.

As discussed in Section 5.3.5, beneficial microorganisms should be considered as part of an overall strategy to conserve existing ecological resources on the site, including existing beneficial soil microorganisms. These strategies include:

- Minimizing soil disturbance,
- Conserving and reapplying topsoil and organic matter,
- Leaving undisturbed islands or pockets on the project site, and
- Minimizing use of fast-release fertilizers.

On projects where soil disturbance will be minimal, or where healthy topsoil is still present and contains functional communities of beneficial microorganisms, reintroducing the organisms will usually not be necessary. However, most road projects involve severe disturbances and so healthy populations of beneficial microorganisms may be depleted or even absent. Soil compaction and removal of topsoil which is routine during road construction is particularly detrimental to beneficial soil microorganisms. Also, beneficial bacteria and fungi do not survive in soil in the absence of their host plants and so are killed during soil removal and stockpiling. Reintroducing beneficial microorganisms is therefore a key part of roadside revegetation.

Appropriate beneficial microorganism can be reintroduced by "inoculating" seeds as they are sown in the field or in the nursery, or by introducing the microorganism in the planting hole. Inoculated plants may establish more quickly with less water, fertilizer, and weed control, thereby reducing installation costs. Healthy, sustainable plant communities are our ultimate goal in roadside revegetation; inoculation can help accelerate the process.

The two most important microsymbionts for revegetation projects are mycorrhizal fungi and nitrogen-fixing bacteria.

10.1.7.2 What are Mycorrhizae?

Mycorrhizae are one of the most fascinating symbiotic relationships in nature. "Myco" means "fungus" and "rhizae" means "root"; the word "mycorrhizae" means "fungus-roots." The host plant roots provide a convenient substrate for the fungus, and also supply food in the form of simple carbohydrates. In exchange for this free "room-and-board", the mycorrhizal fungus offers benefits to the host plant:

Increased Water and Nutrient Uptake – Beneficial fungi help plants absorb mineral nutrients, especially phosphorus and micronutrients such as zinc and copper. Mycorrhizae increase the root surface area, and the fungal hyphae access water and nutrients beyond the roots (Figure 10.32A). When plants lack mycorrhizae, they become stunted and sometimes chlorotic ("yellow") in appearance.

Stress and Disease Protection – Mycorrhizal fungi protect the plant host in several ways. With some fungi, the mantle completely covers fragile root tips (Figure 10.32A) and acts as a physical barrier from drying, other pests, and toxic soil contaminants. Other fungal symbionts produce antibiotics that provide chemical protection.

Increased Vigor and Growth – Plants with mycorrhizal roots survive and grow better after they are planted out on the project site. This effect is often difficult to demonstrate but can sometimes be seen in nurseries where soil fumigation has eliminated mycorrhizal fungi from seedbeds. After emergence, some plants become naturally inoculated by airborne spores and grow much larger and healthier than those that lack the fungal symbiont (Figure 10.32B).

Mycorrhizal fungi form partnerships with most plant families, and three types of mycorrhizae are recognized:

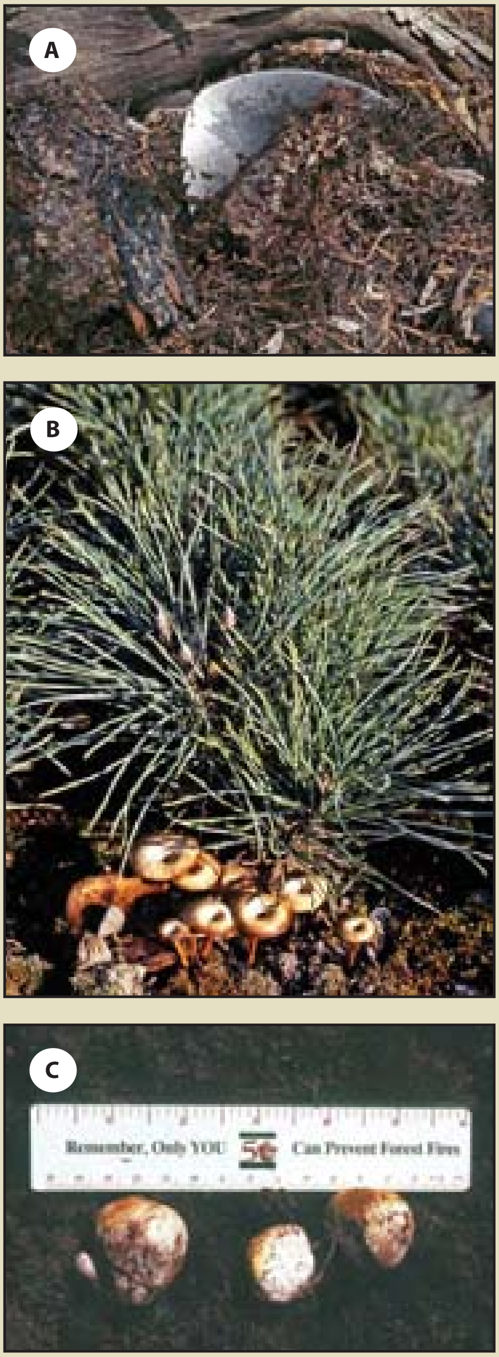
- ***Ectomycorrhizal fungi (ECM)*** have relatively narrow host ranges and form partnerships with many temperate forest plants, especially pines, oaks, beeches, spruces, and firs.
- ***Arbuscular mycorrhizal fungi (AMF)*** are also known as endomycorrhizae or vesicular-arbuscular mycorrhizae. These fungi have wide host ranges and are found on most wild and cultivated grasses and annual crops, most tropical plants, and some temperate tree species including cedars, alders, and maples.
- ***Ericoid mycorrhizal fungi*** form partnerships with the Epacridaceae, Empetraceae, and most of the Ericaceae; plants affected include blueberries, cranberries, crowberries, huckleberries, azaleas, rhododendrons, and sedges. Because these mycorrhizal associations involve unique species of fungi, few commercial inoculants are available and the best option is to use soil from around healthy plants.

Figure 10.32 – *Mycorrhizal fungi offer many benefits to the host plant. The fungal hyphae increase the area of absorption for water and mineral nutrients, whereas fungal mantle covers the root and protects it from desiccation and pathogens (A). In fumigated nursery soils, inoculated seedlings are much larger and healthier than those that lack the fungal partner (B).*

For restoration purposes, the important thing to remember is that different plant species have specific fungal partners. ECM fungi are generally specific to one genus or group of plants whereas the same AMF fungus can colonize a wide variety of species. In addition, the three types of mycorrhizal fungi have to be inoculated differently. ECM species have airborne spores that can reinoculate soils naturally over time, or the spores can be harvested and used to inoculate nursery stock. On the other hand, the spores of AMF species are large and released underground and so cannot reinoculate plants very quickly. This makes artificial inoculation even more critical.

Conserving existing topsoil and organic matter is a key practice to protect existing populations of beneficial microorganisms. If disturbance will take place, then other interventions will be necessary to introduce the key microsymbionts for the plants you are trying to establish. Consider the needs for mycorrhizal inoculants. Are the species to be established endomycorrhizal, ectomycorrhizal, ericoid or non-mycorrhizal? The selection of the mycorrhizal inoculants must be based on the target host plants and the site condition. Conifer seedlings, for example, require very specific ectomycorrhizal fungi for successful inoculation. Endomycorrhizal species, on the other hand, are broad in range and therefore a general mix of several endomycorrhizal species can be utilized for a broader range of plants. Knowing which species you are working with is essential in order to match the plants with their appropriate microsymbiont partners.

***Figure 10.33** – Soil inoculum can be collected from adjacent plants if done carefully (A). Inoculum can also be made from the spores of mushrooms (B), puffballs, or truffles (C) collected from around the proper host plant.*



10.1.7.3 Sources and Application of Ectomycorrhizal Fungi

Three common sources of ECM inoculants are soil, spores, or pure culture vegetative inoculum.

Soil – Topsoil, humus or duff from beneath ECM host plants can be used for inoculum if done properly. Because disturbance and exposure to direct sunlight may kill these beneficial fungi, soil inoculation must be done as quickly as possible. Soil inoculum can also be collected under the same plant species adjacent to the project site (Figure 10.33A). Small amounts should be collected from several different locations and care should be taken not to damage the host plants. If topsoil and organic matter are not available on the project site, spores or commercial inoculants can be used instead.

Spores **–** Spore suspensions are sometimes available from commercial suppliers. However, the quality of commercial sources can be variable so it is important to verify the quality of the inoculum. It is possible to make your own inoculum from spores. Collect ripe fruiting bodies of mushrooms (Figure 10.33B), puffballs, or truffles (Figure 10.33C) from beneath healthy plants. Then, rinse and pulverize them in a blender for several minutes to make a slurry. Fungal spores do not have a long shelf-life and should be applied immediately.

Pure Culture Inoculum **–** Mycorrhizal fungi are available commercially as pure cultures, usually in a peat-based carrier (Figure 10.34). Most commercial sources contain several different species of ECM. Because this type of inoculum is made from pure fungal cultures and does not store well, it is rarely available from suppliers.

Application rates and methods for ectomycorrhizal inoculums will vary by species. Since these mycorrhizal fungi are very specific to their host species, it is important to work closely with company representatives when using ectomycorrhizal inoculum. Nurseries may inoculate plants; if this service is desired, it must be stated in the seedling-growing contract. Some ectomycorrhizal fungi products can be incorporated into the nursery growing media prior to sowing (Figure 10.34A) or a liquid slurry of fungal spores can be applied during the growing season. However, there is no guarantee that the plants will still be colonized when they are planted at the project site.

Other ectomycorrhizal fungal inoculums are applied at the time of planting and here the objective is to get the inoculum in contact with the plant roots. Some formulations are mixed with water and the slurry is applied to the roots of nursery stock. Tablets or packets can be placed in the planting hole (Figure 10.34B). However, the effectiveness of many of these applications has not been verified by research under roadside revegetation conditions.

Verifying the Effectiveness of ECM Inoculation **–** Luckily, it is fairly easy to recognize ECM as the fungi can be seen with the naked eye on the root system. Short feeder roots should be examined for a cottony-white appearance on the roots or a white or brightly colored mantle or sheath over the roots (Figure 10.35). Unlike pathogenic fungi, mycorrhizae will never show signs of root decay and the mycelia around the root will be visible. Sometimes, mushrooms or other fruiting bodies will occasionally appear alongside their host plants. For verification, it is recommended that plant samples be sent to a laboratory where they can also provide a numerical rating of inoculation effectiveness.

10.1.7.4 Sources and Application of Arbuscular Mycorrhizal Fungi

The two main sources of AMF inoculants include "pot culture," (also known as "crude" inoculant), and commercially available pure cultures.

Figure 10.34 – *Commercial sources of ectomycorrhizal inoculum are available in several forms: pure cultures grown on peat moss or vermiculite (A) are perishable but spore-based products can be applied as root dips. Tablets and packets are put in the hole during planting.*

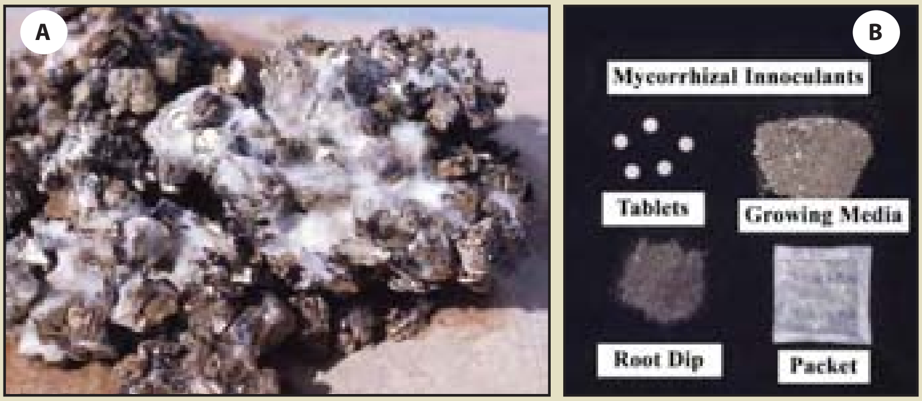


Figure 10.35 *– Ectomycorrhizae are visible on plant root systems as white or colored structures with a cottony or felt-like texture.*

Nursery Pot Culture – This option is only viable in a nursery when plants are being grown for a specific restoration project, and is unique to AMF fungi because of their wide host range. A specific AMF is acquired either commercially or from a field site as a starter culture, and then added to a sterile potting medium. A host plant such as corn, sorghum, clover, or an herbaceous native plant is then grown in this substrate; as the host grows, the AMF multiply in the growing medium (Figure 10.36A). The shoots of host plants are removed and the substrate, now rich in roots, spores, and mycelium, is chopped up (Figure 10.36B). The resultant inoculum can then be incorporated into growing media or planting beds before seeds or cuttings are sown. This is a highly effective technique for propagating AMF in the nursery and could also be used on the planting site. For details refer to *Arbuscular Mycorrhizas: Producing and Applying Arbuscular Mycorrhizal Inoculum* (Habte and Osorio 2001).

Commercial Products – Several brands of commercial AMF inoculants are available, and usually contain a mix of several fungal species. Because AMF spores are so small and fragile, they are mixed with a carrier such as vermiculite or calcined clay to aid in application. Coarser textured products (Figure 10.37A) are meant for incorporation into soil or growing media, and finer-textured products (Figure 10.37B) are applied as wettable powders through sprayers or injected into irrigation systems. Inoculation effectiveness has been shown to vary considerably between different products (Figure 10.37C), so it is wise to install tests before purchasing large quantities of a specific product. Laboratories can provide a live spore count which is the best measure of inoculum quality.

Application of AMF Inoculants – Because AMF spores are relatively large, ensuring that spores come in direct contact with the root systems or seeds is critical. Spores will not easily pass through irrigation injectors or nozzles, and do not move downward or through the soil into the soil with water. Therefore, applying AMF inoculum as a topdressing is not a good option. AMF

Figure 10.36 *– Because of their wide host range, AMF fungi can be raised on host plants (A) and their roots chopped-up for inoculum (B).*

inoculums typically come in a granular form with different grades of fineness. Coarse grade products (Figure 10.37A) are mixed in the soil prior to sowing seed. Finer grade inoculums (Figure 10.37B), which are more expensive, may be mixed with water and applied directly onto seeds or as a root dip. Use of fine-grade inoculum through hydroseeding equipment is a recent application method that shows promise as a way to combine AMF with seeds as they are sown. Again, there is little research on AMF inoculation effectiveness on roadside revegetation sites.

Verifying the Effectiveness of AMF Inoculation **–** Unlike ECM, AMF are not visible to the unaided eye. To verify the effectiveness of AMF inoculation, roots must be stained and examined under a microscope (Figure 10.37D). This verification can often be done easily and inexpensively in a laboratory.

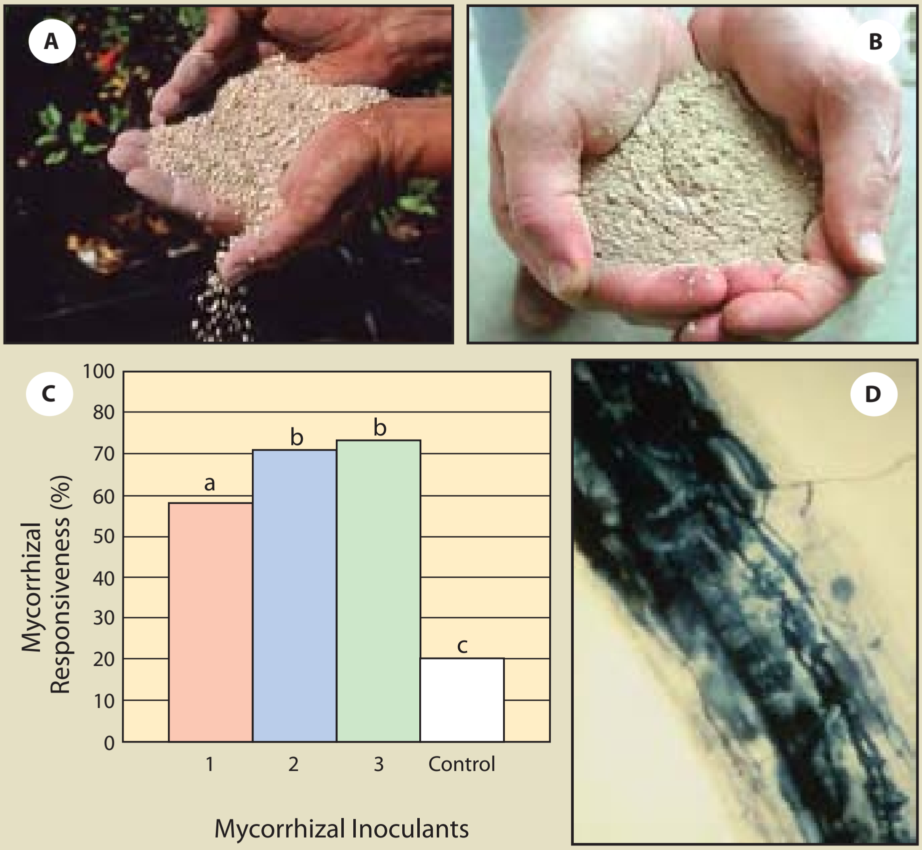
10.1.7.5 Management Considerations for Mycorrhizal Fungi

If possible, work with a specialist to help with the following:

- Selecting appropriate mycorrhizal partners for the species and outplanting sites;
- Determining the best sources of inoculant and evaluating their effectiveness in the field conditions; and
- Designing outplanting trials to evaluate seedling survival and mycorrhizal performance in the field, and modifying the inoculant sources if improvements are needed.

In addition to learning how to effectively apply mycorrhizal fungi, some soil management modifications will be required to promote formation of mycorrhizal partnerships in the field.

Figure 10.37 – *Several commercial AMF inoculums are available and consist of fungal spores mixed with an inert carrier to aid in application. Coarser-textured products (A) can be incorporated into soil or growing media, whereas finer-textured products can be sprayed like a wettable powder (B). Tests of inoculation effectiveness have shown significant differences between products (C). To confirm inoculation, plant roots must be stained so that the fungal hyphae are visible under a microscope (D). C modified from Corkidi and others (2005).*



Fertilization is probably the most significant adjustment. Mycorrhizal fungi extend the plant's root system, and extract nutrients and water from the soil. High levels of soluble fertilizers may inhibit their presence. In some cases, fertilizer applications can be reduced by half or more due to the increased nutrient uptake by mycorrhizal fungi. Fertilizer type and form is also important. An excessive amount of phosphorus in the fertilizer inhibits formation of the partnership; therefore phosphorus should be reduced. If nitrogen is applied, ammonium-N is better used by the plant than nitrate-N (Landis 1989). Controlled release fertilizers are preferred because they release small doses of nutrients gradually, compared to the more rapid nutrient release from traditional products. Applications of certain herbicides, pesticides, insecticides, fungicides, and nematicides are detrimental to mycorrhizal fungi.

10.1.7.6 Nitrogen-Fixing Bacteria

Nitrogen-fixing bacteria live in nodules on plant roots and accumulate ("fix") nitrogen from the air and share it with their host plants. Unlike mycorrhizal fungi, which are found on most trees and plants, only certain species of plants can form symbiotic partnerships with nitrogen-fixing bacteria.

The role of nitrogen-fixing bacteria and their partner plants is crucial to roadside restoration. Because nitrogen-fixing plants are often "pioneer" species that are the first to colonize disturbed sites, they are ideal for revegetation or restoration projects. Nitrogen-fixing species are usually outplanted in order to help restore fertility and organic matter to the project site. Nitrogen-fixing bacteria form nodules on roots of certain plants (Figure 10.38A) and accumulate nitrogen from the air (Figure 10.38B). While plants that form this association are sometimes called "nitrogen-fixing plants", the plant itself is not able to fix nitrogen from the air. It is only through the partnership with bacteria that these plants are able to obtain atmospheric nitrogen. In this symbiotic partnership the bacteria give nitrogen accumulated from the atmosphere to the plant, and in exchange the bacteria get a site to grow and energy in the form of carbohydrates from the plant. Without these bacterial partnerships, plants are not able to make direct use of atmospheric nitrogen.

Soil on restoration sites, however, may not contain the proper species of bacteria to form a symbiotic partnership with the plant. This is particularly true for compacted soils and those that have been removed and stockpiled. Inoculating plants ensures that "nitrogen-fixing"

***Figure 10.38 –** Nitrogen-fixing plants, such as legumes, have symbiotic bacteria on their roots (A) which can chemically "fix" atmospheric nitrogen into forms that can be used by plants as fertilizer (B).*

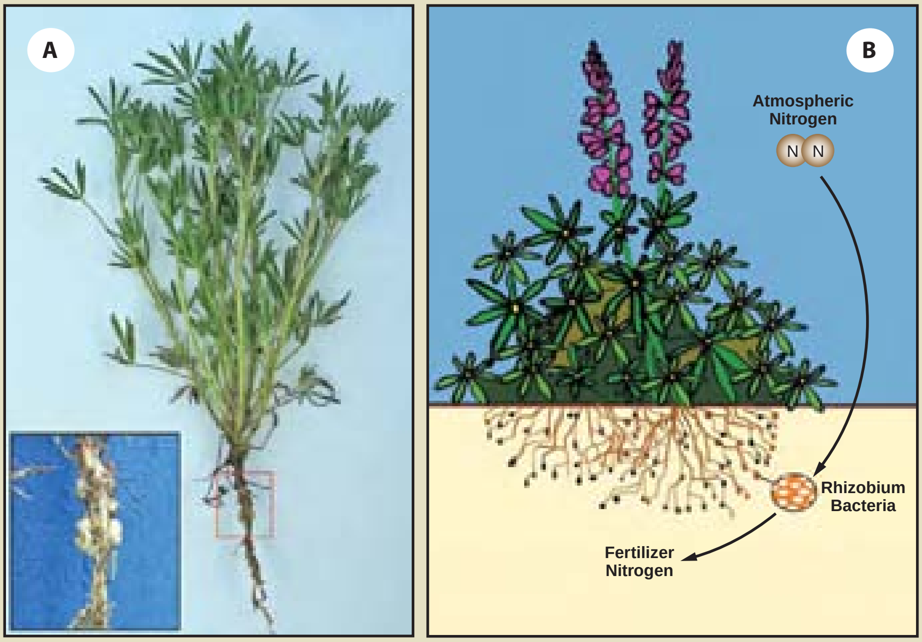


***Figure 10.39** – Nitrogen-fixing bacteria include Rhizobium that forms relationships with plants in the legume family including lupines (A), and clovers (B) and Frankia that forms relationships with other non-leguminous plants such as snowbrush ceanothus (C), and mountain-avens (D) . Photos A, C, & D by Tara Luna.*

plants form an effective partnership to fix nitrogen. Therefore, use of nitrogen-fixing plants can be an important part of accelerating rehabilitation of degraded land.

Two species of nitrogen-fixing bacteria that are important in revegetation are *Rhizobium* and *Frankia*. *Rhizobium* grow with some members of the legume family (Figure 10.39 A&B), and plants of the elm family. They form nodules on the roots and fixing nitrogen for the plant. *Frankia* are

***Table 10.11** – Nitrogen-fixing bacteria and their plant hosts.*

Nitrogen-Fixing Bacteria	Host Plants		% Nitrogen Fixing Plants	Common Plant Species
	Family	Subfamily		
Rhizobium spp.	Legume	Caesalpinioideae	23	Redbud, honeylocust
	Legume	Mimosoideae	90	Mesquite, acacia
	Legume	Papilionoideae	97	Lupine, milkvetch, black locust, clover
	Family			**Common Plant Species**
Frankia spp.	Birch			Alder, birch
	Oleaster			Silverberry, buffaloberry
	Myrtle			Myrtle
	Buckthorn			Cascara, snowbrush, deerbrush
	Rose			Mountain mahogany, cliffrose, bitterbrush

Inset 10.9 – Example of Contract Specifications for Purchasing Mycorrhizal Inoculum

Purchase of Mycorrhizal Inoculum

The mycorrhizal inoculum must have a Statement of Claims that certifies the 1) date inoculum was produced, 2) mycorrhizal fungi species present in the inoculum, 3) number of propagules per pound of product, and 4) the type and grade of carrier.

Product Specifications

Date of inoculum application will be within one year of production date.

The storage, transportation and application temperatures of the mycorrhizae shall not exceed 90 °F. Inoculum must consist of at least 5 species of (choose endomycorrhizal, ectomycorrhizal or a combination of endo and ectomycorrhizal) fungi with no one species making up more than 25% of the propagules.

The inoculum will contain these species: __________________.

The inoculum will contain __________ live propagules per pound (Typical rates for endomycorrhizal inoculums average around 60,000 to 100,000 propagules per pound and 110,000,000 propagules per pound in ectomycorrhizal inoculums.)

(For applications to the soil surface only) Live propagules must be smaller than 0.3mm.

(Optional) A one ounce sample will be collected from each inoculum and sent to _______ laboratory for analysis using the ______ standardized test to determine the number of propagules.

Application of Endomycorrhizal Inoculum to Soil Surface

Endomycorrhizal inoculum will be applied at a rate of __________________ live propagules per acre (typical rates range from 1,000,000 to 3,600,00 live propagules per acre).

Inoculum will be applied in the same operational period as seed application.

If inoculum is applied through a hydroseeder, it should be applied within 45 minutes of being mixed in the hydroseeding tank.

Application of Mycorrhizal Fungi to Planting Holes

Mycorrhizal inoculum will be applied at a rate of ______________ live propagules per seedling.

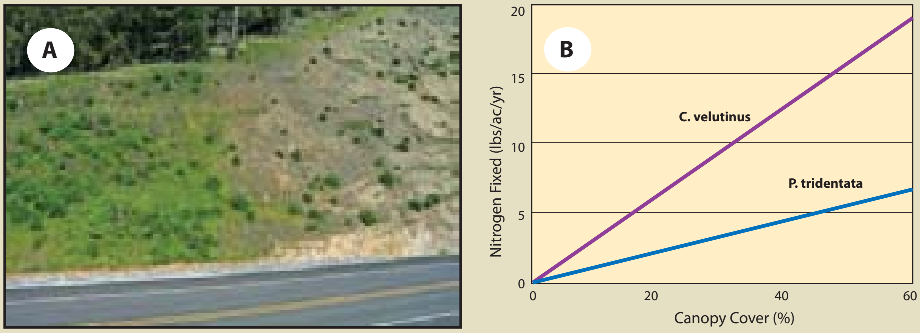
a different kind of bacteria. *Frankia* partner with non-leguminous plants, such as casuarinas, alders, bitterbrush, and buffaloberry (Figure 10.39 C&D), and over 200 different plant species, distributed over eight families. The species affected by *Frankia* are called "actinorhizal" plants (Table 10.11).

10.1.7.7 Uses for Nitrogen-Fixing Plants in Revegetation

Only a fraction of native species are nitrogen-fixing host plants. In the western United States, the most common are the lupines, vetch, bitterbrush, ceanothus, alder, and myrtle (Table 10.11). On nitrogen-poor sites, sowing or planting a higher proportion of these species can help a site to recover nitrogen fertility and organic matter (Figure 10.40A). The amount of nitrogen that will be fixed on a site is related to the area of vegetative cover in nitrogen fixing host plants, the productivity of the plants, and factors such as temperature and moisture. If percent cover of nitrogen fixing host plants is low, then the amount of nitrogen supplied to the site will be correspondingly low (Figure 10.40B). Likewise, dry or cold conditions tend to result in slower accumulation of nitrogen.

To determine how nitrogen-fixing plants should be used in revegetation project, assess which nitrogen-fixing host species are native to the area and consider the nitrogen fixation rates that can be expected. A plant survey of reference sites will reveal which nitrogen fixing plant host species are native to the area. Finding host plants on recovered reference sites can give an indication of whether they grow on disturbances, and consequently how much nitrogen will be fixed on the site. Observing the abundance of root nodules on these plants can give some indication whether they are fixing nitrogen.

Figure 10.40 – *The accumulation of nitrogen by N-fixating bacteria is directly related to the cover of nitrogen-fixing host plants on a site. The large plants shown in this photograph are lupines, which are nitrogen-fixing (A). The nitrogen-fixing potential of 15-year-old stands of* Ceanothus velutinus *and* Purshia tridentata *was directly proportional to plant cover (B) (adapted after Busse 2000).*



10.1.7.8 Inoculating with Nitrogen-Fixing Bacteria

Nitrogen-fixing nursery stock with nodulated root systems have exhibited faster early growth than seedlings that were not inoculated. Nursery inoculation can reduce costs in establishment and maintenance; a few dollars worth of inoculant applied in the nursery can replace a lot of purchased nitrogen fertilizer over the life of the nitrogen-fixing plant. Faster growth early can also lead to faster canopy closure, which shades the soil and reduces weed establishment and growth. When the nitrogen-fixing plant sheds leaves or dies, the nitrogen stored in the plant's tissues is cycled to adjacent plants. Early establishment of nitrogen-fixing plants accelerates natural nutrient cycling on the project sites and promotes the establishment of sustainable plant communities.

It should be noted that in many cases, uninoculated seedlings may eventually form a partnership with some kind of *Frankia* or *Rhizobium* strain after they are outplanted. These may not be with optimal or highly productive bacterial partners, and it may take months or even years on highly disturbed sites. Until they become naturally inoculated, plants are dependent on nitrogen fertilizers and may become out-competed by weeds. Inoculating in the nursery ensures that plants form effective, productive partnerships in a timely fashion.

Acquiring Nitrogen-Fixing Bacterial Inoculants – Nitrogen-fixing bacteria are very specific; in other words, one inoculant cannot be used for all plants. On the contrary, a different inoculant strain for each nitrogen-fixing species is usually necessary. Superior strains can yield significant differences in productivity and growth rate of the host plant; in some cases over 40% better growth (Schmit, 2003).

Inoculants are live nitrogen-fixing bacteria cultures that are applied to seeds or young plants. Two forms of inoculant can be used: pure culture inoculant, and homemade (often called "crude") inoculant. Cultured inoculant is purchased from commercial suppliers, seed banks, or sometimes, universities. Crude inoculant is made from nodules collected from roots of nitrogen-fixing plants of the same species to be inoculated. Whichever form is used, care should be taken when handling nitrogen-fixing bacteria inoculants because they are very perishable. These soil bacteria live underground in moist, dark conditions with relatively stable, cool temperatures. Similar conditions should be maintained to ensure the viability of inoculants during storage, handling, and application.

Pure culture inoculants of nitrogen-fixing bacteria usually come in small packets of finely ground peat moss (Figure 10.41A). Some manufactured inoculants contain select strains, tested for forming optimally productive partnerships with their host species. Select inoculant should be used if it can be obtained; these contain optimal partners for the species they were matched for, providing a good supply of nitrogen at a low cost to the plant. Manufactured products usually come with application instructions; these should be followed. In general, about 100 grams of cultured inoculant is usually sufficient to inoculate up to 3,000 seedlings in nursery conditions. Because they contain living cultures of bacteria, these inoculants are perishable and should be kept in cool, dark conditions, such as inside a refrigerator.

Figure 10.41 – *Nitrogen-fixing bacteria are commercially available as pure culture inoculant, often in a carrier (A), or can be prepared by collecting nodules off of plants from the wild (B). Photos by Tara Luna.*

Peat-based inoculants are added to chlorine-free water to create a liquid slurry (Allowing a bucket of tap water to stand uncovered for 24 hours is a good way to let chlorine evaporate). If a blender is available, using it to blend some inoculant in water is a very good practice to ensure the bacteria will be evenly mixed in the solution. If a blender is not available, a mortar can be used. Five to ten grams (about 0.2–0.4 ounce) of manufactured inoculant can inoculate about 500 seedlings, usually exceeding the recommended 100,000 bacteria per seedling. Once seedlings begin to nodulate, nodules from their roots can serve as the basis for making crude inoculant as described below. This way, inoculant need only be purchased once for each plant species grown, and thereafter, crude inoculant can be made from nodules.

Preparing Crude Inoculant – Crude inoculant is made using nodules, the small root structures that house the bacteria. Each one of the nodules can house millions of bacteria. For *Rhizobium*, a brown, pink, or red color inside is usually a good indicator that the millions of bacteria in the nodule are actively fixing nitrogen. For *Frankia*, desirable nodules will be white or yellow inside. Grey or green nodules should be avoided, as they are likely inactive.

To make your own crude inoculant, select healthy, vigorous plants of the same species as the plants to be inoculated. Expose some of the root system of a nodulating plant in the nursery or field (Figure 10.41B). If available, choose seedlings that were inoculated with select bacteria. Young roots often contain the most active nodules. Search for nodules with the proper color and pick them off cleanly. If possible, collect nodules from several plants. Put nodules in a plastic bag or container and place them in a cooler for protection from direct sunlight and heat. As soon as possible after collection (within a few hours), put the nodules in a blender with clean, chlorine-free water. About 50-100 nodules blended in a liter of water is enough to inoculate about 500 seedlings. This solution is a homemade liquid inoculant, ready to apply in the same method as cultured inoculant as described below.

Applying Inoculant – Inoculant must be applied in a timely fashion, when seedlings are just emerging, usually within 2 weeks of sowing. This helps ensure successful nodulation and

Figure 10.42 – *After successful inoculation, nitrogen-fixing bacteria will multiply on the root system as plants grow. The arrow points to a visible* Frankia *nodule on an* alnus *seedling. Photo by Tara Luna.*

maximizes the benefits of using inoculants. Therefore inoculant must be introduced in the nursery for nursery-grown plant materials, or introduced at the time of sowing for seeds that are sown directly at the field site. One liter of liquefied inoculant made from either nodules or cultured inoculant as per the instructions above is diluted in more chlorine-free water. For 500 seedlings, about 5 liters of water is used. This solution is then watered into the root system of each seedling using a watering can. In the field, for direct seeding applications, the slurry of commercial or crude inoculant can be added to the hydroseeder tank and mixed in with seed mixes.

10.1.7.9 Management Considerations for Nitrogen-Fixing Inoculations

Verifying the Nitrogen-Fixing Partnership – Allow two to six weeks for noticeable signs that the plant has formed a symbiotic partnership with nitrogen-fixing bacteria. Signs include:

- Seedlings begin to grow well and are deep green despite the absence of added nitrogen fertilizer,
- The root systems give off a faint but distinctive ammonia-like scent,
- Nodules are usually visible on the root system after about four to six weeks (Figure 10.42), and nodules are pink, red, or brown (for *Rhizobium*), or yellow or white (for *Frankia*).

Inset 10.10 – How Does Biological Nitrogen Fixation Work?

The symbiotic partnership between plants and their nitrogen-fixing microsymbionts works this way: The bacteria live in nodules on roots of the plant. Each nodule contains millions of the bacteria that accumulate atmospheric nitrogen and share this nitrogen with the plant. In exchange, the plant provides energy in the form of carbohydrates to the bacteria.

The bacteria must come in contact with the root systems early in the plant's life, ideally within the first 2 to 6 weeks of growth. For nursery-grown materials, nitrogen-fixing bacteria must be introduced in the nursery. For direct field sowing of seed, inoculants should be applied as the seeds are being sown.

When the "nitrogen-fixing" plant sheds its leaves, dies, or dies back, the nitrogen stored in the plant's tissues is cycled to other plants and through the ecosystem. This process, part of the nitrogen cycle, is the major source of nitrogen fertility in most natural ecosystems.

Post-Planting Care – Several factors are of primary concern when using inoculants for nitrogen-fixing bacteria:

- ***Fertilization.*** The use of nitrogen-fixing bacterial inoculant requires some adjustments in fertilization. Excessive nitrogen fertilizer will inhibit formation of the partnership.
- ***Water quality.*** Excessive chlorine in water is detrimental to Rhizobium and Frankia. The water source may need to be tested and a chlorine filter used if excessive chlorine is a problem.
- ***Micronutrients and soil quality.*** Some nutrients are necessary to facilitate nodulation, including calcium, potassium, molybdenum, and iron. Excessively compacted soils, extremes of pH or temperature also inhibit nodulation.

10.1.7.10 Other Beneficial Microorganisms

In nature, communities of bacteria, fungi, algae, protozoa, and other microorganisms in the soil make nutrients available to plants, create channels for water and air, maintain soil structure, and cycle nutrients and organic matter. A healthy population of soil microorganisms can also maintain ecological balance, preventing the onset of major problems from viruses or other pathogens that reside in the soil. The practice of protecting and re-establishing beneficial microorganisms is a key one for revegetation. As a science, however, the use of beneficial microorganisms is in its infancy. Although thousands of species of microorganisms have been recognized and named, the number of unknown species is estimated to be in the millions. Almost every time microbiologists examine a soil sample, they discover a previously unknown species (Margulis and others, 1997). Revegetation specialists should keep an eye on developments in this field and see how their plants can benefit from new insights into the roles of microorganisms. Conserving and utilizing healthy topsoil will also help to sustain the natural populations of beneficial microorganisms.

10.1.8 TOPOGRAPHIC ENHANCEMENTS

10.1.8.1 Introduction

Topographic enhancements are alterations to the roadside landscape designed to improve the growing environment for plants. Topographic enhancements should be considered when site resources such as topsoil, organic matter, and water are limited (See Section 5.11, Inventory Site Resources). It is often better to concentrate limited resources in key areas where resources can be most effective, rather than spread them across the larger project area and dilute them to the point of having little benefit to reestablishing native vegetation.

Topographic enhancement integrates three components into the roadside design – soil improvement, site stability, and water harvesting (Figure 10.43). Soil improvement can occur when limited topsoil and organic matter are strategically used to create growing areas with optimum rooting depth (See Section 5.3 and Section 5.5). Stable landforms are created that reduce surface erosion and increase slope stability (See Section 5.6 and Section 5.7). Water harvesting can result when local topography is modified to capture runoff water and concentrate it in areas where it can be used by plants (See Section 5.2) (For background on water harvesting, see Fidelibus and Bainbridge 2006).The integration of these three components will determine the success of a topographic enhancement design.

Topographic enhancement strategies must be considered during the initial planning stages of road design. These structures will require the input of the design engineer and cooperation of the project engineer, and must be built during the construction phase of the project. Structural changes to the topography following construction are not usually an option for revegetation purposes.

There are many options for topographic enhancement. This discussion is by no means exhaustive, but intended to introduce the reader to a variety of structures that can be installed during road construction to enhance the establishment of native plants.

10.1.8.2 Contour Bench Terraces, Planting Pockets, and Microcatchments

Contour bench terraces are structures carved out of cut or fill slopes that capture and store runoff water and sediments from road surfaces, road shoulders, and the slopes above. If infiltration rates of soils above the terraces are low, runoff will occur, even from low intensity rainfall. Contour bench terraces are designed to collect enough water to recharge soils and provide sufficient water for plant growth during the summer, but also be protected from erosion during peak rainstorm events. Design criteria for determining the distance between terraces include slope gradient, rainfall intensities, and infiltration rates. Observing erosional patterns on unvegetated road cuts near the project site can give an indication of approximate spacing for benches (See Section 5.6.8).

Contour bench terraces can be long and contiguous or separate and discrete. For long and contiguous terraces, concentrated water from high runoff events can flow down the terraces (assuming they are not completely level), potentially causing gullies. Placing berms or "plugs" in the terraces at frequent intervals can reduce this potential.

When terraces are filled with growing media (topsoil or amended subsoil) and planted, they are referred to as planting pockets (Figure 10.44). Planting pockets must have adequate soil depth to store intercepted water and support establishment of planted seedlings. The surface of the planting

Figure 10.43 – *Integrating soil improvement, site stability, and water harvesting is critical when designing topographic enhancement features.*

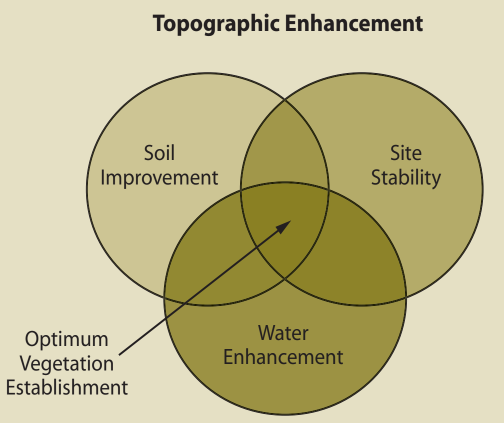
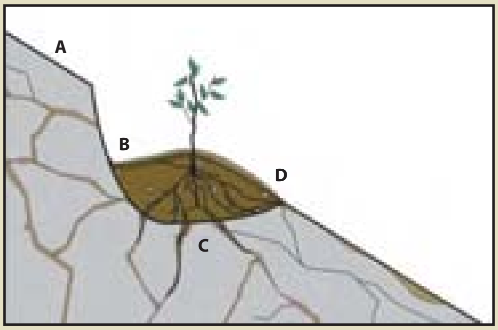


__Figure 10.44__ – Planting pockets collect and store runoff water from areas directly upslope during rainstorms (A). Water and sediments collect in the back slope of the pocket (B). Moisture fills the soil and moves into fractured bedrock (C) where roots have penetrated. The face of the planting pocket is protected by mulch or erosion cloth (D). The photograph on the right was taken looking down on a planting pocket after a rainstorm. The back slope has ponded water and collected sediments from the surface above.



pocket should be insloped to capture water and sediment, and the face of the pocket should be protected from surface erosion.

Fill slope microcatchments are structures that capture runoff from outsloped road surfaces and compacted shoulders into terraces and berms where it can be used for plant growth (Figure 10.45). Microcatchments include a storage basin and berm. Berms are typically 4- to 8-inch high obstacles placed on the contour. They are formed from soil or woody debris (logs), or manufactured products such as straw waddles (Figure 10.45) or compost berms. Manufactured products and woody debris are "keyed" (partially buried) into the soil surface to prevent water from eroding under the structure. Compost berms are continuous mounds of compost that can slow water and filter sediments. Seedlings can be planted on, or immediately above, berms or obstacles to access captured water. Unless species that propagate vegetatively are used in these structures (See Section 10.2.2), care must be taken to avoid planting where sediment will bury the seedling. The storage basin, created by terraces or berms, can be improved for plant growth with soil tillage and incorporation of soil amendments.

__Figure 10.45__ – Fill slope microcatchments take advantage of the low infiltration rates of compacted fill slopes (A) by capturing the runoff from road drainage at the bottom of the fill into topsoil or amended subsoil favorable for plant growth (B). The extra water from these surfaces can support trees and shrubs. Straw waddles, as shown in the picture on the right, can be used in fill slope microcatchments to collect water and sediment. Straw waddles must be installed on the contour and keyed into the soil to be effective.

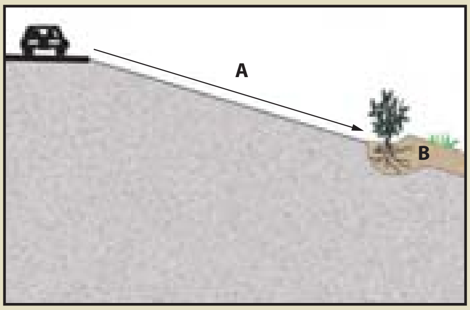


Figure 10.46 – *Constructed wetlands capture water from roadside runoff and filter sediments before water enters perennial streams. Constructed wetlands can create favorable habitat for unique flora and fauna.*

10.1.8.3 Runoff Strips and Constructed Wetlands

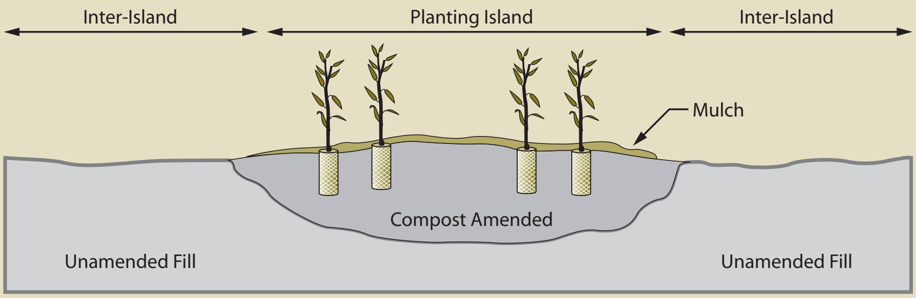
Runoff strips are catchment structures constructed in areas where intermittent concentrated road drainage occurs. These are typically at the outlets of culverts or in road drainage dips. Runoff strips capture concentrated runoff into small ponds or catchment basins. These areas can be planted with riparian species, such as willows (*Salix* spp).and cottonwoods (*Populus* spp.), or wetland species, such as rushes (*Juncus* spp).and sedges (*Carex* spp.). Runoff strips are placed in draws or concave topography and are composed of engineered impoundment barriers, using riprap, logs, or gabion baskets, that store water from runoff events. The barrier must have a spillway (a low point in the structure) and be keyed into the sides to assure that concentrated water does not erode around its sides. Where runoff strips are on gentle gradients, constructed wetlands may possibly be developed (Figure 10.46).

10.1.8.4 Planting Islands

Planting islands are used where deep-rooted tree and shrub species are desired, but topsoil, soil amendments, or soil depth are limiting. They are designed into such revegetation projects as obliterated roads, view corridors, waste areas, and other highly disturbed sites. The strategy behind planting islands is to create an ideal growing environment for tree and shrub seedlings that replicates the natural patterns or features observed in the surrounding landscape and plant communities (Figure 10.47).

Figure 10.47 – *Most planting islands are designed to mimic the natural surrounding environment of the project site. In this photograph, seedlings were planted in clumps to mimic the small islands of trees that grew in this geographic area. The inter-island areas were planted with lower growing grasses, forbs, and shrubs.*

***Figure 10.48** – Illustration of a typical cross-section of a planting island where soil depth is enhanced for tree establishment. Inter-island areas are planted to shrubs and grasses.*



Islands can be created by excavating an appropriate area to a depth of several feet and backfilling with either topsoil or compost-amended material (Figure 10.48). Alternatively, compost and other soil amendments (including lime and fertilizers) can be spread over planting islands at the depth needed to amend the soil profile and mixed thoroughly through the islands with an excavator or backhoe. Soil compaction must be avoided in these operations or during any subsequent operation. After planting, mulch can be applied across the surface of the entire island.

In Figure 10.48, compost is mixed to a depth of 3 feet by an excavator in irregular shaped planting islands. The islands are planted with conifers and 3 inches of mulch are applied to entire islands to keep them free of competing vegetation. The layout of planting islands should be designed with a vision of how the vegetation will appear once established, and should be based on recovered and undisturbed reference sites. Planting islands will generally occupy less than a quarter to a third of the entire site, leaving the remainder as "inter-island." The inter-islands will be much less productive than the planting islands. Grass and forb plant communities are therefore more suited to these areas.

10.1.8.5 Biotechnical Engineering Structures

Topographic enhancement also includes many biotechnical engineering structures, such as vegetated retaining walls, brush layers, and live pole drains. Incorporating soil improvement strategies into these structures will stabilize the soil and capture runoff water, making them very suitable to the establishment of a range of native vegetation (See Section 10.3.3 and Section 10.3.4).

10.2 OBTAINING PLANT MATERIALS

Obtaining the appropriate species and stocktype for a revegetation project takes good planning and lead time. To obtain genetically adapted materials often requires the collection of plant materials near or in the general geographic area of the project site. This requires collecting plant materials several years in advance of project implementation. The group of implementation guides in the following section focuses on three types of plant materials – seeds, cuttings, and plants. Section 10.2.1, Collecting Wild Seeds, covers how to determine the amount of wild seed to collect, wild seed collection methods, cleaning techniques, storage conditions, and quality testing. Methods for collecting the stems of willows and cottonwoods in the wild (as well as several other native species that propagate vegetatively) are discussed in Section 10.2.2, Collecting Wild Cuttings. Salvaging plants from the wild and replanting them on project sites is discussed in Section 10.2.3, Collecting Wild Plants.

For most projects, the collection of wild seeds, cuttings, or plants is not sufficient to meet project objectives. To increase plant materials, wild collections must be sent to native plant nurseries for propagation. Section 10.2.4, Nursery Seed Production, outlines the basic steps necessary to work with nurseries in establishing seed production beds for increasing seed banks. Producing large quantities of cutting material of willow and cottonwood species can be accomplished by establishing stooling beds from wild collections at nurseries. This is covered in Section 10.2.5, Nursery Cutting Production. Section 10.2.6, Nursery Plant Production, covers how to work with seedling nurseries to obtain high quality plants.

10.2.1 COLLECTING WILD SEEDS

10.2.1.1 Introduction

Wild seeds are collected from native stands of grasses, forbs, shrubs, trees, and wetland plants found in or near project sites. The primary objective for wild seed collection is to obtain source-identified seeds for starting nursery grown plants (See Section 10.2.6), nursery grown seeds (See Section 10.2.4), and/or occasionally to sow directly on a disturbed site. Since seed and seedling propagation hinges on availability of wild seeds, collection is one of the first major tasks of a revegetation plan. Depending on the purpose, the lead-time for collecting wild seeds might be up to 3 to 4 years before sowing or planting the project site (Figure 10.49).

Grass and forb species are usually seeded directly onto disturbed sites. In order to obtain enough seeds for direct seeding, wild seed collections are usually "increased" in nursery production (See Section 10.2.4). Trees and shrubs, on the other hand, are not typically seeded across disturbed sites. Wild seed collections for these species are sent to nurseries for seedling propagation, then outplanted. Seeds from wetland genera, such as sedges (*Carex* spp).and rushes (*Juncus* spp).are often collected for both seed and seedling production purposes.

Revegetation plans are seldom finalized before wild seeds are collected. At a minimum, planning should have identified revegetation units, described reference areas, determined species to propagate, and completed a survey of the construction site to determine the amount of area to be revegetated. The quantity and location of wild seed collection is based on these early surveys.

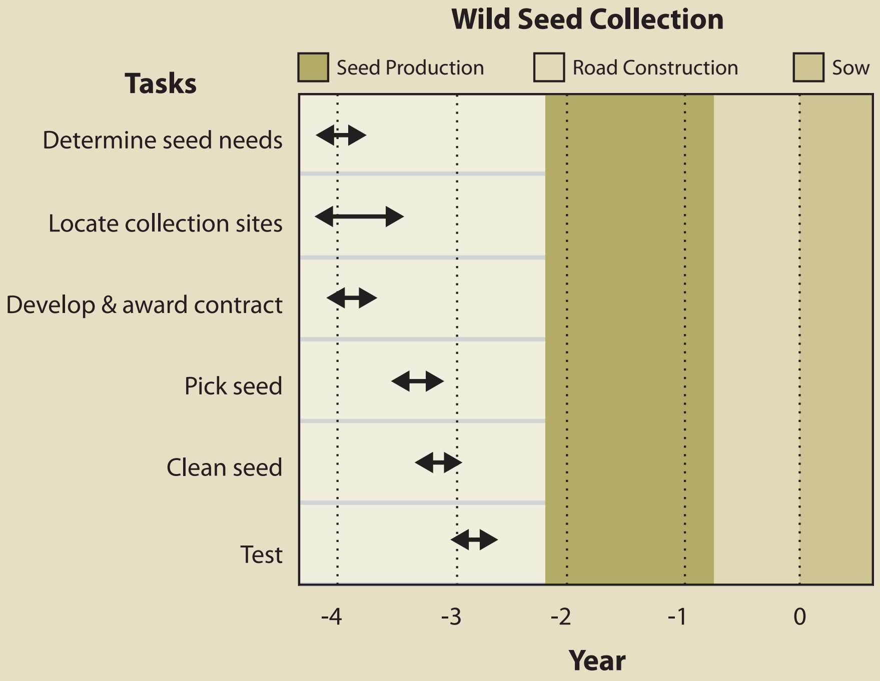
Collecting wild seeds can be expensive. Multiple collection trips are often needed to monitor and collect each species. Each species has a small ripening window, and most species do not ripen at the same time. In addition, many species do not consistently produce seeds from year to year, requiring multiple year collections. Working around these complexities to obtain adequate supplies of wild seeds requires excellent planning and administration of seed collection and cleaning contracts.

Before collecting wild seeds or setting up collection contracts, it is worth the effort to contact Forest Service district or BLM area offices first to see if seeds are already available for your project. Often these local agencies will have seeds in storage for many of the species growing near the project area, especially species used for reforestation.

10.2.1.2 Develop Timeline

Wild seed collection should be one of the first tasks to consider when beginning revegetation planning because other tasks, such as seed and seedling propagation contracts, cannot be conducted without this plant material. Up to 3 or 4 years are often necessary in order to locate,

Figure 10.49 – *Wild seed collection is one of the first contracts developed during planning. Seeds are needed to implement seed and seedling propagation contracts. A lead-time of 2 to 4 years is typically needed for wild seed collection.*



collect, clean, and test wild seeds, and still allow the nursery or seed producer enough lead time for plant and seed production (Figure 10.49).

The seed collection contract is awarded early in the spring to give the contractor enough time to locate and assess the collection areas. Seeds are monitored from June through August and collected when ripe. Wild seed harvests are cleaned from September through October and then tested. Results from seed testing facilities are returned by December. Seeds designated for seedling propagation must be sent immediately to the nursery for preparation for sowing in early winter. If seed propagation is the objective, seeds are stored until the following summer and sent to seed producers for a late summer sowing.

10.2.1.3 Determine Wild Seed Needs for Seed Production

Wild seed collection and the nursery seed increase contracts are often developed simultaneously because the information needed for wild seed collection is based on the expected seed yields of the seed increase contract. This section describes how to calculate the amount of wild seeds to collect based on the amount of seeds expected from a nursery seed producer.

The amount of uncleaned wild seeds to collect for seed propagation contracts requires the following information (used in calculations in Figure 10.50):

- Seed needs,
- Years in seed production,
- Sowing rates,
- Annual seed yields, and
- "Cleaned-to-rough cleaned" seed ratio.

Seed Needs – The total seeds needed for each species on a revegetation project is based on the total planned revegetation acreage, seedlot characteristics (germination, purity, seeds per pound), site limitations (how well seeds will survive), and the desired seedling densities after seeds have germinated. The reader is referred to Section 10.2.4.3 for methods to calculate how many seeds are needed for each species in a revegetation project.

***Figure 10.50** – The quantity of wild seeds to collect can be determined from this spreadsheet. Pearly everlasting (*Anaphalis margaritacea*) is used in this example.*

A	Seed production needs	22	lbs	From seed needs plan (See Section 10.2.4.3)
B	Years in production	2	yrs	Seed production can span several years depending on lead time of project.
C	Sowing rates	1	lbs/ac	See Table 10.14 in Section 10.2.4 or discuss with seed producer
D	Annual seed yields	50	lbs/ac/yr	See Table 10.14 in Section 10.2.4. If spanning more than one year, average the expected first and second year yields
E	(A/B) / D	0.22	ac	Area seed producer needs to sow
F	E * C =	0.22	lbs	Cleaned wild seeds that seed producer needs to sow
G	"Cleaned to rough cleaned" seed ratio	33	%	Estimated
H	(100 / G) * F	0.67	lbs	Rough weight of seeds to collect

Years in Seed Production – Every species has its own seed production characteristics. For instance, species such as blue wildrye (*Elymus glaucus*) and California brome (*Bromus carinatus*) produce high seed quantities the first and second year, then level off or decline in years three and four. Species such as fescues (*Festuca* spp).and Junegrass (*Koeleria* spp).yield few seeds in the first year, but seed harvest levels increase to full production in the second or third year. For these species, a minimum of two years must be scheduled for seed production. Table 10.14 in Section 10.2.4 shows first- and second-year yields for some commonly produced species.

Since seeds can be stored for many years, seed production does not have to occur all in one year. For projects that have several years lead time, maintaining production fields gives the revegetation specialist more flexibility. By spreading the seed production over several years, the acreage in production and the amount of wild seed to collect can be cut in half. For example, if 800 lb California brome (*Bromus carinatus*) seeds for a revegetation project are needed and there are two production years to produce it in, the amount of seeds to produce per year would be 400 lb. Since half the acreage would be sown, the amount of wild seed to collect would be cut in half, from 10 pounds to 5 pounds.

Sowing Rates – All growers require a minimum amount of clean, wild seeds to produce a given quantity of nursery-grown seeds. While these rates differ somewhat between seed producers, general sowing rates for commonly propagated species are shown in Table 10.14 in Section 10.2.4.

Annual Seed Production Yields – The amount of seeds that are produced annually varies by species, geographic location of the fields, weather conditions, and experience of the seed producer. Knowing what yields can be expected from seed producers will determine how many acres will be under production and the amount of wild seeds needed to start the crop. Average seed yields for some species are presented in Table 10.14 in Section 10.2.4.

Cleaned-to-Rough Cleaned Seed Ratio – Seed collection from the wild will include stems, chaff, and flower parts (Figure 10.51). This material should be cleaned as much as possible by the seed collectors before it is sent to the seed extractory for final cleaning. The amount of non-seed collected can be a substantial part of the wild seed collection weight. "Cleaned to rough cleaned" seed ratios (Table 10.12) can help calculate the extra weight of seeds to collect in the wild to compensate for seed cleaning. Dividing the desired amount of cleaned seeds by this ratio will yield the amount of wild seed that needs to be collected.

***Figure 10.51** – Field collected seeds include stems, chaff, flower parts, and seed attachments. Species such as cutleaf silverpuffs* (Microseris laciniata) *have a low "clean-to-rough" seed ratio and must be sent to a seed extractory for cleaning prior to sending to seed producers.*

10.2.1.4 Determine Seed Needs for Seedling Production

The quantity of wild seeds to collect for propagating seedlings at plant nurseries will be based on an estimate of 1) quantity of seedlings needed, 2) % seed germination, 3) % seed purity, 4) seeds per pound, and 5) nursery factor. An estimate of germination, purity, and seeds per pound can be obtained through published sources, seed inventories, or from seed extractory managers. The nursery factor is a prediction of the percentage of viable seeds that will actually become "shippable" seedlings. Each nursery has developed a set of factors based on culturing experience and practices. Nursery managers should supply nursery factors for each species or information on the amount of seeds to collect to meet the seedling order. Nursery factors are often less than 50%.

Using the following equation, the amount of wild seed to collect can be estimated:

$$\text{Wild seed to collect} = \frac{\text{quantity of seedlings needed}}{(\text{\% germ}/100 * \text{\% purity}/100 * \text{seeds/pound} * \text{nursery factor}/100)}$$

10.2.1.5 Locate Plants in the Wild

Collection areas are located in the field during the vegetation analysis phase (See Section 6.2). General collection locations can be established by the revegetation specialist under the direction of a botanist familiar with the local vegetation. Contracts often require seed collectors

***Table 10.12** – Typical ranges of "cleaned-to-rough cleaned" seed ratios. To obtain the amounts of "rough" seeds to collect, divide the amount of cleaned seeds needed by the "cleaned-to-rough cleaned" ratio. For example, if 5 lb cleaned seeds of prairie Junegrass (*Koeleria macrantha*) are needed, a minimum of 12.5 lb rough cleaned seeds must be collected (5/40*100=12.5) (Chart based on R6 Forest Service seed collections data.)*

Common Name	Scientific name	Cleaned-to-Rough Cleaned Ratio
Bluebunch Wheatgrass	*Pseudoroegneria spicata*	**25 to 33**
Idaho Fescue	*Festuca idahoensis*	**33 to 50**
Prairie Junegrass	*Koelaria macrantha*	**20 to 40**
Squirreltail	*Elymus elymoides*	**20 to 25**
Yarrow	*Achillea* spp.	**20 to 25**
Sandberg Bluegrass	*Poa secunda*	**33 to 40**
Blue Wildrye	*Elymus glaucus*	**50 to 65**

Inset 10.11 – Stages of Grass Seed Maturity

For grasses, the stages of seed ripening can be determined by squeezing a seed between the thumb and forefinger. The stage of seed maturity is broadly defined by the following response:

Milk stage. A milky substance is secreted, indicating an immature seed lacking viability.

Soft-dough stage. Seed has a doughy texture, indicating it will have low germination and viability if collected.

Hard-dough stage. No excretion of dough or milky substance when squeezed. Seeds are collected at this stage. Seeds can be collected at the transition between soft-dough and hard-dough stages. If collection occurs between these stages, seeds should not be stripped from the plant. Instead, seed heads should be cut and placed in collection bags where seeds will continue to mature.

Mature. Seeds in this stage are usually too hard to bite. Collection should begin immediately because seeds can dislodge from the stem at any time.

to identify individual collection areas for approval prior to collection. Since seed collection can start in late spring for some species, collection site location must be completed by this time.

Collection areas for each species should not occur in one location, but represent a cross-section of populations in the general area of the project. A minimum of five collection areas, at least a mile apart, should be identified for each species. This ensures that a range of genetic characteristics is represented in each seedlot. While some populations will be located in the project area, most areas will have to be found in adjacent areas. When seed collection is conducted outside of the project area or agency administered lands, permission must be obtained from the landowner or manager.

Collection sites must be free of any plants listed as noxious weeds by the Oregon Department of Agriculture ("A and B" weed lists) because of the potential of seed contamination. Once located, the collection sites should be marked with flagging at a point easily visible from the road used to access the site. The flagging should have a written description that includes the GPS location (including elevation and UTM [Universal Transverse Mercator] coordinates) or a compass bearing and approximate distance in feet from the access road to the collection site. Each site should be approved by the revegetation specialist/botanist. Locations will be numbered sequentially and the location placed on 7.5° topographic maps and each collection site must be described and documented in the field notes.

10.2.1.6 Collect Seeds

Only viable seeds that are visually sound and sufficiently mature should be collected. Seeds are considered sound when the embryo is developing normally and there is no evidence of insect, disease, climatic, or other types of damage. Seed maturity in plants with fleshy fruits (many shrub and some tree species) often corresponds with changes in color (e.g., color changes from green to red, blue, purple, or white), taste (higher in sugars when mature), or hardness (fruit softens with maturity). Wind-dispersed seeds (which include many of the conifer species) usually change from green to brown when ripe. For grass species, seed maturity can be determined by how seeds respond to being squeezed (Inset 10.11). Since seed ripeness is influenced by the local weather and microclimate, determining seed ripeness often requires several monitoring trips to the field prior to collection.

Seed collection techniques are tailored to the species being collected. Grass and forb species, for instance, can be hand-harvested by stripping or clipping stems just below the seed heads and placing them in collection bags or containers. Collection bags should be made of materials that allow airflow, such as paper or fine mesh. Plastic bags or plastic containers should not be used. Other methods of collecting grass and forb seeds include mechanical flails and vacuums. While these methods can increase seed harvesting rates significantly, they must be done on nearly pure stands of a single species to avoid contaminating the seedlot with more than one species. Some forbs, such as lupine (*Lupinus* spp.), have indeterminate inflorescence, which means they continuously bloom, starting from the bottom of the flower head and progressing to the top (Figure 10.52). These species present a problem in seed collection because seeds

***Figure 10.52** – Species such as lupine (*Lupinus spp).*have indeterminate inflorescence bloom and set seeds all summer. Seeds ripen first at the bottom of the stem and continue to ripen up the stalk as the season progresses.*

ripen continuously through the growing season. Seeds from these species are often obtained by making multiple trips to the field and collecting seeds from the lower portions of the stem without disturbing the flowers or immature seeds above.

Seeds of many shrub species are often collected by holding a bag or tray under the plant and shaking the plant or flailing the branches with a stick or tennis racket. While the seeds of some shrub species ripen and remain on the seed head, others, such as *Ceanothus* spp., shatter when they ripen and must be collected as soon as they ripen. Since multiple collection trips can be expensive, an alternative approach is to enclose the seed head of each plant in a mesh or paper bag before the seeds have begun to ripen. At the end of the season, ripened seeds will have dispersed into the bags, which can be easily collected. The seed collection contractor should specify the methods that will be used for collection.

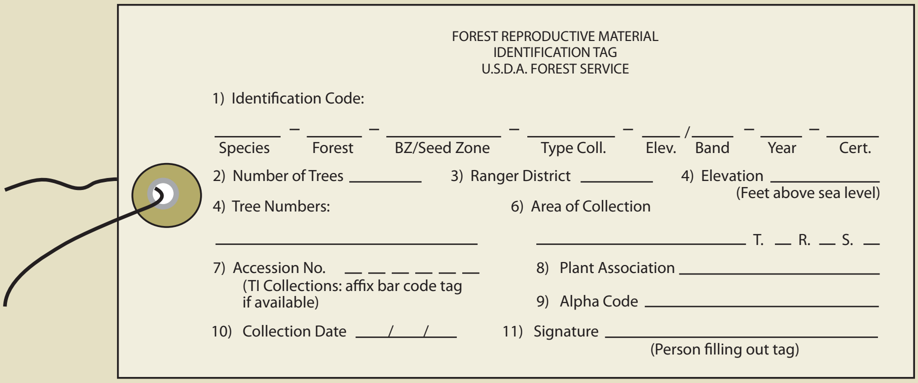
Seeds should be collected in approximately equal quantities from approved collection areas (See Section 10.2.1.5). To ensure adequate genetic representation, collect from a large number of widely spaced or unrelated parent plants per area (over 50 is optimal). To preserve populations, no more than 50% of the seed crop at each site should be collected in a year. Seeds or seed bearing fruits should not be collected from the ground.

Each seed collection bag or container must be clearly identified in the field with the following information:

- Species (scientific name),
- Forest or BLM district,
- District or BLM resource area,
- Legal description,
- Date of collection,
- Name of collector,
- Number of populations collected,
- Elevation, and
- Road project name.

The Forest Reproductive Material Identification Tag is an excellent way to capture this information (Figure 10.53). These are often available at Forest Service district offices or seed extractories. To assure the identity of the seedlot in case the tag is accidentally removed during handling or shipping, it is a good idea to duplicate the tag and place it into the collection bag. Field collections must be grouped into seedlots prior to sending these collections to the seed extractory for cleaning. Individual collections within a species are only maintained as separate seedlots if the objective is genetic testing or research. The expense of cleaning, packaging, and keeping records of a multitude of collections outweighs the necessity of storing them separately.

***Figure 10.53** – A Forest Reproductive Materials Identification Tag should be completed and attached to each collection bag sent to the seed extractory. A copy should also be placed inside the bag.*



FOREST REPRODUCTIVE MATERIAL
IDENTIFICATION TAG
U.S.D.A. FOREST SERVICE

1) Identification Code:

_____ – _____ – _____ – _____ – ____ /____ – ____ – ____

Species Forest BZ/Seed Zone Type Coll. Elev. Band Year Cert.

2) Number of Trees ________ 3) Ranger District ________ 4) Elevation ________ (Feet above sea level)

4) Tree Numbers: ________ 6) Area of Collection ________ T. __ R. __ S. __

7) Accession No. __ __ __ __ __ __ (TI Collections: affix bar code tag if available)

8) Plant Association ________

9) Alpha Code ________

10) Collection Date ___/___/___

11) Signature ________ (Person filling out tag)

The information displayed on the seed tag can be used to identify or name a seedlot. Each seedlot is identified by a seedlot identification code constructed in the following manner:

Species - Forest - Seed Zone - Elevation - Project Name - Collection Year

Species **–** The species short code can be obtained from the Plants Database on the National Resource Conservation Service website (http://plants.usda.gov/index.html).

Forest or BLM District Office **–** This is a numerical number assigned to each forest or BLM district office.

Seed Zone or Breeding Zone **–** For conifer and many native species, seed zones and breeding zones are geographic areas that have been identified by geneticists. Consult with the local reforestation, botanist, or area geneticist for seed zone and breeding zone maps.

Elevation **–** Elevation is generally listed as a range and abbreviated for conifer and many native species (For example, a 4,000 to 5,000 elevation band is listed as 4,050).

Project Name **–** The highway or revegetation project name is usually abbreviated.

Collection Year **–** The year in which the seeds were collected is abbreviated.

Certification **–** Certification codes apply to conifer tree species and are used to differentiate what is known about the parentage of the seeds. For example, codes pertain to whether the seeds were collected from the wild, seed collection areas, seed orchards, or if seeds are from tested material.

For example, the seedlot code, ARNE-10-502-2030-Elk-04, identifies a pinemat manzanita (*Arctostaphylos nevadensis*) seed source, collected on the Rogue River National Forest in seed zone 502 in an elevation range of 2,000 to 3,000 ft. Seeds were collected for the Elk Creek Road project in 2004.

Inset 10.12 – State Certified Seed Testing Laboratories

Oregon State University Seed Laboratory
Corvallis, OR 97331-3801
Telephone: 541.737.4464

Idaho State Department of Agriculture
3340 Kellogg Lane
Boise, ID 83712
Telephone: 208.332.8630

Washington State Department of Agriculture
21 North 1st Avenue, Suite 203
Yakima, WA 98902
Telephone: 509.225.2630

Inset 10.13 – Seed Tests
(modified from Tanaka 1984)

Seed testing is used to evaluate seedlot quality and provide information for determining sowing rates for seed and seedling production. Methods used for seed testing are based on rules of the Association of Official Seed Analysts (AOSA). A number of tests are normally conducted on each seedlot to evaluate physical and biological seed characteristics.

Physical Characteristics

Purity. Purity tests are used to determine the percentage by weight of four components: 1) pure seeds of the desired species, 2) seeds of other species, 3) weed seeds, 4) inert matter, such as stems, chaff, scales, and small stones. Graminoid seeds with more than 10% to 15% inert matter will be difficult to apply through a rotary seeder or rangeland drill. Purity tests should verify the seedlot contains no "prohibited" noxious weed seeds and meets or exceeds standards for "restricted" or "other weed seeds" according to state standards for Certified Seed. Because each state has different lists of prohibited and restricted noxious weeds, it is important to request an "All-States Noxious Weed Exam." While not prohibited or restricted by the State, some aggressive non-natives found through seed testing may still pose a threat to native plant communities.

Moisture content. Seed moisture content for most species is determined by oven-drying. Seed samples are weighed and heated at 105 °C (221 °F) for 16 hours, then weighed again. Seed moisture is expressed as the percentage of the weight of the water lost over oven-dry weight. Electronic moisture meters are also frequently used, but are not as accurate as the oven-drying method. They give rapid measurements when checking moisture in a large number of seedlots.

Moisture tests are important for determining the storability of seeds. Typically, seed moistures for long-term storage should be less than 10%.

Seeds per pound. Seeds per pound is the weight of a given number of seeds of the desired species, and does not include seeds of other species or weed seeds. The method weighs 100 seeds of ten random samples and converts the values to number of seeds per pound.

Biological Characteristics

Germination. A germination test conducted in a controlled environment is the most reliable method for testing seeds. At least 400 seeds from the pure-seed component of the purity test are used in the test. Depending on the species, the seeds are usually divided into four replicates of 100 seeds each and chilled (stratified) for a pre-determined period and placed on trays in controlled germination chambers. At 7-day intervals, the number of seeds that have germinated (when all essential structures appear normal) are counted (AOSA 2002).

Tetrazolium staining. Although controlled-environment germination tests are reliable, they are also time-consuming, particularly for those species requiring chilling. A rapid method of estimating viability is tetrazolium (TZ) staining. This test is preferred if results are needed immediately, or if species to be tested have unknown chilling or germination requirements, which is often typical of many native species (Rauch 2006). The TZ test requires seeds to be immersed in 2,3,5-triphenyl tetrazolium chloride. Living cells stain red as the chemical is reduced by dehydrogenase enzymes to form a stable red triphenyl formazan, which is insoluble in water. Seeds are cut and the embryos are that are red-stained are counted as viable seeds. This test is very useful for native species that produce seeds that are dormant and will not germinate without after-ripening (that is, seeds placed in an environment where they will continue to ripen) or without special germination enhancement treatments (stratification, scarification, gibberellic acid, and so on). In these cases, germination tests usually report out lower viability rates than actually exist. Since TZ tests measure the percentage of live embryos, they typically give a better indication of potential germination rates.

X-ray. At least 400 seeds, divided into four replicates of 100, are x-rayed and evaluated for presence of mature embryos, insect damage, filled seeds, damaged seeds, and other seed characteristics that might affect germination. X-raying is a quick test, but not as accurate as germination or TZ tests.

10.2.1.7 Clean and Test Seeds

Wild seed collections must be cleaned to a standard that can be uniformly applied through seed sowing equipment for seedling production or seed increase. Seed extractories have the experience and equipment to clean wild seeds of most species. Seed cleaning is typically completed in two to three steps: 1) removing seeds from cones or seedpods (conifer species and some hardwood tree and shrub species), 2) detaching structures from seeds, and 3) removing all non-seed materials from collections. Removing seeds from most conifer cones involves using tumbling equipment to allow seeds to separate from scales. Some conifer species and many shrub and hardwood species require specialized equipment to break open the seedpod without damaging the seeds. Detaching seed structures involves the mechanical removal of awns (grasses), wings (conifers), and fleshy structures (shrubs). Once seed structures are detached, all non-seed materials, including stems and chaff, can be removed from the collections, leaving only pure seeds. Seed extractories will dry, package, and store seeds, as well as test seeds on-site or send seeds to a testing facility. It must be noted that seed extractories cannot improve a poorly collected seedlot. For example, seed extractories cannot remove weed seeds, damaged seeds, or immature seeds from a collection, nor separate seeds from different crop species mixed in a seedlot. Prior to collecting wild seeds, it is important to contact the seed extractory manager to discuss which species will be cleaned. Seed extractory managers are great sources of information on collection and care of a variety of native species seeds.

Cleaned seeds should be tested for germination, purity, seeds per pound, and presence of noxious weeds (Inset 10.13) by an approved seed testing laboratory (Inset 10.12). Testing requires representative samples be collected from each seedlot. Seeds are usually stored in large sealed drums or bags. Seeds should be sampled with probes that reach to all parts of the storage container. If there are multiple containers per seedlot, samples from each container should be drawn in proportion to the size of the container. Since the amount of seeds needed for testing may vary by species and laboratory, seed testing facilities should be contacted prior to submitting samples for special instructions.

Seed viability usually decreases with time in storage. Seed testing should be conducted every few years, or at least the year before it is sown, to obtain the most accurate germination rates. Copies of seed tests should be retained in contract files and on seed inventories.

10.2.2 COLLECTING WILD CUTTINGS

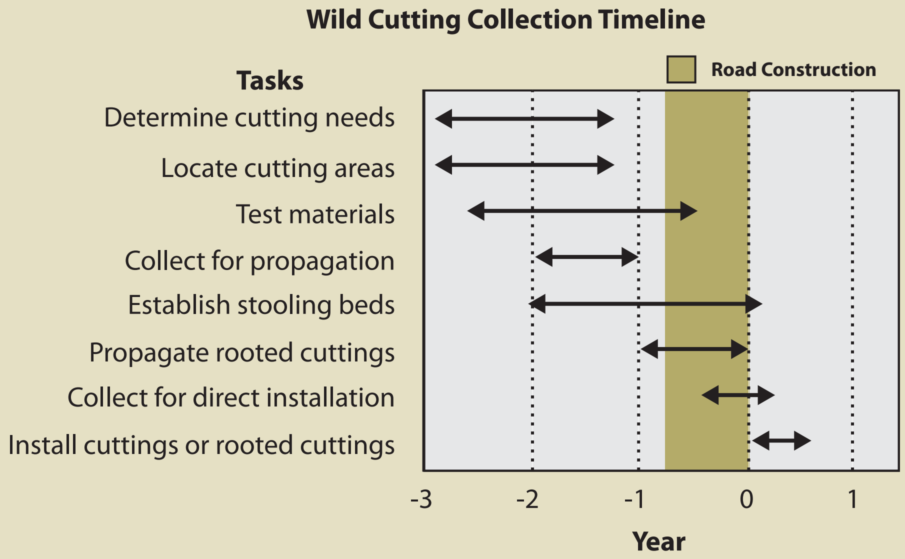
10.2.2.1 Introduction

Using cuttings can be a viable alternative to planting seedlings or sowing seeds to reestablish native vegetation. Vegetative material is collected from stems, roots, or other parts of donor plants and directly planted on the project site or sent to a nursery to produce rooted cuttings. The potential to produce roots from vegetative cuttings varies by species – from easy to propagate to extremely difficult. The most common species propagated from vegetative cuttings are shrubs and some trees. Many deciduous species that grow well in riparian settings, such as willows (*Salix* spp).and cottonwoods (*Populus* spp.), have a high success rate when propagated from cuttings. Most temperate evergreen trees and shrubs, however, only root under very controlled environments with specialized propagation techniques.

The intent of this section is to provide the reader with a greater understanding of how to select and collect cuttings in the wild. The primary focus will be on the species in the genera *Salix* and *Populus*, because these are these are most frequently used for direct sticking. Most other temperate tree and shrub species must be sent to the nursery for the production of rooted cuttings before they are installed on project sites (In tropical and subtropical areas, a wider variety of species can be collected as wild cuttings).If temperate species other than willow and cottonwood are considered for propagation, nurseries should be contacted to determine the best methods for selecting, cutting, and handling the material.

Cuttings can be obtained from wild collections or from cultivated stands of donor plants, called stooling beds. Stooling beds are established at nurseries or other agricultural facilities from wild collections. In this section, we will focus on how to obtain cuttings from wild locations and leave the discussion of producing cuttings from stooling beds to Section 10.2.5, Nursery Cutting Production.

__Figure 10.54 –__ Collecting wild cuttings requires a lead-time of several years depending on whether it is used to propagate stooling beds, rooted cuttings, or direction installation.



Wild cuttings are used in revegetation projects when 1) seeds or seedlings are difficult to obtain, 2) seeds germinate poorly in the nursery, or 3) cuttings are needed for biotechnical engineering objectives. Seed yields can be low for many species due to a variety of reasons, including poor pollination, disease, and insect damage. Some species, such as pinemat manzanita (*Arctostaphylos nevadensis*) and Pacific yew (*Taxus brevifolia*), produce seeds which can be very difficult to germinate in nursery environments. Other species, which include many tree species, produce seeds on an irregular basis; there may be many years between seed crops. Some seeds are difficult to collect either because they are inaccessible (in the upper portions of trees) or the window of seed collection is very narrow (e.g., *Ceanothus* spp.). For these species, starting plants in the nursery from rooted cuttings may be the only viable and economical alternative (See Section 10.2.6, Nursery Plant Production). Another important use of cuttings is in biotechnical engineering projects. These projects combine the physical strength of cuttings with root strength of establishing plants to increase surface and slope stability (See Section 10.3.3, Installing Cuttings).

When considering the use of cuttings over seeds or seedlings, the benefits must outweigh the potential limitations. Some factors that can limit the successful establishment of cutting material are the accessibility and availability of donor plants, how well the material roots (rooting potential), and how well the material survives once it has rooted. A common oversight when working with cuttings is forgetting that this material is alive and subsequently handling the material poorly. Another oversight is collecting cuttings outside of dormancy, when plants are actively growing. Neglecting either of these facts often leads to failed revegetation projects. This implementation guide covers the major factors that are important to consider when working with wild cuttings.

10.2.2.2 Develop Timeline

Locating cutting areas in the field might seem like a simple task, but it can be quite difficult when you are faced with such realities as land ownership, accessibility of the cutting areas to roads, winter weather conditions, and poor quality of plant materials. For these reasons, a lead-time of several years should be considered for projects requiring large quantities of wild cuttings (Figure 10.54). On large projects, sufficient lead-time allows for the location of potential collection sites and testing of the rooting potential of cutting material. If cuttings are used to propagate stooling beds (See Section 10.2.5), which are recommended for large projects, cuttings need to be collected at least 2 years or more before cuttings are installed on a project site. If the material is to be used to produce rooted cuttings at a nursery, the material should be collected at least a year prior to installation. When the materials are cut for direct installation on a project site, the cuttings will be made in the fall through winter prior to planting.

10.2.2.3 Locate Cutting Areas

The vegetation assessment during the planning phase (See Chapter 6) is an opportunity to locate potential sources of cuttings. During this field survey, cutting sites are mapped and assessed for the following characteristics:

Proximity and Accessibility **–** Good sources for cuttings are not always found within the project site, so it is necessary to survey large areas. Sometimes good collection sites are miles away from the project, which can substantially increase costs. However, the benefits of collecting quality plant materials far outweigh the additional transportation costs. The large size and weight of cutting materials often limits collections to areas adjacent to and accessible by roads. Poor road conditions during the winter months, when cuttings are most likely to be collected, should be considered in site selection, because of the potential of being closed by snow or winter road damage. It is often possible to collect quality cutting material within the right-of-way clearance, which is identified during the vegetation assessment.

Ownership **–** Some of the best collection sites may be on private lands. Always obtain permission from the landowner prior to collecting. Cutting from areas located on federal, state, and local government managed lands must be coordinated through these agencies. Observe collection standards for size and quantity dictated by the landowners.

Viability **–** The quality of the cutting material is an important criteria for determining the suitability of a collection site. Determining the viability of the collection material should be completed prior to selecting the collection site (See Section 10.2.2.4).

Genetic Considerations **–** It is important to determine if the species to be collected is monoecious (male and female reproductive parts on the same plant) or dioecious (male and female reproductive parts on different plants). If the species is dioecious (Inset 10.14), such as willow or cottonwood, an attempt to collect cuttings from both male and female plants in equal amounts should be made. If one of the objectives for using dioecious species is to promote or restore a species, donor plants must be located during periods of identifiable phenology, which is typically spring through summer. This might add an additional year to the timeline. To help preserve genetic integrity, it is recommended to collect from a minimum of 50 donor individuals within a watershed (See Chapter 6 for genetic transfer guidelines). Differentiating between individual plants within an area can be difficult with clonal species, such as willows and cottonwoods, because what often appear as a group of individual plants are actually offshoots from a single parent plant.

Diameter Size **–** The project objectives will determine which stem diameters must be collected (NRCS 1997). This must be assessed when a collection site is evaluated.

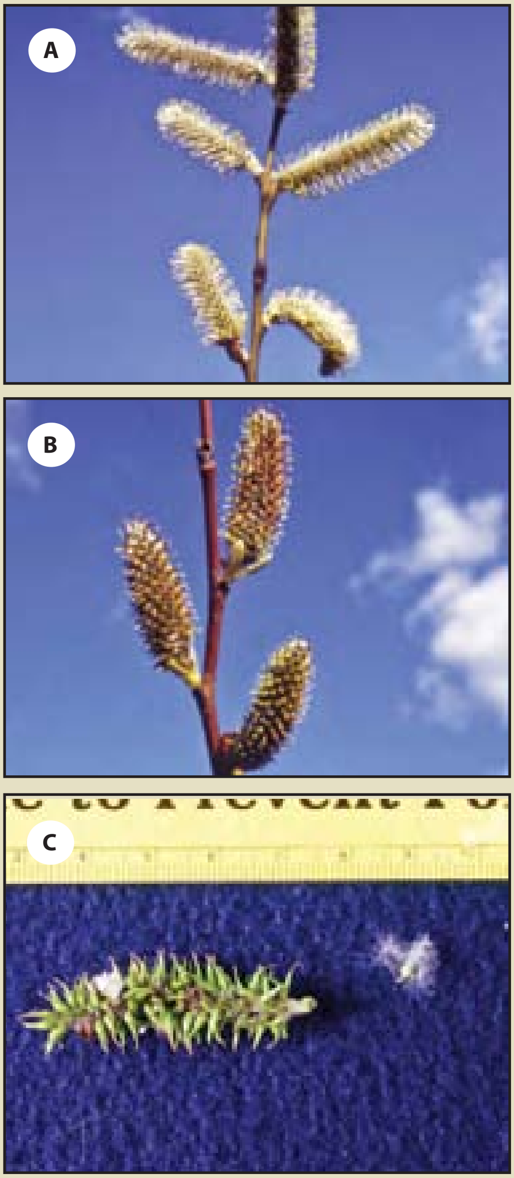
Small diameter. Small diameter materials, called branched cuttings, average less than 1.0 inch in diameter and are derived from the fine branches of vigorously growing donor plants. This material is tied into long bundles to form live fascines (See Section 10.3.3.4, Live Fascines) or laid on the surface of the soil to form brush mattresses. Live fascines are placed in shallow trenches on slope contours to function like small water and sediment collection dams, or they are placed at an angle to the slope to facilitate slope drainage (See Section 10.3.3.3, Live Brush Layers). Small diameter materials are also used for branch packing and to vegetate geogrids and rock gabions. Additionally, small diameter materials are used for rooted cutting production at nurseries. The typical diameter size preferred by most nurseries ranges from 3/8 to 1/2 inch.

Medium diameter. Medium diameter cutting materials are used to make live stakes (See Section 10.3.3.2, Live Stakes), which range in size from 1.0 to 3.0 inches in diameter. Stakes are tamped into the ground at right angles to the soil surface to secure small slumps, live fascines, and erosion control materials. Joint plantings are stakes that are driven between rocks or riprap, and must be greater than 1.5 inches in diameter and several feet long. Materials ranging from 0.5 to 2.5 inches are used to revegetate live crib walls. Crib wall cuttings must be long enough to reach 4 to 6 feet back to the end of the wall.

Large diameter. Larger diameter materials are used as dormant post plantings to stabilize streambanks. The diameter of these poles range from 3 to 5 inches and are 7 to 9 feet long. Large posts are not always easy to obtain in the wild, but can be produced from nursery stooling beds.

Inset 10.14 – How to Tell the Difference Between Male and Female Willows and Cottonwoods

Identifying the sex of dioecious plants is easiest when they are flowering or fruiting. Willow (*Salix spp)*.catkins may appear before, during, or after new leaves appear in spring. Identifying anthers in male catkins (photo A) and pistils in female catkins (photo B) with a hand lens is relatively easy, especially with a little practice. Female plants can easily be identified when the cottony seeds are mature (photo C). During the winter dormant season, it is possible to identify the sex of dormant cottonwoods by dissecting floral buds, although this is more difficult with willows. Detailed instructions on how to sex willows and cottonwoods can be found in Landis and others (2003).



***Cutting Footage* –** The total length of cuttings available for harvest should be estimated for each potential cutting area. This can be roughly calculated by evaluating 10 to 20 donor plants and estimating the average length and number of usable stems (by diameter size categories) that could be obtained from each. The average length is then multiplied by the estimated number of plants in the cutting area to obtain a total estimated cutting footage. This will be the high end of an estimate, since most landowners are likely to place a restriction on the amount of cuttings that can be harvested at one time. For example, a landowner might limit the amount of cuttings that can be taken from an area to 25% in a riparian area. The cutting footage would be 25% of the total length of the cuttings.

10.2.2.4 Determine Rooting Potential

Not all cuttings will root and become established plants when installed on a project site. The success rate of those that actually do become plants is dependent on 1) the percentage of cuttings that form roots when placed in an ideal growing environment, or the rooting potential and 2) the percentage of viable cuttings (those that root) that become established after a growing season, or the survival potential.

Rooting potential is analogous to germination rates obtained from seed testing. Seed tests are performed under uniform, ideal growing conditions, and are a measure of the potential of seeds to germinate (See Sections 10.2.1, 10.2.4, and 10.3.1). Rooting potential is similar to germination in that it assesses the potential of cutting materials to produce roots under an ideal rooting environment. The potential of cutting materials to initiate roots is the basis for determining how many cuttings to collect and the density to plant. For example, if the rooting potential of a specific collection is low, more cuttings will need to be planted at closer spacing to compensate for those cuttings that do not root.

Root potential tests have been developed for measuring the viability of nursery-produced plants (Ritchie 1985), but there are no standardized tests for determining the rooting potential of cuttings. Labs that offer seedling quality tests might, on request, use or adapt the root growth potential (RGP) tests developed for seedlings to assess the rooting potential of vegetative materials. Inset 10.15 gives one possible method for assessing rooting potential.

Rooting potential is affected by several plant factors, the most important of which are 1) species, 2) genotype, 3) date of collection, 4) portion of plant collected, 5) age of material, 6) condition of material, 7) preparation techniques.

Species **–** A small percentage of species in the western United States root consistently from cuttings. Those that root well can be cut and used directly on revegetation projects. Other species initiate roots only under controlled nursery environments, and must be grown into rooted cuttings before they can be planted on a project site. A list of commonly used native species that root from cuttings are shown in Table 10.13.

Genotypes **–** Within each species, there is variability in rooting potential. Some donor plants (genotypes) will have greater rooting potential than other plants. Unless tests are run, it is hard to know which donor plants are optimal rooters.

Date of Collection **–** The optimal time to collect cutting material is during plant dormancy. For most willow and cottonwood species, this period extends from mid-fall, after the donor plant drops its leaves, to bud swell in late winter to early spring. It is safe to assume that if donor plants have lost their leaves, cuttings will be at their highest rooting potential.

Planting unrooted cuttings within the dormancy period is not always possible because most construction work is curtailed during winter months. If unrooted cuttings must be planted outside the dormancy period, establishment rates will significantly decrease. There are several alternative measures that can be taken: 1) collect cuttings during dormancy and keep in cold storage until they can be installed (See Section 10.2.2.7), 2) collect cuttings outside the dormancy period and plant more cuttings to compensate for the anticipated downfall (See Section 10.2.2.5), or 3) use rooted cuttings in lieu of unrooted cuttings (See Section 10.2.2.4).

Table 10.13 – *Some common species that can be propagated from vegetative material.*

		Rooting Potential	
Species	**Vegetative Material**	**In Field**	**In Greenhouse**
Willows (*Salix* spp.)	Stems	Easy	Easy
Cottonwoods (*Populus* spp.)	Stems	Easy	Easy
Snowberry (*Symphoricarpos albus*)	Stems	Easy to Moderate[1]	Easy to Moderate[1]
Pacific ninebark (*Physocarpus capitatus*)	Stems	Easy to Moderate[1]	Easy to Moderate[1]
Black twinberry (*Lonicera involucrata*)	Stems	Easy to Moderate[1]	Easy to Moderate[1]
Douglas spirea (*Spiraea douglasii*)	Stems	Moderate[1]	Moderate[1]
Salmonberry (*Rubus spectabilis*)	Stems	Moderate[1]	Moderate[1]
Quaking aspen (*Populus tremuloides*)	Roots	Poor	Moderate
Redosier dogwood (*Cornus sericea*)	Stems	Moderate[2]	Moderate
Chokecherry (*Prunus virginiana*)	Roots	Moderate[2]	Moderate
Golden currant (*Ribes aureum*)	Stems	Poor	Moderate[2]
Woods' rose (*Rosa woodsii*)	Stems	Poor	Moderate[2]
Manzanita (*Arctostaphylos* spp.)	Stems	Poor	Moderate

[1] From Darris and Williams 2001
[2] From Bentrup and Hoag 1998

Inset 10.15 – Testing Method for Determining Rooting Potential for Willow and Cottonwood Species

Testing the viability of willow and cottonwood cuttings takes much of the guesswork out of establishing plants through this method of propagation. While is not a common practice in revegetation work, testing the viability of cuttings should be considered for similar reasons as seed testing. Most revegetation specialists would not think of applying seeds on a project without first testing for germination, purity, and seeds per pound, yet not think twice about using cuttings without having tested them first. This oversight can lead to higher costs, as well as low establishment rates.

There are no established testing procedures for assessing rooting potential of cutting materials. Until these tests are established, we present a means of root assessment that can be used to compare results from year to year. Ideally, a controlled environment, such as a greenhouse, is the best place to conduct a rooting potential test. Temperatures should range between 65 and 75 ° F degrees. Using bottom heat or rooting hormones is not necessary; in fact, for some species, it can be detrimental for rooting (Darris and Williams 2001). Where a greenhouse is not available, use an indoor space where relatively constant temperatures can be maintained. Grow lights should provide at least 12 hours of light per day.

Fifteen samples, at a minimum, should be randomly collected from different donor plants at each collection area. They should be of the same size and treated in a manner similar to what would be expected under normal operations. For example, if stakes with diameters between 2 and 3 inches are to be collected in August and soaked for 10 days before planting, then the cuttings used for the tests would be of similar size, collected in August, and soaked in the same manner, and planted. Prepare each sample by cutting them into 12-inch lengths. Stick them 3 inches apart in pots that are at least 16 inches deep, filled with 1 part peat to 4 parts perlite. Cuttings should be stuck so that two buds are exposed above the media.

After sticking, water the pots and set them in their testing location. At weekly intervals, observe the cuttings and note the status of the leaves developing from the buds. At 28 days, record how many cuttings have developed new leaves, gently remove the media from around the cuttings, and lightly wash the stems. Viable cuttings should have developed roots during this period. Record how many cuttings did not initiate roots (see cutting on the left in picture below). For those cuttings that did establish roots, a quantitative estimate of root initiation can be measured by removing the roots from the stem and weighing the new roots or counting the number of new roots for each cutting.

To interpret this data, you will have to assume that any cutting that did not initiate roots or develop foliage during 28 days, probably will not immediately initiate roots in the field. A comparison of average root weights or number of roots between testing samples can indicate which collection sites or treatment methods will produce the best rooting materials. Those test samples with high average root weights should perform better than those with lower weights.

Collecting plant materials outside the dormancy period has been tried in biotechnical engineering projects with varying degrees of success (Figure 10.55). Species that root easily, such as willows (*Salix* spp). and cottonwoods (*Populus* spp.), will root from cuttings collected outside dormancy, albeit at very low rates (Steinfeld 2002; Steinfeld 2005). In some instances however, this may be the only option available to the revegetation specialist. When these are the circumstances, collecting outside the dormancy period should be done with an understanding of how establishment rates will be affected and whether the overall project objectives will be met. For large projects, it is important to conduct rooting and survival potential tests (Inset 10.15) several years before cuttings are installed so that the appropriate amount of cuttings can be collected and planting densities can be determined (See Section 10.2.2.5). An alternative to dealing with low survival potential of wild cuttings is to establish stooling beds (See Section 10.2.5).

***Figure 10.55** – Collecting cuttings outside of plant dormancy as was done for the project shown in this photograph, can lead to extremely poor results. If this practice is considered, rooting potential tests should be performed first.*

Portion of Plant – Most cuttings are taken from stems and branches. However, the rooting potential for some species is greatest when cuttings are taken from roots (Table 10.13).

Age of Material – The rooting potential changes with the age of the donor plant. Many species have greater rooting potential from new growth, while others perform better when materials are collected from older branches or stems. Species having a higher rooting potential in the older portions of the plant make excellent live stakes because the size of the material is often large enough to withstand being driven into the ground (Darris and Williams 2001).

Condition of Material – Vegetative material from donor plants can be affected by insects and disease which can severely reduce rooting potential (See Section 10.2.5 for more discussion).

Preparation Techniques – Several practices can potentially enhance rooting potential. One method involves soaking dormant cuttings in water prior to planting. Schaff and others (2002) found that soaking black willow (*Salix nigra*) for up to 10 days in water doubled the survival rates of large diameter, dormant cuttings over unsoaked cuttings. Some revegetation specialists have reported an increase in rooting potential of cuttings collected outside the dormancy period by stripping leaves from stems, while others have found this ineffective (Steinfeld 2002). Soaking cuttings in hormones can increase rooting in some species (Shaw 2004), while it can be detrimental to others (Darris and Williams 2001). Testing rooting treatments on a small scale through rooting potential tests should be conducted prior to applying these methods on a larger scale.

10.2.2.5 Determine Survival Potential

Not all cuttings that initiate roots under ideal testing conditions will establish into plants when outplanted on a project site. The percentage of viable cuttings that root and survive one year after planting is called the survival potential. The survival potential is controlled by 1) climate, 2) soils, 3) planting methods, and 4) maintenance practices for each project. It can be determined though field testing conducted prior to installing cuttings, or estimated from previous field experience on similar sites using unrooted cuttings, rooted cuttings, or planted seedlings.

Climate – Survival potential is strongly influenced by the water loss potential of the site (See Section 5.4). Sites with low moisture stress during root initiation (typically spring through early summer) will have high survival potentials. The longer cuttings can initiate and grow roots without being under moisture stress, the greater the potential for survival. Climates with high humidity during root initiation occur in riparian areas.

Within a project area, survival potential often changes with aspect. Cuttings subjected to hot, dry conditions of south aspects typically will have a lower survival potential than north aspects. Survival potential also increases in areas that have occasional summer rainstorms that wet the soil profile.

Soils – Survival potential is affected by soil water storage and accessibility (See Section 5.3). Soils with low water-holding capacity will have lower survival potentials than those with high water-holding capacity. Installation of cuttings on compacted soils will result in lower survival than loose or tilled soils. Areas that have high water tables during the growing season, such as slumps, seeps, and springs, will have higher survival potentials for riparian species.

Installation Methods – Compensations can be made for sites with poor soils or dry climates. One option is to install longer cuttings. Studies have shown that higher survival rates and greater vegetative growth can be achieved with longer cuttings (Rossi 1999). This is especially important on drier sites, since longer cuttings access deeper soil moisture. Cuttings up to 2 feet in length have been shown to produce better survival and growth on harsher sites (McElroy and Dawson 1986; Rossi 1999). In areas where freeze-thaw potential is high (See Section 5.6.2), shorter cuttings have a greater likelihood of being pushed out of the ground before they can form roots to anchor them in place. Survival rates are also affected by the quality of planting methods. For instance there can be a significant decrease in survival when cuttings are planted without good soil–to-stem contact and many large air pockets. Section 10.3.3 covers the different methods of installing cuttings.

Plant Maintenance – Survival potential can also be increased if the plants are maintained during the first year after planting, including the control of competing vegetation and protection from animal browse (See Section 10.4, Post Installation Care of Plant Materials).

10.2.2.6 Determine Cutting Needs

Once the survival and rooting potentials have been determined, the quantity of cuttings to collect can be calculated. The information needed for determining cutting quantities and cutting spacing (density) is:

- Rooting potential,
- Survival potential,
- Target plant density,
- Area to plant,
- Desired established plant densities, and
- Length of cuttings.

An example of how to calculate cutting quantities and planting spacing is shown in Figure 10.56. In this example, the project objective is to stabilize the slope by installing willow stakes. In the short term, this practice will increase slope stability by physically "pinning" the surface soil. The primary benefit to slope stability, however, will develop over time as the roots of the establishing willows begin to tie the soil particles together and increase soil strength. The desired spacing between established plants is 6 ft. When inventories are taken one year after planting, they should find an established plant approximately every 6 feet (D), or approximately 303 established plants for the entire planting site (E).

To achieve the desired density of established plants, we must determine how many cuttings to plant and the average spacing between installed cuttings. This determination is based primarily on the rooting and survival potentials (See Section 10.2.2.4 and Section 10.2.2.5). In this example, the rooting potential was 68% based on rooting potential tests. The survival factor was estimated to be around 35% from previous experiences on similar sites. These factors are used in the equation shown in Line F, to calculate the number of cuttings needed to install. To obtain 303 established plants, it would be necessary to install approximately 1,271 cuttings. This is approximately four times the number of established plants. It is necessary to install this

***Figure 10.56** – This spreadsheet can be used to calculate the number of cuttings to collect and how close to plant them on the project site.*

A	Area to plant:	0.25	acres	Area that will be planted with cuttings
B	Rooting potential:	68	%	Percent of cuttings that root under ideal rooting environment
C	Survival potential:	35	%	Percent of cuttings that root which are established one year after planting
D	Target plant spacing (1st year):	6.0	feet	Desired distance between established plants after one year
E	(43,560 / (D * D)) * A =	303	plants	Desired number of established plants after one growing season
F	E * (100/B) * (100/C) =	1,271	cuttings	Number of cuttings that need to be planted
G	Cutting Length:	2.5	feet	Approximate length of cuttings
H	F * G =	3,178	feet	Total footage of cuttings to collect for site
I	SQRT ((43,560 * A) / F) =	2.9	feet	Distance that cuttings must be planted from each other

many to compensate for the number of cuttings that either do not root, or root and do not survive the summer. The planting spacing is calculated using the equation in Line I. Cuttings must be installed at half the distance of the desired established plant spacing. Since the site conditions in this example are harsh, the cuttings will need to be planted deeply to access soil moisture. For this reason, the cutting lengths are approximately 2.5 ft. Multiplying 2.5 ft by the number of cuttings needed (F) gives the total length of cuttings that must be collected (H). Knowing that 3,178 ft of cuttings are needed, the number and location of cutting areas can be selected from a cutting area map, and a contract can be developed.

10.2.2.7 Long-Term Storage

If cuttings are not installed immediately, long-term storage will be required. Cuttings collected in the fall or winter and stored until the following spring or summer must be held in refrigerated units. The optimum temperatures for long-term storage range between 28 to 31 °F. Freezing temperatures prevent disease and curtail respiration, thereby increasing cutting viability. If freezing is not possible, then storing cuttings at temperatures between 33 and 35 °F should maintain cutting viability for several months.

For long-term storage, cuttings should be relatively free of leaves and other material that might mold in storage. They must be packaged in plastic or storage bags so they will not dry out. Cuttings should not be wrapped in moist burlap or placed in plastic bags, especially if cuttings are not frozen. Diseases could potentially develop that will rot the stems.

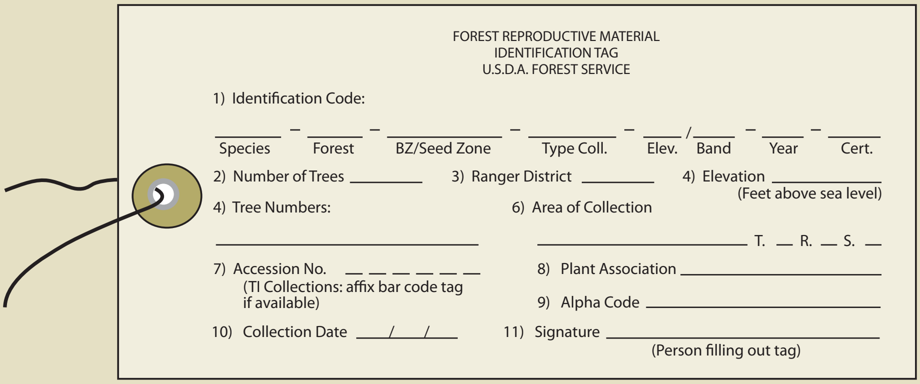
10.2.2.8 Develop and Administer Contracts

A good plan that includes the location of cutting sites and how the cuttings will be treated, transported, and stored will be the basis for the development of a collection contract. The contract must specify:

Cutting Locations – A map or GPS locations must identify cutting areas and specify an estimated range of cutting quantities (See Section 10.2.2.3). If the contractor elects to collect from other areas, then these areas must be approved prior to cutting. For each cutting area, the percentage of the donor population that can be collected should be specified. Typically this is no greater than 25% of the population.

Dates of Collection – The contract must specify a period of time that cuttings must be collected (See Section 10.2.2.4). Collecting outside this time period must be discussed in advance with the revegetation specialist.

__Figure 10.57__ – A forest reproductive material identification tag should be filled out and attached to each bundle of cutting material.


FOREST REPRODUCTIVE MATERIAL
IDENTIFICATION TAG
U.S.D.A. FOREST SERVICE

1) Identification Code:

_____ – _____ – _____ – _____ – ____ / ____ – ____ – ____

Species Forest BZ/Seed Zone Type Coll. Elev. Band Year Cert.

2) Number of Trees _____ 3) Ranger District _____ 4) Elevation _____ (Feet above sea level)

4) Tree Numbers: 6) Area of Collection

_____ _____ T. __ R. __ S. __

7) Accession No. _ _ _ _ _ _ (TI Collections: affix bar code tag if available) 8) Plant Association _____

9) Alpha Code _____

10) Collection Date __/__/__ 11) Signature _____ (Person filling out tag)

Collection Size, Lengths, and Quantities **–** Quantities must be specified for each size category. For example, if material is to be used for stakes, then a specification might require 200 stakes, 18 inches long, with a range of diameters between 1.0 inch to 3.0 inches.

Collection Methods **–** The contract should identify how the contractor will collect the cuttings. For example, it should state how the contractor will identify which end of a stake is basal and which is terminal. This is typically done by cutting the basal end of each stake at an angle. The contract should also specify how the cuttings will be packaged or bundled. Contracts often call for all stakes to be aligned with basal ends of the cuttings in the same direction. Bundle sizes or weights must be specified. The bundles must be light enough to transport by one person (45 lb or less). The contract must also state that the bundles must be securely tied or bundled together for hand transportation.

Source Identification **–** Each bundle must be identified with a Forest Reproductive Materials Identification Tag (Figure 10.57), which specifies the species, collection location, elevation, and date of collection.

Special Treatments – Special measures such as soaking must be stated in the contract. If soaking is required, then the location of the soaking area must be identified on a map (See Section 10.2.2.4).

Temporary Storage and Transportation **–** The contractor must address how cuttings will be temporarily stored when the weather is warm or dry. Cuttings must not be allowed to dry out once they are collected. Temporarily storing in shaded areas covered by plastic sheets or wet burlap are acceptable methods. Delivery of cuttings must be done in a manner that does not allow the cuttings to dry. Closed transportation or covering with plastic for long distances should be considered.

10.2.3 COLLECTING WILD PLANTS

10.2.3.1 Introduction

Wild seedlings, commonly referred to as wildlings, are indigenous plants growing in their native habitat (Therrell and others 2006). They are naturally reproduced outside of a nursery situation, but can be transplanted directly into a restoration site or into a nursery for culturing and future use.

The collection and use of wildlings in native plant restoration can be a viable alternative to direct seeding, nursery seedlings, or rooted cuttings. As with wild cutting collections (See Section 10.2.2), wildlings can be used in situations where it is difficult or impossible to collect or use seeds for plant production because : 1) the plant either does not produce seeds or produces seeds very infrequently; 2) seeds are often unfilled or non-viable; 3) seeds have a very narrow collection window; 4) seeds have already dispersed prior to collection planning; and 5) insects or animals are a problem with collection (Priadjati and others 2001; St John and others 2003). Unlike cuttings, they can be available immediately with little to no transport costs, and no direct nursery costs, if used within the same time frame of collection.

***Figure 10.58** – Wetland plants are often salvaged from areas that are planned for disturbance. Removing plants from wetland settings can be difficult due to wet soils and massive root systems of many species. The heavy weight of these plants makes transportation and handling difficult. Tubs (A) are used for hand-transporting to planting sites while pallets (B) have been used for large quantities.*

There are several advantages to using wildlings in restoration plantings. Large wildlings provide "vertical relief" (visual prominence) more quickly to a site than other methods, and, depending on the species and environment, will establish and spread quickly (Hoag 2003). Use of wildlings reduces the risk of introducing non-native organisms such as weeds and pathogens (Therrell and others 2006). If reproduction of the plant is more successful via rhizomes (e.g., sedges), transplanting wildlings may be the most efficient and effective method for reestablishing these species (Steed and DeWald 2003). In addition, if plant propagation is difficult from seeds or rooted cuttings, use of whole plants may be the only alternative for a particular species.

Transplanting of wildling plants, however, can be unsuccessful for a number of reasons. Wildlings are often growing in stressful conditions, and do not recover from transplanting shock as quickly as cultivated seedlings. Wildlings often have smaller, coarser root systems than cultivated seedlings, or heavier taproots which are not easily removed from soil in their entirety (St John and others 2003). Successful transplanting requires experience, skill, proper handling, ideal temporary storage, and proper care of the plant both before and after transplanting.

10.2.3.2 Develop Timeline

Although wildling plants may provide an opportunity for quick establishment of larger plants on restoration sites, several factors must be considered in the planning process which could impact their availability. Suitable locations that can provide the number of plants required must be determined. If large quantities of plants are necessary, several years may be required to identify these locations. Once sites are identified, 1 or 2 seasons of plant preparation prior to removal, transport, and transplanting may be required (See Section 10.2.3.5).

Wildling plants may be removed from their native site and either transplanted immediately or transported to a nursery, potted, and cultured for future outplanting. Transplanting following removal may occur if the plant source is undisturbed areas outside the restoration site. If plants are removed prior to site disturbance, or if additional time is needed for production of sturdy plants, culturing in a nursery for some specified period of time may be necessary. Lead time of 1 to 2 years may be necessary for nursery-assisted wildlings, depending on the situation. This lead time may include contract procurement and administration for both collection and nursery culturing.

10.2.3.3 Locate Wildling Collection Areas

Potential sources for wildling plants can be identified through field surveys during the vegetative assessment phase (See Chapter 6). Sites should be located on maps and both plants and sites should be assessed for the following traits:

***Accessibility* –** Handling of wildling plants during removal and transport is a critical factor in ensuring survival. Roots may require protection if the rootball is not totally contained in soil; or plants may be heavy if the rootball is intact. Therefore, it is necessary that collection sites be accessible by roads. Since most collections will be taken in fall or early spring, it is also necessary to determine whether or not road conditions at these times of year will preclude collection.

The best collection areas may not always be found within the project site, so large areas surrounding the project may need to be surveyed for plants. Costs will increase substantially if it is necessary to transport plants for long distances.

***Land Ownership* –** Permission to remove plants must always be obtained from either the private landowner or public land management agency. In addition, any required permits should be obtained from state or federal agencies to ensure compliance with regulations (Hoag 2003).

***Viability* –** If possible, areas of healthy forest or rangeland areas should be designated as collection sites (Priadjati and others 2001). Sites should contain healthy, vigorous, and adequately sized material with a minimum number of unhealthy plants (St John and others 2003). Stunted needles, off-color foliage, and poor annual growth are indications of stress plants that should not be collected. Plants should only be removed from sites that show good regeneration over the area (Hoag 2003). Determining the viability of the collection material and timing of use (See Section 10.2.3.4) should be completed prior to selection of the collection site. It is important to transplant wildlings into similar growing environments. For instance plants growing under shade should be placed back into a shaded environment to achieve optimum viability.

***Genetics* –** One of the disadvantages or limitations of using wildlings, or any form of asexual propagation, in restoration is the potential to restrict the genetic diversity of the plant population. As adequate population sampling is important to maintain this diversity, it may be advisable to identify several sites over a large area from which to collect (St John 2003). Collecting many plants over a large area will help capture both inherited and environmental variation. However, sites must be chosen carefully so that they are reasonably similar.

Prior to collection, it is necessary to determine whether species are monoecious (male and female reproductive structures on the same plant) or dioecious (male and female reproductive structures on different plants). If the species of interest is dioecious, both male and female plants will need to be collected in somewhat equal proportions. If one of the objectives for using dioecious species is to promote, restore, or increase species, then target plants must be located during a period when reproductive phenology is evident, which is typically spring through summer.

10.2.3.4 Determine Transplanting Versus Nursery Culture

Although cost may be the biggest deciding factor in whether wildlings are collected for immediate transplant or growing in a nursery, other factors should enter into the decision in the restoration plan.

***Timing* –** Wildling plants should be transplanted into their new location as quickly as possible. If plants are to be collected from sites outside the disturbed area, these can potentially be removed and transplanted to the restoration site within the same time frame. However, if plant removal is part of a salvage operation, where plants are located within the area of disturbance, then plants could be transported to a nursery or similar growing situation. Plants should be transplanted into pots and maintained until the appropriate outplanting season.

***Species* –** Some plant species may be more successful than others for direct transplanting from one site to another. Plants that spread underground or with stolons will perform well, although dry, compacted sites will slow the rate of spread significantly (Therrell 2006). Species that recover quickly from root damage, such as willows (*Salix* spp).and cottonwoods (*Populus* spp.), will also perform well when large plants are needed quickly. These types of plants may lend themselves easily to transplanting within the same time frame as removal.

Plants with taproots, such as conifers and many shrubs, and plants with long, brittle horizontal roots, such as heather or vine maple, are difficult to transplant. Special care must be taken during removal to extract as much of the roots as possible. To ensure a higher success rate, further culturing in an optimal environment following removal may provide a healthier, more viable plant for outplanting.

Size and Availability – If wildling plants of the target species are plentiful and appropriately sized on undisturbed sites, immediate transplant during the appropriate season is feasible. However, if available wildlings are smaller than desired, an additional 1 or 2 years of nursery culture may provide a better plant for colonization of the site.

Certain plants have the ability to root by layering, such as pinemat manzanita (*Arctostaphylos nevadensis*). If entire plants are not plentiful, portions of individual plants can be removed and cultured in a nursery situation for outplanting the following year.

10.2.3.5 Collection and Handling

Date of Collection and Timing of Transplanting – The season during which collection and transplanting occur has been shown to dramatically affect the survival and growth of wildling plants (Yetka and Galatowitsch 1999). Plants allocate carbohydrates and nutrients during various phases of phenological development. Different levels of tolerance to transplanting stress during the year are the result of physiological needs shifting among shoot and root growth, flowering and seed production, and storage. In addition, seasonal variation in environmental factors, such as soil moisture and temperature, can affect planting establishment (Steed and DeWald 2003).

Timing of collection will depend on whether the wildlings are to be transplanted in the same time frame or cultured in a nursery. If wildlings are to be transplanted into the restoration site following collection, the chances for survival will increase for most species if operations occur in winter to early spring. The seedlings are dormant during this period and can handle the stresses associated with transplanting. There is also less chance of damaging new roots that occur during the spring and fall. In addition, planting early extends the period for root growth prior to soil-drying in summer.

Collection could occur in either fall or spring if wildlings are to be cultured in a nursery. However, if plants are collected in the fall, care must be taken to avoid excessive root damage, since plants will not be dormant. Due to the perishable nature of wildlings, the timing of collection must be coordinated with the nursery to assure that the facilities, supplies, equipment, and labor are available following harvest (St John 2003). Once collected, plants should be transplanted immediately into containers.

Genetics – Collection of wildlings can consist of a single plant, a clump, or several pieces of a plant that have rooted through layering (NRCS 1997). A collection of individual plants should be large enough to assure adequate population sampling. A minimum of 50 plants within at least a range of 1 mile from the restoration site is recommended when possible.

Source Identification – Every collection must be identified with a Forest Reproductive Materials Identification Tag, which specifies the species, collection location, elevation, and date of collection (See Figure 10.53 in Section 10.2.1, or Figure 10.57 in Section 10.2.2).

Figure 10.59 – *Be sure to select small plants with a protective ball of soil around the roots (A). Do not attempt to transplant plants if the soil falls off the root system (B).*

Quality and Size – Only healthy, turgid, moderately vigorous, and adequately sized wildlings should be collected for either transplanting or nursery culturing. Unhealthy or stressed plants should be avoided.

Although species dependent, successful transplanting typically increases as plant size decreases (St John 2003). Transplanting of large shrubs and trees is usually unsuccessful. Their root-to-shoot ratio is unbalanced, and these plants often do not recover from or survive transplanting shock. Transplanting of larger willows, sedges, or herbaceous material into riparian zones, however, may be appropriate depending on the vegetative competition and other establishment conditions (Hoag 2003; Steed and DeWald 2003).

Handling, Transport, and Storage – Collection of wildling plants will be most successful if the soil is moist during plant removal. If precipitation has not occurred, irrigation prior to lifting would be desirable. Removal and transplanting should only occur in the mornings on cool, cloudy days, when the plant is fully turgid.

A tile spade or similar flat-bladed shovel is the best tool for small to medium plant removal. Using the "dripline" of the plant as a guide, make shovel cuts with the blade as perpendicular to the surface of the ground as possible, since maintaining an intact ball of soil around the roots is important (Figure 10.59). Root morphology should also be considered in this process. Roots growing in deep soils or arid soils will tend to grow down rather than out. Roots growing in shallow soils will tend to spread, requiring a much larger area of disturbance (Therrell 2006).

The shovel, as well as hands, can be used to lift the root ball gently out of the hole while attempting to keep the root ball intact. Hand pruners can be used to cut away woody roots that do not come free with the shovel. The root ball can then be transferred to a suitable container (large bucket, pot, burlap, or plastic bag) for transport to the transplanting site (Therrell 2006). If wildlings are to be transported to a nursery, plants should be placed in plastic bags in coolers. Plastic bags should also contain moistened towels or similar material if roots are not covered with soil.

A tree spade can be used if larger plants are to be excavated and transplanted (Figure 10.60). The factors important for using a tree spade are: 1) the terrain is accessible to the tree spade equipment (slope gradients no greater than 20%), 2) soils are relatively free of cobble size rock fragment, and 3) soils are moist. In this operation, planting holes are created first, then plants are excavated, moved, and replanted. The size of the plant to be transplanted depends on the soil volume that can be removed by the tree spade. Typically plants up to 6 feet tall can be transplanted with success. Taller trees should be irrigated into the soil to improve survival. Using a backhoe has also been successful in transplanting large willow clumps (Hoag 2003).

Wildlings should be transplanted into their new location as quickly as possible, with minimal to no storage time. All vegetative material must be kept cool and moist during the process. If wildlings are transported to a nursery, the plants should be kept in a cooler and transplanted into pots within 1 to 2 days of collection.

Figure 10.60 – *Plants can be excavated from the soil using the drip line (dashed lines) as a guide.*

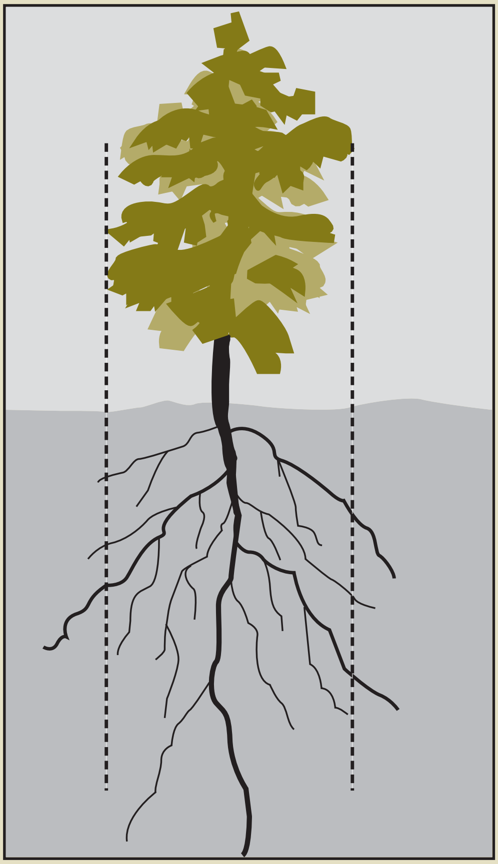


Figure 10.61 – Mechanical tree spades (A) can extract large plants quickly. A planting hole must be excavated prior to transplanting (B) and this can be accomplished with a tree spade. Photo credit: Chris Jensen, USFS.

10.2.3.6 Survival Potential

As with rooted cuttings (See Section 10.2.2.5), not all wildlings will become established and thrive following transplanting. Survival is controlled by climate, soils, planting methods, and maintenance practices on the project.

Climate – Water loss potential (See Section 5.4) is probably the main determining factor for survival on many sites in the western United States. Sites with low moisture stress during root initiation (spring through early summer), and sites that have the potential for longer root initiation periods, will have higher survival.

Within a project area, aspect can also affect root initiation and survival. Transplanted wildlings subjected to hot, dry conditions on southern aspects have a lower potential for survival than those on cooler northern aspects.

Soils – Survival of wildlings is affected by soil water storage and accessibility (See Section 5.3). Soils with low water-holding capacity or compacted soils will have lower survival than those with high water-holding capacity and greater porosity.

Planting Methods – Good transplanting techniques will improve the survival rates of wildlings significantly. Planting methods are the same for wildlings and nursery-grown seedlings. Common mistakes include planting too shallow or too deep, planting too loosely, damaging roots by exposing them to air, or failing to place root systems properly (Therrell 2006).

Ideally, transplanting should occur on a cool, cloudy day. Planting holes should not be allowed to stand empty for an extended period of time, as soil will dry rapidly. When possible, microsites should be used (rocks, logs, depressions, and so on) to provide protection from the sun or wind.

Plant Maintenance – Survival potential can also be increased if the plants are maintained during the first year after planting. Practices including the control of competing vegetation and protection from animal browse. For large wildlings, irrigation during the summer will improve survival. Also large wildlings might need additional support depending on such site conditions as wind and snow.

10.2.3.7 Develop and Administer Contracts

A plan that includes the location of collection sites, and how the wildlings will be handled, transported, transplanted, and stored (for short periods of time) will be the basis for the development of a collection contract. The contract must specify:

- ***Collection Locations.*** A map or GPS locations must identify wildling collection areas and specify a range of quantities that can be expected. If the contractor elects to collect from other areas, then these areas must be approved prior to collection. For each collection area, it should be specified what percentage of the natural population can be collected.

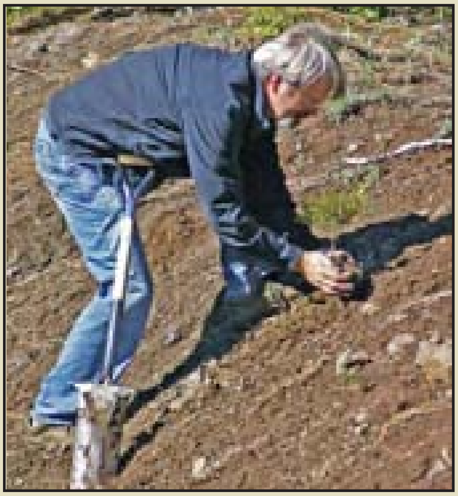


***Figure 10.62** – Transplant wildlings immediately following collection to minimize moisture stress.*

- ***Dates of Collection.*** The contract must specify a period of time that the collections can be made (See Section 10.2.3.5). Collecting outside of this time period must be discussed in advance with the revegetation specialist.
- ***Collection Quality and Size.*** Minimum and maximum plant sizes should be specified in the contract. In addition, specifications for health and vigor should be included.
- ***Collection, Handling, and Storage Methods.*** The contract should identify how the collections will be made, how the wildlings will be handled and processed following removal, and how wildlings will be temporarily stored prior to transplant or transport to the nursery.

The contractor must address how plants will be temporarily stored when the weather is warm or dry. Wildlings must not be allow to dry out once they are collected. See Section 10.2.3.5 for proper handling and storage methods.

10.2.4 NURSERY SEED PRODUCTION

10.2.4.1 Introduction

Most revegetation projects require large quantities of source-identified seed. The most common approach to obtaining such quantities is to issue seed increase contracts. In these contracts stands of grasses and forbs are established from source-identified seed (typically wild seed collections) and cultured specifically to produce seed (Figure 10.63). Usually the seeds are produced by the end of the first or second year of production.

Considering the costs and amounts of seeds that can be obtained from wild seed collection, propagating grass and forb seed is very efficient. For example, mountain brome (*Bromus carinatus*) requires 8 pounds of wild seed to sow an acre of seed fields. At the end of the first year, the seed collected from the field will average 800 pounds, a hundred-fold increase. For most species grown in production beds for two years, the return is at least 50 pounds of seed produced for every pound of wild seed collected and sown. In some cases 100 pounds are collected per pound of wild seed sown. This section will outline the steps required for developing and administering seed increase contracts.

10.2.4.2 Develop Timeline

Seed production varies by species but typically it takes three years to obtain seed. This involves one year to obtain seed from wild collections, and at least two years for seed production (Figure 10.64). There are a series of steps or tasks that are required to obtain seed that will be discussed in detail in this section:

- Determine seed needs,
- Obtain starter seed,
- Develop and award contract,

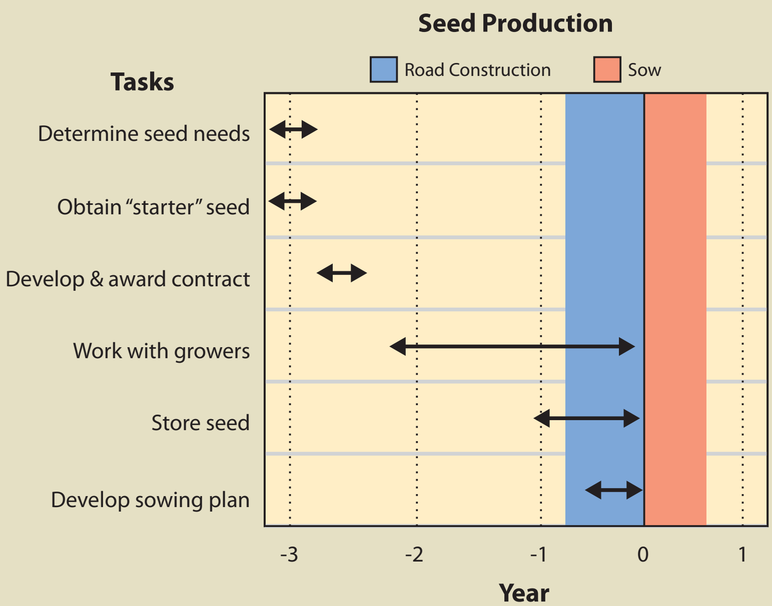
***Figure 10.63** – A variety of species can be propagated for seed. In this photograph small seedlots of forbs are being propagated. The beds in the upper left are western buttercup* (Ranunculus occidentalis); *lower left is fragrant popcornflower* (Plagiobothrys figuratus), *and the bed on the right is elegant calicoflower* (Downingia elegans).

- Administer contract, and
- Store seed.

Early in the planning phase a rough approximation of the quantity of needed seed for each species must be determined. Seed quantities will be refined as planning progresses, but because of the amount of time that is takes for wild seed collection and seed production, it is important to make an estimate early in the planning stages. Developing and awarding wild seed collection contracts is the first task and this can take several months (See Section 10.2.4). To avoid missing the seed collection window, these contracts must be awarded by early spring, otherwise an additional year will be needed for wild seed collection.

Seed production contracts should be awarded by mid-July for fall sowing and late January for spring sowing. It is important to prepare and award seed increase contracts well in advance of sowing to allow the contractor enough time to prepare and sow their fields. Specific sowing dates will differ for each seed producer because of differences in geographic location, climate, or experience. Some growers may want to certify the seed, so this may require additional

***Figure 10.64** – Up to three years should be allowed when obtaining nursery grown seed because of the time it takes to obtain wild collected seed and obtaining seed from seed producers.*



preparation time as well. It is beneficial to contact the potential growers prior to award of contracts to find out when sowing and first harvests are expected. Once wild seed has been collected, cleaned, and tested, it is delivered to the seed producers.

Seed increase contracts should cover a span of at least two years, to account for the possibility of a low first year harvest. Seed harvests take place during the summer and seed cleaning in the fall of each year. Once seed has been cleaned, the grower submits a sample from each seedlot to a seed laboratory for testing. Seed testing typically takes place in the fall and is completed in several months. Seed is placed into seed storage until it is needed. For many revegetation projects, the seed that is harvested in the summer is needed for immediate fall sowing. This can be accomplished if those seedlots are put on a "fast track" for seed cleaning and testing. The seed production contract should state those seedlots that need to be ready for early fall sowing.

10.2.4.3 Determine Seed Needs

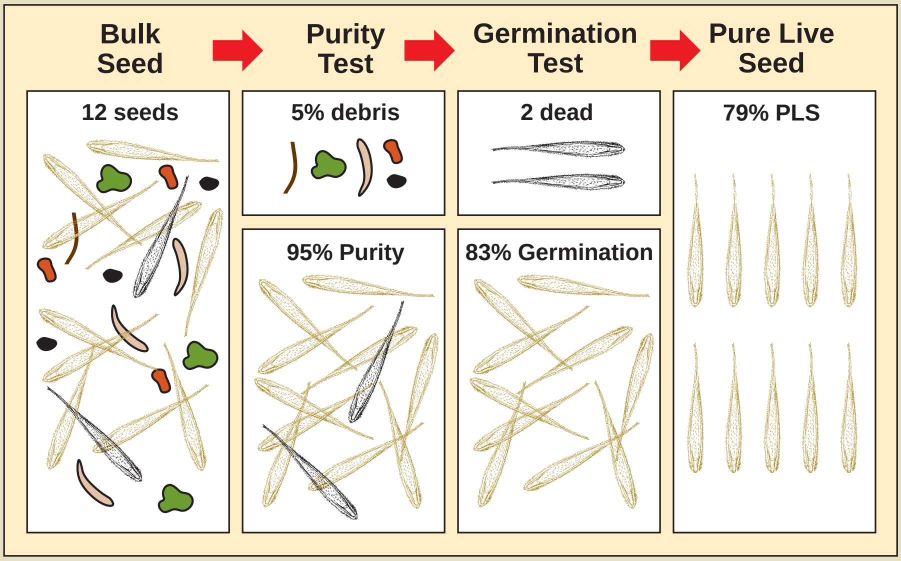
Determining total seed quantities for a revegetation project must be done as soon in the planning process as is feasible since wild seed collection contracts and seed propagation contracts are based on these figures. At this point, only a rough approximation of seed needs is required.

Calculating the needed quantities of seed is performed for every species that will be used on a revegetation project. Each species requires a set of data which must be estimated since specific seed data is unavailable at this point in planning. The information that is needed includes an estimate of the following factors:

- Pure live seeds per pound,
- Field survival,
- Target seedling density,
- Target species composition, and
- Area to seed.

Pure Live Seeds Per Pound (PLS/lb) – The quality of seedlots can vary greatly. One method to assess seed quality is to calculate % pure live seed (PLS). This value represents the percent of the gross seed weight composed of viable seeds. For example, if a seed producer did not clean the harvested seed of a seedlot very thoroughly, the PLS would be low because there would be a lot of additional weight associated with non-seed debris. Seedlots that were cleaned well, on

Figure 10.65 – *Pure live seed (PLS) is the percent of the bulk seed weight that is composed of viable seed. In this example 95% of the bulk weight is composed of seed and of this seed 83% was found to germinate from seed tests. Multiplying % purity by % germination gives % pure live seed.*



the other hand, would have a higher PLS because the debris weight would have been removed. Seedlots that have higher germination rates also have higher PLS. These two factors, % purity and % germination, when multiplied together and divided by 100, give the pure live seed (PLS) of a seedlot. The concept of PLS is illustrated in Figure 10.65. In this example, purity of a grass seedlot is 95% and germination is 83% which results in a PLS of 79%.

Another example of calculating PLS/lb is shown in Figure 10.66 for western pearly everlasting (*Anaphalis margaritacea*). For this seedlot the estimated purity is 60% which indicates that over half of the gross weight of seed is actually viable seed and the remaining part is either debris or non-viable seed. Multiplying this value by the percent of seeds per pound and by the percent of germination will yield the number of viable seeds per pound. In this example, the number of seeds in a pound of a western pearly everlasting seedlot is tested at 8,000,000. Multiplied by 60% purity and 85% germination gives a value of approximately 4,080,000 PLS per pound of bulk seed. This value can be used in sowing calculations as shown in the example. Keep in mind that for each additional seedlot in a mix, similar calculations will have to be made. Estimates for purity, germination, and seeds per pound can be obtained from Table 10.14, seed inventories, or seed extractory managers.

Field Survival – Field survival factors account for the viable seeds that, for one reason or another, do not grow into plants within the year after seeding. It accounts for viable seeds that did not germinate because of the harsh site conditions, or did germinate but could not survive the site. The field survival factor reflects the harshness of the site. For example, seeds that are sown under mulch on a moist, cool site will survive better than seeds sown on hot, dry sites without mulch, in which case the survival factor would be much lower. Only an estimate of field survival can be made at this time, based on general understanding of the site (See Section 10.3.1.5 for more discussion on estimating survival). Choosing a survival factor between 3% (poor site conditions and poor seeding practices) and 25% (good site conditions and practices) should be sufficient for this estimate. In Figure 10.66, the field survival was set very low because of the harshness of the site.

Target Seedling Density – The target first year density indicates the number of plants/square foot that is desired one year after sowing. This is the target number of seedlings, for all species sown, in a one square foot area. Seedling densities range from a target of less than one plant per square foot for shrub and tree species to 10 and 25 seedlings per square foot for grasses and forbs (See Section 10.3.1.5).

Figure 10.66 *– Determining the quantity of seed that will be needed for a revegetation project can be made by completing this spreadsheet for each species. The estimated pounds of seed determined for each species can be the basis for ordering seed through a seed increase contract. This example calculates the quantity of western pearly everlasting (*Anaphalis margaritacea *[ANMA]) seeds needed for a project.*

A	Number of seeds/lb:	8,000,000	seeds/lb	From Table 10.14 or other sources
B	Purity:	60	%	From Table 10.14 or other sources
C	Germination:	85	%	From Table 10.14 or other sources
D	A * B / 100 * C /100 =	4,080,000	PLS/lb	Pure Live Seeds (PLS) per bulk pound of seed
E	Field survival:	3	%	Estimate of the pure live seeds that become seedlings (as low as 3% for harsh sites and up to 25% for excellent sites)
F	Target seedling density:	25	seedlings/ft^2	Desired number of seedlings per square foot — all species (10 to 30 for grasses and forbs)
G	Target composition	10	%	Percent of total plants composed of ANMA
H	(F / E) * G =	83	PLS/ft^2	PLS of ANMA to sow per ft^2
I	43,560 * H / D	0.9	lbs/acre	Pounds of ANMA to sow on a per acre basis
J	Area to seed:	25	acres	Total area for seed mix
K	I * J =	22	lbs	Total ANMA needed

Table 10.14 – *A seed increase reference table showing the approximate maximum cleaned seed needed for a seed producer to produce a 1-acre production field. It also shows average first and second year yields and germination and purity standards for commonly produced species.*

Species	Sowing Rates (lbs of clean seed to sow per acre)	Average first year yields (lbs/ac)	Average second year yields (lbs/ac)	Average seeds per pound	Average germination/ purity of harvested seeds
Bluebunch Wheatgrass *(Pseudoroegneria spicata)*	8	200	300	140,000	75/95
Blue Wildrye *(Elymus glaucus)*	6	450	200	110,000	65/96
Bottlebrush Squirreltail *(Elymus elymoides)*	6	0	125	110,000	75/90
California Oatgrass *(Danthonia californica)*	8	25	250	125,000	75/90
Basin Wildrye *(Leymus cinereus)*	8	25	160	130,000	75/95
Idaho Fescue *(Festuca idahoensis)*	4	50	400	450,000	75/90
Indian Ricegrass *(Oryzopsis hymenoides)*	6	0	200	120,000	80/85
Lemmon's Needlegrass *(Achnatherum lemmonii)*	8	150	750	150,000	50/95
Mountain Brome *(Bromus carinatus)*	10	800	600	70,000	85/90
Needle and Thread *(Hesperostipa comata)*	6	0	150	100,000	50/95
Pinegrass *(Calamagrostis rubescens)*	2	0	130	2,500,000	75/75
Prairie Junegrass *(Koeleria macrantha)*	2	150	500	2,315,000	80/97
Sandberg Bluegrass *(Poa secunda)*	3	300	600	1,314,000	75/97
Slender Hairgrass *(Deschampsia elongata)*	3	600	350	2,000,000	80/95
Thurber's Needlegrass *(Achnatherum thurberianum)*	5	0	150	225,000	50/95
Tufted Hairgrass *(Deschampsia caespitosa)*	2	110	510	2,500,000	75/90
Western Needlegrass *(Achnatherum occidentale)*	5	100	190	275,000	50/95
Common Yarrow *(Achillea millefolium)*	2	165	165	3,000,000	85/98
Western Pearly Everlasting *(Anaphalis margaritacea)*	1	50	50	8,000,000	60/85

Target Species Composition **–** The target composition defines the percent of established plants that are made up of each sown species. For example, if three species are sown, the target composition of plants might be 50% species A, 35% species B and 15% species C. The target species composition is developed from reviewing field surveys of disturbed and undisturbed reference sites. In the example shown in Figure 10.66, only 10 percent of the composition of plants is targeted to be pearly everlasting.

Area to Seed **–** This is the total area that is planned to be revegetated from seed based on the estimated acres presented in the preliminary road plans.

In the example shown in Figure 10.66, the seed needs for pearly everlasting is calculated to be approximately 22 pounds for the entire 25 acre project. This might seem like a very low amount of seed for a project of this size, but it reflects the high live seeds per pound for this species.

10.2.4.4 Obtain Starter Seed

Once the seed needs for a project are determined then the next step is to obtain starter seed to supply to the seed producer. Seed furnished to the seed producer must be of high quality and tested for purity, germination (or TZ), seeds per pound, and noxious weed content (See Section 10.2.1.7 for seed testing). Seedlots with high weed content will produce weedy fields. It is very expensive to weed non-target species out of seed production fields or clean non-target seeds from harvested seedlots, so it is important to give seed producers only the highest quality seed. It is worth the investment of sending all wild seed collections to a seed extractory to be cleaned prior to sending to the seed producer. Section 10.2.1.3 discusses how to determine how much wild seed to collect for starting seed production crops.

There will be some projects where not enough wild seed is collected to establish a seed crop through seed sowing. In these cases, small collections of seed can still be used by first sowing seed in small plugs (1 to 2 cubic inch size) at a nursery, then transplanting the plugs into a seed production field at low densities (<1 seedling per foot). Not only will this reduce the amount of seed needed to establish a seedbed but seed production from these beds is often greater because plants are evenly spaced.

10.2.4.5 Develop Contract

The seed production contract must state for each seedlot being grown:

- Seedlot ID,
- Years each seedlot will be in production,
- Minimum annual seed yields for each seedlot, and
- Minimum purity and germination rates.

Minimum annual seed yields and average germination and purity rates can be obtained from Table 10.14. The years that a seedlot will be in production will vary by species and lead-time (See Section 10.2.1.2 for further discussion).

In addition, the seed production contract must address what is required or expected of the contractor in respect to the following criteria:

- Seed production experience;
- Timelines;
- History of production fields;
- Location of other seed crops;
- Irrigation system;
- Culturing practices;
- Control measures for non-target species;
- Seed harvest methods;
- Seed cleaning, packaging, and labeling; and
- Seed testing.

The response to these criteria becomes the basis for selection of contractors.

Seed Production Experience – Seed production is a specialized form of agriculture requiring different growing strategies and equipment. While many seed producers have

Inset 10.16 – Source Identified Straw Bales

A secondary product from the seed production contracts is the straw that remains after harvest. This material can be used for erosion control or seed covering. It can be used as a mulch and has the additional advantage of being a source of unharvested viable seed. This product must be treated similarly to certified straw sources (See Section 10.1.3). There should be no noxious or undesirable weed seed in the bales. A visit to the seed production fields prior to seed harvest will indicate if there are any unwanted species that will be present in the hay bales. Bales of each seedlot must be kept separate from other sources to prevent mixing. If straw bales are stored for any length of time, they must be protected from rain.

transitioned in seed production easily, it still requires several years of experience to understand how to efficiently grow native seed. Many seed producers who have moved into growing native seed have previous experience growing vegetable or commercial grass seed. These seed producers bring great experience and perspective to the native seed industry. Seed producers who have had little experience growing seed, often start small with "easier" species (i.e., workhorse species) to gain experience. It is important to know the capability of each seed producer, and make frequent site visits. Those with a long history of good seed production can be contracted for species that are more difficult or have not been grown before. It is good to request production records, as well as seed tests, to include species, seed yields, seed quality, and clients served by the producer.

Seed Production Timelines – Seed producers are located in many parts of the western United States, covering a range of climates affecting when seeds are sown and harvested. It is important to know the general growing schedule of each seed producer to determine when you will need to supply starter seed to the seed producer and when the first shipment of harvested seed can be expected. Seed producers from east of the Cascade Mountains might need starter seed in the middle of the summer for an August sow, while those west of the Cascades might not need it until early fall. Some seed producers wait until the spring to sow seed crops, in which case the seed harvest in the first year may be significantly reduced. Depending on the climate, seed harvests occur as early as May to as late as August. It is important to specify a date in the contract when seed will be delivered, especially if you plan on using the seed in the same year it is harvested.

History of Production Fields – Every field will have some amount of residue seeds from previous crops which will germinate along with the starter seed. Knowing the history of the fields during the planning stages helps determine whether these non-crop plants pose a problem for the seed production. Noxious weeds or undesirable non-native species are obviously a real concern, but many of these species can be roughed out of the seed beds prior to harvesting. Of more concern are fields where the same native species, but from a different seed source, were grown. For example, a field is being prepared for sowing California fescue (*Festuca californica*) from a seed source in the Blue Mountains of northeastern Oregon. The field had previously grown California fescue from a seedlot collected west of the Cascades. Since seed from the previous fescue crop would germinate in the same bed, the resulting crop would include both seedlots. Since the plants from these seedlots would appear almost identical, it would be impossible to weed out the plants that came from the previous crop. Even species in the same genera are difficult to distinguish by untrained weeders and cannot be weeded out of beds.

Fields that previously produced seed from the same or similar appearing species should be evaluated for the risk of seed contamination from previous seed crops. There are measures seed producers can take to reduce contamination risks. These include growing non-seed crops for several years between seed crops, rotating between grass and forb seed production (forb seed is easy to discern from grass seed), and fumigating between seed crops. These strategies must be discussed with the seed producers.

Location of Other Seedlots – Equally important to the history of seed production fields, is the location of adjacent seed crops of the same species. If seedlots of the same species are being grown close by, the risk of cross-pollination between crops increases and the genetic integrity of the proposed seed crop would potentially be compromised. There can even be cross-pollination between similar species. For example, blue wildrye (*Elymus glaucus*), bottlebrush squirreltail (*Elymus elymoides*), and bluebunch wheatgrass (*Pseudoroegneria spicata*) are known to cross-pollinate. Talk to a local botanist or geneticist about which species can potentially cross breed. Seed crops that can cross-pollinate should also be separated by a minimum isolation distance. Under most circumstances, the isolation distances should be in accordance with State Certification Standards (certified class). These standards can be found at the departments of agriculture for each state.

Irrigation System – Many native species must be grown under irrigation to meet the quantities of seed specified in the contract. Seed producers that have minimal or no irrigation capacity are often unlikely to meet seed production requirements and time frames. Only those species that do not require irrigation should be offered to growers lacking irrigation systems.

Culturing Practices – A review of the culturing practices, which include irrigation, fertilization, disease, and insect control, should be done to determine whether they are appropriate for the

Figure 10.67 – Seed harvesting equipment varies by seed producers and species being harvested. Discuss with the seed producer how each species will be harvested and see that equipment is cleaned between seedlots.

production of the species being grown. Culturing practices are often written up in propagation protocols that can be found at http://www.nativeplantnetwork.org.

Control Measures for Non-Target Species – Specific attention must be given to how weeds and other non-crop species will be controlled. Typical measures include 1) the use of herbicides prior to sowing and after the crop has been established, and 2) hand weeding of non-target species. The most important period of weed control is just prior to seed harvest because of the importance of eliminating potential non-target seed before seed harvest.

Seed Harvest Methods – Most seed harvests are carried out with specialized equipment that detaches seed from the stock, separates it from plant and soil debris, and collects it into storage containers (Figure 10.67). It is important to know the seed harvesting equipment that will be used for each species and how it will be cleaned between seedlot crops to prevent the possibility of seed contamination.

Species with indeterminate inflorescences (seeds that ripen on the seed stock all summer long) must be hand collected more than once in the summer. Periodic seed harvests of these species must be planned so that the full range of seed can be collected. The seed producer should address how these species will be harvested to obtain the maximum seed yield.

Seed Cleaning, Packaging, and Labeling – After seed is harvested, it must be dried and further cleaned. Seeds are air dried (Figure 10.68) or placed in a forced air drying system. Seeds are then extracted and cleaned. Awns and flower parts are removed and dirt, stems, and other debris are separated from the bulk seed. Understanding the cleaning operation is important because viable seeds can be damaged or discarded during this process.

Dry cleaned seed should be packaged in "breathable" woven poly bags at uniform weights. Industry standards are 25 or 50 lb bags. Bags of seed must be clearly identified (labeled by stencil or permanent marking pens, with characters at least 1 inch in size) with the Government's source seedlot identification. In addition, all bags should have an affixed tag stating the species name (scientific and common), seedlot identification, % germination, % purity (including other crop seed, weed seed, and noxious weeds), date of seed test, and seed producer's name. Additional labeling information may be requested, such as project name, National Forest or BLM office, or seed owner name.

Seed Testing and Acceptance – The contract must state the minimum acceptable standards for each species and seedlot. Acceptance and payment should be based on meeting the standards set for:

- Germination,
- Purity,
- Weeds, and
- Moisture content.

Seed testing is typically the responsibility of the contractor. Seed samples used for testing and contract performance must be taken by a certification agency representative or the contract inspector. Samples must be tested by a state certified seed laboratory (See Section 10.2.1.7). Seed test results must be identified by the seed source identification and task order number.

Figure 10.68 *– Seed is harvested and dried prior to cleaning and storage. This photograph shows a recently harvested seedlot in drying trays prior to being set on a forced air drier. Seed ID tags are attached to the side of each seed drying bin.*

Test results must be satisfactory to the Government before final acceptance of the seed is made.

Establishing minimum germination and purity rates can be based on averages obtained from commonly produced species shown in Table 10.14 or through discussion with seed extractory managers. The contract should address what actions the contractor can take to increase either germination or purity, if these rates fall below the standards. Lower purity rates can be accepted if seed will be used in a hydroseeder (See Section 10.3.2). A tetrazolium test (TZ) may be made in lieu of a germination test for a seed viability test depending on time constraints and species involved. All-State Noxious Weed examinations are required and if any of these species are present, then the seedlot is either rejected or recleaned. Seed moisture test must also be conducted and seed must not exceed 10% moisture.

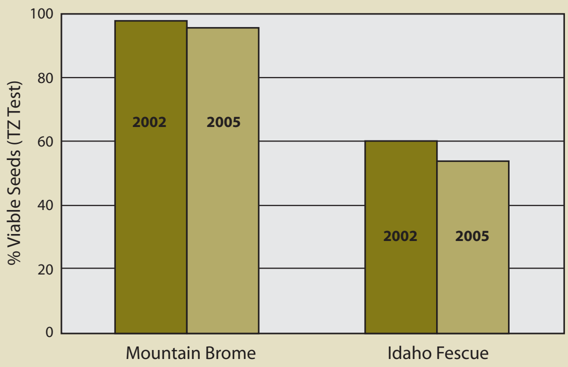
10.2.4.6 Administer Contract

Seed producers are required to maintain adequate records to allow the Government to monitor contract progress. Records should include information and dates of field preparation, seed sowing, field treatments, fertilization, seed harvest, cleaning, storage, seed yields, and any other activity relating to seed production. It is a good practice to make contact either by phone or by visiting the seed producers two to three times a year to go over the progress of the contract. The best time of year for field visits is just prior to or during seed harvest. A visit or phone contact in fall is important to discuss the potential of keeping seedlots additional years. Unless it is stated in the contract, seedlots are likely to be plowed under once the seed orders have been met. Visiting in the late summer or fall is also a good time to observe the seed extraction and cleaning processes.

During these visits, it is important to note the condition of the seedlots and how they are being identified throughout the process; are there clear labels stating the seedlot identification in the

Figure 10.69 *– It is important to visit seed producers to assess isolation distances, noxious weeds, culturing practices (e.g., irrigation, fertilization), and expected seed yields. The best period to visit is during seed ripening and seed harvest.*

Figure 10.70 – *Properly cleaned, packaged, and dried seed can remain viable for many years under acceptable granary storage conditions. Seed germination for two Umatilla National Forest seedlots did not significantly decrease in storage after three years as shown in this graph (Riley 2006).*



field, during drying, extraction, and storage? Are seed harvest and extraction equipment being thoroughly cleaned between seedlots or are there remnant seeds remaining in the equipment that can contaminate the next seedlot being processed? Note the condition of the fields prior to seed harvest; are the fields weedy and will there be a final weeding before harvest? Are seeds being handled with care or are they roughly handled?

A good working relationship with the seed producer is essential in meeting the overall seed increase objectives. It should be realized that some factors, such as weather, are beyond the control of seed producers, and on some years seed harvests will fall short of the minimum amounts stated in the contract. Good communications with the seed producer will alert you to crop failures or fall down in orders as soon as they occur so that alternative measures can be taken. An inventory of the number of acres in each seedlot and the condition of the crop should be supplied by the contractor upon request.

10.2.4.7 Store Seed

Seeds can remain viable in storage for many years after harvest. How well seeds keep depends on the moisture content of the seed, the quality of the seed being stored, and the storage conditions (temperature and humidity). Riley (2006) found that there was minimal reduction of seed viability in granary storage after three years for mountain brome (*Bromus marginatus*) and Idaho fescue (*Festuca idahoensis*) (Figure 10.70). Seeds typically store poorly when seed quality is low or seed moisture content is above 10 percent. If seedlots are stored for more than a couple of years, it is important to periodically test the seed for germination.

Granary Storage – Most seedlots are stored for short periods of time before they are used on projects (usually less than five years). For this reason, granary storage is the most common and economical form of seed storage. Granary storage unit are enclosed rooms sheltered from rainfall and temperature extremes. They are typically insulated and protected from rodent and insects. Many granary storage units are tree coolers that have been reconfigured for this use. While seedlots can store for long periods, low quality seed should be used first because it is more likely that this seed will loose viability in storage, than high quality seed.

Freezer Storage – Freezer storage is usually reserved for seedlots that will be stored for many years. Conifer and shrub seeds as well as forb and grass wild seed collections are usually stored under these conditions, whereas bulk grass and forb seeds typically are not.

10.2.5 NURSERY CUTTING PRODUCTION

10.2.5.1 Introduction

Obtaining cutting materials in the wild for restoration and bioengineering applications can be a difficult and expensive task, especially if populations of parent material are small or access is limited. Native plant nurseries can be an alternative source of a variety of woody cuttings. Understanding how nurseries establish and manage “stooling beds” can be a great help to revegetation specialists and project engineers.

10.2.5.2 What are Stooling Beds?

"Mother plants" are established in nurseries for the sole purpose of providing a ready source of cuttings. Stooling beds are hedge-like rows of mother plants that are established in bareroot nurseries or in vacant fields adjacent to container nurseries (Figure 10.71A).

Stooling beds take advantage of the ability of many broadleaved woody plants to sprout profusely from the base after being cut off just above the root crown. Plants remain in the juvenile state, which means they have a higher tendency to sprout and produce roots. Once stooling beds are established, annual cutting ensures that juvenility can be prolonged indefinitely.

Stooling beds allow the efficient collection of dormant hardwood cuttings during the winter when it may be difficult or impossible to make field collections (Figure 10.71B). Because they are located at nurseries, the beds can be irrigated and cultured; processing and storing the cuttings is also much more efficient and cost-effective. Stooling beds have several advantages over wild collected cuttings.

Maintaining Genetic and Sexual Diversity – It is much easier to correctly identify different plant species and ecotypes from labeled stooling beds as compared to wild collections. For example, willows often grow together along streams and can be difficult to identify during the winter dormant season. Stooling beds offer the ability to produce a large number of cuttings of unique species or ecotypes quickly and easily.

Many government nurseries have established stooling beds of the species and ecotypes that are adapted to their local area and can thus be a potential source of cutting material for private growers or revegetation specialists. Private native plant nurseries are also establishing stooling beds of desirable species for their local areas, and several are specializing in riparian and wetland species. For specific revegetation projects, however, the odds of a nursery having existing stooling beds of the proper species and local ecotype are low. Therefore, collecting cuttings and establishing stooling beds should be done early in the planning process so a good supply of cuttings will be available when needed.

Some plants, such as willows and cottonwoods, are either male or female, which can create a serious problem in restoration (Landis and others 2003). If a balanced mixture of male and female plants is not collected from the project site, the resultant stooling beds will not produce both male and female cuttings. When working with dioecious plants, the sexual identity of potential mother plants must be determined prior to collection (See Section 10.2.2, Collecting Wild Cuttings).

Producing Healthy and Vigorous Cuttings – One of the most practical advantages of establishing stooling beds in nurseries is that the cuttings are often healthier and more vigorous than those collected from the project site. Willows are host to many insects and fungal pests, such as galls and cankers (Figure 10.72). They are also subject to animal browsing.

Figure 10.71 – *Stooling beds (A) are an efficient way of ensuring that a ready supply of hardwood cuttings of the proper species and source are available (B).*

These factors can significantly lower the quality of wild-collected cuttings. For example, on a riparian restoration project in Idaho, cuttings were collected from heavily browsed willows on the project site and then planted in nursery beds to produce rooted cuttings. The yield of shippable plants was low and these wild-collected cuttings rooted poorly (<50%) when outplanted. These failures increased production costs and threatened the project's replanting schedule. Subsequently, about 150 rooted cuttings from the first nursery crop were used to start a stooling bed. The following year, harvesting just half of the stooling bed yielded more than 6,000 healthy cuttings. Cuttings from the stooling beds rooted at over 99%, thereby lowering establishment costs and keeping the project on schedule (Dumroese and others 1998).

Reducing Costs – It might seem that collecting cuttings in the wild would be the least expensive means of obtaining cutting materials. This is not necessarily the case. Inefficiencies of driving to remote locations, pulling cutting materials to road ways, using make-shift cutting practices, and working under severe winter conditions all add up to high costs per cutting.

10.2.5.3 Select Species Suitable for Stooling Beds

Poplars, cottonwoods, and willows are the species most often used in stooling beds. It should not be assumed, however, that all species of the willow family are good candidates for stooling beds. Some species have growth characteristics that reduce their potential. For example, trials at the Colorado State Forest Service Nursery in Fort Collins have shown that narrowleaf cottonwood (*Populus angustifolia*) and narrowleaf willow (*Salix exigua*) do not "stool" well and must be propagated by other methods (Grubb 2007).

There is great potential for using other woody species that have the propensity to sprout and form roots easily. For example, redosier dogwood (*Cornus sericea*) is commonly grown in stooling blocks and used as a source of cuttings for restoration sites. Outplanting success is higher than with wild cuttings collected on the project site, and has ranged from 50% to 90% (Hoag 2007). In North Dakota, twinberry honeysuckle (*Lonicera involucrata*) is being investigated (Morgenson 2007). Native species that root easily from hardwood cuttings have the potential to be grown in stooling beds to generate cuttings. Species that have inherent deep seed dormancy characteristics, such as snowberry, honeysuckle, elderberry, and some species of currants, could be more easily propagated in the nursery using stooling beds than sowing seeds to produce

Figure 10.72 – *Stooling beds can be cultured to prevent the occurrence of insect galls (A) and fungus cankers, such as* Cytospora *spp (B).*

Table 10.15 – *Native woody plants of the Pacific Northwest with potential for propagation in stooling beds.*

Plant Species		Rooting Ability	Growth Rate	Establishment Success (1 = Poor, 5 = Good)
Scientific Name	**Common Name**			
Baccharis pilularis	Coyotebrush	Fair to Good	Moderate	3
Cornus sericea	Redosier dogwood	Good	Fast	3
Oemleria cerasiformis	Indian plum	Poor to Good	Moderate	1
Physocarpus capitatus	Pacific ninebark	Good to Very Good	Moderate to Fast	4
Philadelphus lewisii	Lewis' mock orange	Fair	Moderate	1
Populus trichocarpa	Black cottonwood	Fair to Very Good	Very Fast	3
Rosa woodsii	Woods' rose	Poor to Fair	Moderate to Fast	1
Salix amygdaloides	Peachleaf willow	Excellent	Very fast	5
Salix exigua	Narrowleaf willow	Very Good	Fast	4
Salix lasiolepis	Arroyo willow	Excellent	Very Fast	5
Salix scouleriana	Scouler's willow	Good to Very Good	Very Fast	4
Spiraea douglasii	Rose spirea	Very Good	Fast	4
Symphoricarpos albus	Common snowberry	Very Good	Fast	4

* = modified from Crowder and Darris (1999)

seedlings. Species that have consistently low seed viability, such as mock orange and ninebark (*Physocarpus* spp.), may also be produced more economically in stooling beds.

The Plant Materials Centers of the USDA Natural Resources Conservation Service identified the potential of a wide variety of woody native plants that would be suitable for stooling beds (Table 10.15). For example, Crowder and Darris (1999) discuss which plants are suitable in the Pacific Northwest and provide a wealth of information on the installation and culture of stooling beds.

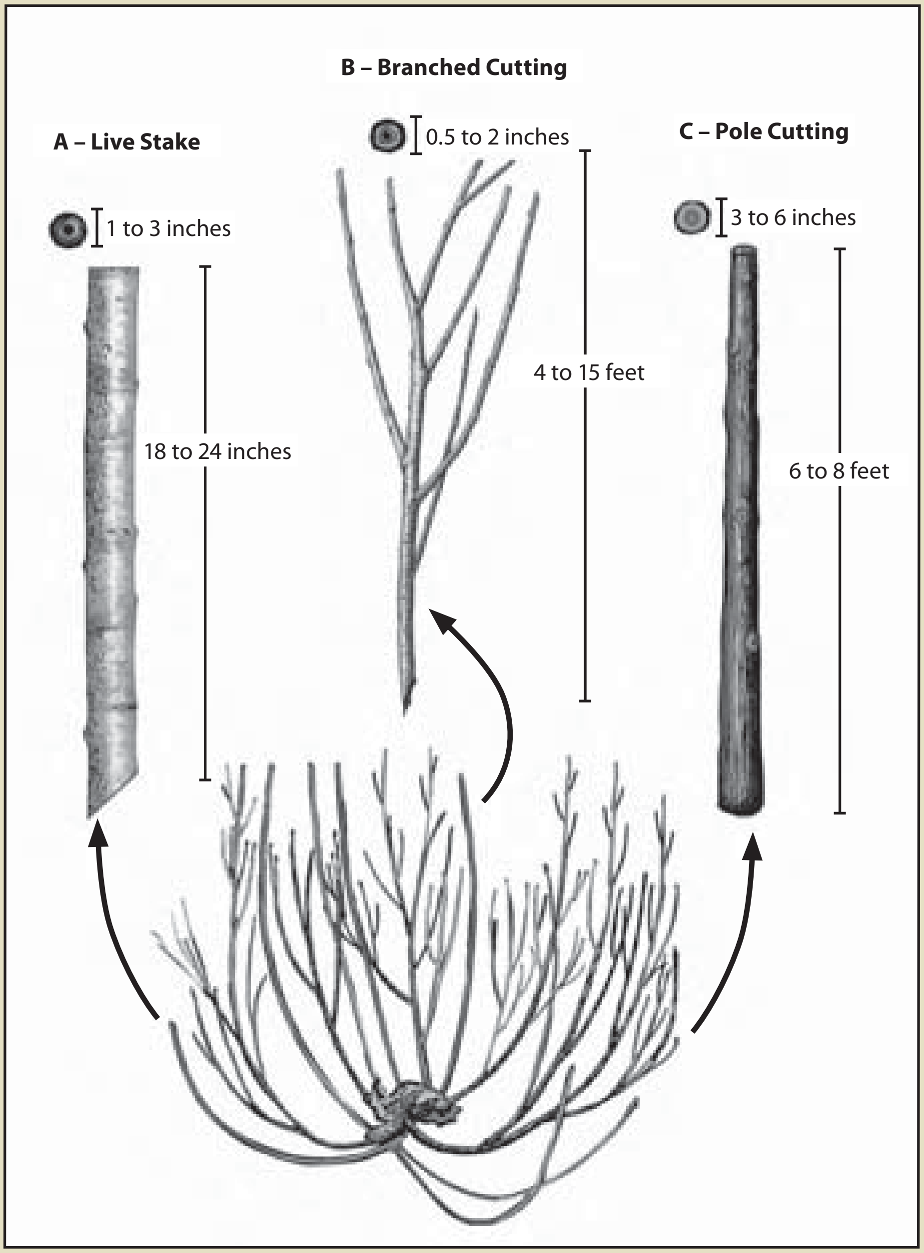
Darris (2002) performed extensive greenhouse and field trials to test the potential of several woody plants for live stake applications. Common snowberry (*Symphoricarpos albus*), salmonberry (*Rubus spectabilis*), Pacific ninebark (*Physocarpus capitatus*), and twinberry honeysuckle (*Lonicera involucrata*) have proven to be effective as live stakes for soil bioengineering in the Pacific Northwest. Notably, several have proven to be superior to willow on some sites, such as salmonberry in wet, shaded environments and snowberry on drier, exposed locations.

10.2.5.4 Select the Type of Cutting Material

Several different types of cutting materials can be collected from stooling beds. Nurseries use small propagation cuttings to start their own bareroot or container plants. Stooling beds can also provide several types of unrooted cuttings used in restoration (Figure 10.73).

Live Stakes **–** Live stakes are so named because, in addition to providing stability on restoration sites, they are expected to root and sprout after installation (See Section 10.3.3.2, Live Stakes). Because they are often pounded into the ground, live stakes are cut from relatively straight

Figure 10.73 – *Several types of hardwood cuttings can be obtained from stooling beds, including cuttings for propagation at the nursery or live stakes and branched cuttings for restoration projects. Note that larger plant materials require extra time to produce.*



sections of second- or third-year wood. Live stakes are typically 18 to 24 inches in length and from 1 to 3 inches in diameter (Figure 10.73A). Depending on the plant species, it can take 2 to 4 years for a stooling bed to produce large enough branches for live stakes. Some of the smaller willow species will never grow large enough.

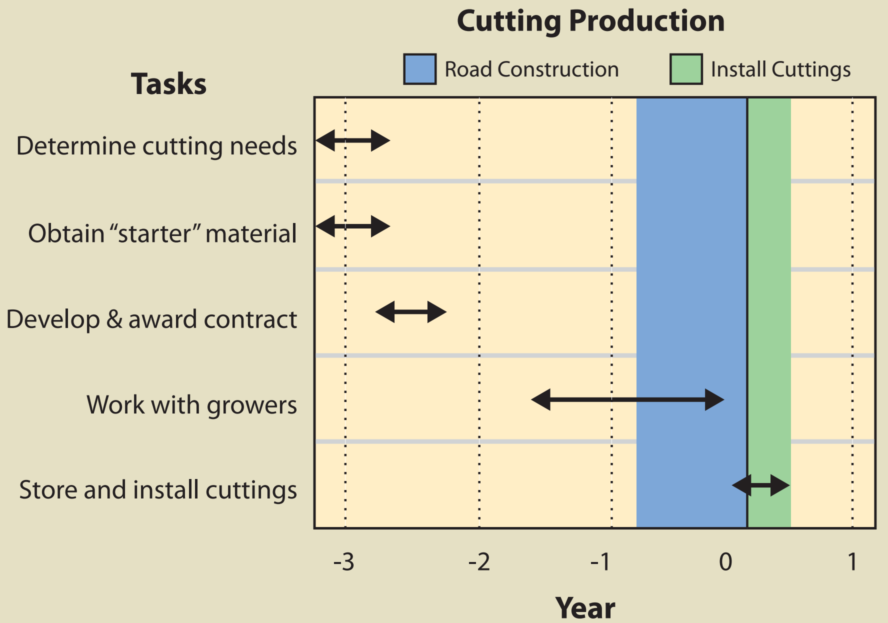
Branched Cuttings – Bioengineering practices, such as live fascines, vertical bundles, brush layers, and pole drains (See Section 10.3.3.3, Live Brush Layers and Section 10.3.3.4, Live Fascines) require a large number of branched hardwood cuttings (Hoag and Landis 2001). The size of this material ranges from 0.5 to 2 inches in stem diameter and 4 to 15 feet in length (Figure 10.73B). Stooling beds may take 2 or more years to produce significant numbers of harvestable branched cuttings.

Pole Cuttings – Pole cuttings (Figure 10.73C) are large diameter (3- to 6-inch) main stems that have all side branches with the top 1 to 2 feet of stem removed. They are used in restoration projects where stability is a main concern. Because of the large size of the plant material necessary for pole cuttings, nursery stooling beds are ideal. Larger trees, such as cottonwoods and tree-sized willows (e.g., Goodding's willow [*Salix gooddingii*]), have primarily been used for pole cuttings. Other large woody plants with the potential to sprout may also prove to be viable material (Dreesen and Harrington 1997).

10.2.5.5 Develop Timeline

Obtaining cutting materials from established stooling beds takes between 1 and 5 years, depending on the type of material. A minimum of one year is necessary to produce branched cuttings; 2 to 4 years to produce live stakes; and pole cutting may require over 4 years (Figure 10.74). In the planning stages of the revegetation project, the number, type, and species of cuttings needed for the project must be determined. Procedures for making these calculations are outlined in Section 10.2.2.6, Determine Cutting Needs. Nurseries or government facilities that specialize in stooling bed production must be contacted to see if they will establish stooling beds for your project. The managers of these facilities will inform you of costs and the time frame for meeting your orders. While there will be some cutting materials produced in the first year, full production of stooling beds does not happen until several years after installation.

Figure 10.74 – *Obtaining cutting materials from stooling beds can take up to four years, depending on the type of material requested. Branched cuttings can be obtained from stooling beds after the first growing season, while live stakes can take from 2 to 4 years. Pole cuttings can take even longer. The following is a timeline for producing branched cuttings and some smaller live stakes. Add several years for large stakes and some poles.*



Most stooling beds are started from cuttings taken from the wild. The sources of starter material must be located in the field during the summer or fall prior to installation of the beds. The sexual identity of dioecious plants must be determined during the appropriate season prior to collection. Section 10.2.2.3, Locate Cutting Areas, gives an outline of the steps necessary to obtain starter material. The nursery managers will tell you the number of feet of starter material, the quality of the wild collections (age, size, condition), and packaging and shipping methods necessary to meet the order. Wild cuttings are collected when the leaves are off the plants. Depending on the climate of the site, collections can begin in mid to late fall and end from late winter to mid spring. Wild cuttings are usually sent immediately to the nursery where they are prepared for installing in stooling beds. Most stooling beds are started directly from cuttings that are stuck in the spring. Cuttings root quickly in the spring and, with irrigation and fertilization, grow into large plants by the end of the summer. The following winter, the beds are ready for harvest. Since stooling beds are relatively uniform, the material can be harvested and processed in a production-oriented manner. Cutting materials are cut to your specifications and stored in either freezer or cold storage facilities until you request delivery.

Developing stooling beds is a long-term investment. While they often take several years to fully establish, stooling beds can remain productive for many years depending on species, ecotype, nursery cultural practices, and pest management. For cottonwoods, stooling beds typically remain productive for 4 to 8 years, after which vigor and productivity start to decline. However, other nurseries have maintained stooling beds of willow and cottonwood for 12 to 15 years without decreases in vigor. *Cytospora* canker, caused by fungi of the genus *Cytospora* spp (Figure 10.72B), is a particularly serious pest of all *Salicaceae* and, because it is transmitted and thrives in wounded stem tissue, can ruin a productive stooling bed. The productivity and longevity of a stooling bed is a direct function of the amount of care given them. Since stooling beds are an investment with long-term payoffs, finding local partners (watershed councils, Forest Service, BLM, state and county land managers), who can utilize these beds after the needs of your project have been met can be a service to the local community.

10.2.6 NURSERY PLANT PRODUCTION

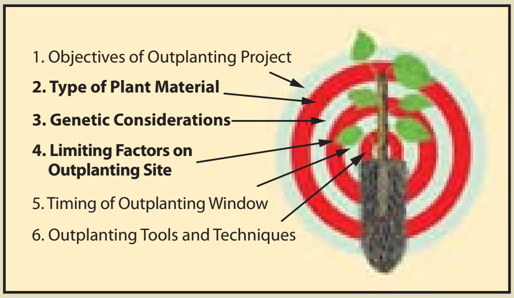
10.2.6.1 Introduction

Woody plants are critically important because they quickly provide vertical structure and aesthetic relief on roadside revegetation projects. When planted within areas seeded with grasses and forbs, trees and shrubs provide the essential matrix of a successful revegetation project. Direct seeding is rarely used to establish woody plants on restoration projects because they are often slow to germinate and take several years to become established. Depending on site characteristics, many sizes of nursery stock can be used, but large plants are favored by revegetation specialists because they establish quickly and dominate the site. Their physical size and deep roots allow them to quickly access deep soil moisture, and their expansive root systems help stabilize soils. In addition to providing wind protection and shade to lower growing vegetation, trees and large shrubs provide habitat for insects, birds, and other animals and can greatly accelerate the development of a sustainable plant community.

Grasses and forbs establish quickly and easily from seeds, so they are not commonly grown in nurseries. However, nursery stock is warranted under certain circumstances:

- Sufficient quantities of grass and forb seeds are rare or hard to collect.
- Increasing grass and forb seeds by seed growers is difficult or excessively expensive.

***Figure 10.75** – Steps 2 through 4 of the Target Plant Concept are very useful when ordering nursery stock (adapted from Landis and Dumroese 2006).*



- Establishing grasses and forbs is difficult on some sites.
- Restoring threatened or sensitive species is a high priority.
- Nursery stock is more effective in restoring wetlands.
- Installing nursery stock is the best and fastest way to achieve a desired plant composition.
- Aggressive weeds are a serious problem.

This guide outlines the steps needed to obtain quality seedlings, transplants, or rooted cuttings from native plant nurseries. Typically, it takes one to two years to grow nursery plants, so the revegetation specialist must develop growing contracts and establish timelines several years in advance.

10.2.6.2 The Target Plant Approach

The target plant concept (Figure 10.75) is one method to optimize the use of native plant materials to ensure successful revegetation of the site. The first two steps in the process were covered during planning (See Section 6.4). Consideration of the plant material that would best meet the project objectives for a given site may lead to the decision to use nursery stock. Nursery stocktype, genetic considerations, and site factors limiting to plant establishment must then be discussed prior to ordering nursery plant materials. These 3 topics will be covered in detail in the following sections. Outplanting windows and outplanting techniques will be discussed in Section 10.3.4, Installing Plants.

Stocktype **–** The term "stocktype" refers to the various products that a native plant nursery can provide (Inset 10.17). In a broad sense, it includes seeds, which are discussed in Section 10.2.4. The oldest nursery stocktypes are bareroot seedlings and transplants. However, container plants are usually most suitable for roadside revegetation projects. Container nurseries are currently producing a wide variety of stocktypes that include seedlings, transplants, and rooted cuttings. Although project objectives and planting site characteristics should be primary considerations, the choice of container stocktype is more often defined by price. The price of container stock is based on the cost of materials and, more important, nursery production space and time. A unit area of greenhouse bench space or outdoor growing compound is a fixed cost, but the number of months or years to grow the plants to shippable size add to the stock price. Although selling prices for each container stocktype are set by tradition and market factors, older and larger plants will cost more.

Genetic Considerations **–** Genetics are a key factor in the target plant concept (Figure 10.75), and two factors must be considered: local adaptation, and genetic and sexual diversity.

"Seed source" is an idea familiar to all foresters and restoration specialists. Plants are adapted to local conditions. If native species can be propagated from seeds, these seeds should always be collected within the local "seed zone." The seed zone is a three-dimensional geographic area that is relatively similar in climate and soil type.

Inset 10.17 – Native Plant Nurseries Produce Two Main Stocktypes

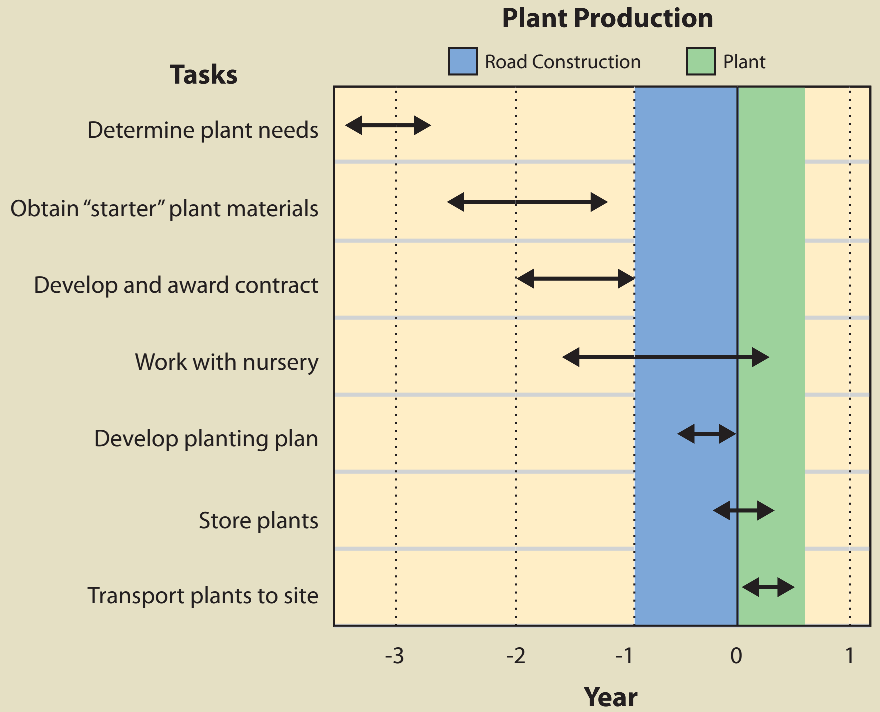
Bareroot stock is grown in native soil in open fields and harvested without soil around the roots. Because of the added care needed and increased potential for transplant shock on highly disturbed sites, bareroot plants are not usually recommended for roadside revegetation.

Container stock is grown in artificial growing media in a controlled environment, such as a greenhouse, and their root systems form cohesive plugs when harvested.

Nursery-grown plants are grown as:

- ***Seedlings*** are plants started from seeds.
- ***Rooted cuttings*** are plants grown from vegetative cuttings.
- ***Transplants*** have been physically removed from the seedbed or container and replanted in a transplant bed or larger container for additional growth.

Figure 10.76 – *Obtaining nursery-grown plants often requires two to three years of advance planning. This timeline can be shorted by up to a year if "starter" plant materials, like willow cuttings or seedlings for transplanting, are available. Certain woody plants require long seed treatments or grow slowly so timetables must be adjusted accordingly.*



Seed source affects plant establishment through growth rate and cold tolerance. In general, plants grown from seeds collected from higher latitudes or elevations will grow slower but tend to be more cold hardy during the winter than those grown from seeds from lower elevations or more southern latitudes (St Clair and Johnson 2003). The majority of seed zone research has focused on conifers in the Pacific Northwest. The same concepts can apply to other native species. Nurseries sow and culture plants according to seed zones. It would therefore be prudent to use nursery seedlings or cuttings from the same geographic zone and elevation in which it will be outplanted.

Target plants should also represent the genetic and sexual diversity present on the outplanting site. To maximize genetic diversity in the nursery plants, seeds and cuttings should be collected from as many different plants as possible. Cuttings must be collected near the outplanting site to assure they are properly adapted. Additional considerations are necessary for dioecious plants, such as *Salix* spp. and *Populus* spp., because all progeny produced by vegetative propagation will have the same sex as the source plant. Therefore, when collecting cuttings at the project site, care must be taken to ensure that male and female plants are equally represented.

Of course, collecting costs must be kept within reason, so the number of seeds or cuttings collected must be a compromise. Guinon (1993) provides an excellent discussion of all factors involved in preserving biodiversity when collecting seeds or cuttings, and suggests a general guideline of 50 to 100 donor plants.

Site Limiting Factors – The fourth aspect of the target plant concept (Figure 10.75) is based on the ecological "principle of limiting factors," which states that any biological process will be limited by that factor present in the least amount. Each planting site must be evaluated to identify the environmental factors most limiting to plant survival and growth (See Chapter 5) as this information is critical to deciding on the proper nursery stocktype. Large container trees with a deep root system typically survive better and establish faster, but woody shrubs and other plants in smaller containers can fill other needs.

Restoration sites pose interesting challenges when evaluating limiting factors. Road construction or decommission typically creates compacted soils that have been severely altered in texture, stability, nutrient status, and so on from their natural state.

In addition to challenging physical soil characteristics, the biological component of roadside planting sites has been severely altered or even destroyed. A variety of mitigating measures may be necessary prior to outplanting. Beneficial soil microorganisms, such as mycorrhizal fungi and nitrogen-fixing bacteria, provide their host plants with many benefits including better water and mineral nutrient uptake. Plants destined for these sites should be inoculated with the appropriate symbiont before outplanting (See Section 10.1.7 for a complete discussion).

10.2.6.3 Develop Timelines

Obtaining some nursery stocktypes can take a considerable amount of lead time and planning. Although most native plant nurseries carry a wide variety of species, it is unlikely they would have plants that are genetically suitable for a specific project. Therefore, "source-identified" native plants must usually be grown by contract. The large nursery stocktypes that will survive and grow on challenging restoration sites typically require several years (Figure 10.76). It is therefore necessary to develop contracts that will assure that the correct genetic material is being propagated and that the resulting plants are of the highest quality that will survive and grow when planted on the revegetation site.

Project plant needs are determined early in the revegetation planning stages, including the number of plants, types of species, and size of plants. From the list of species, seed sources or "starter" plant material sources are located from suppliers or collected in the wild. This can typically take at least a year. Several years before the construction site is ready for planting, a contract for growing plants is developed and awarded. Once awarded, seeds and "starter" plant materials are sent to the nursery so that sowing, transplanting, or sticking can begin promptly.

The growing time for large container stock can extend from 1 to 2 years, depending on the species. The nursery will take a final seedling inventory during the middle of the final growing season. At this time, a planting plan can be developed. Road construction will be moving into its final stage and the planting plan can be tailored to specific on-site conditions. Including lifting, storage, and transporting plant materials, the whole process, from start to finish, takes two to three years.

***Figure 10.77** – A spreadsheet can be used to determine how many plants must be ordered for each species. Each revegetation unit should have separate calculations, since the units will have different survival rates, species mixes, and plant spacing.*

A	Planting area:	0.75	acre	Area that will be planted
B	Target plant spacing:	8	feet	Desired distance between established plants
C	Avg. survival potential:	75	%	Percent of seedlings that survive after one growing season
D	(A * 43,560) / (B * B) =	510	plants	Desired number of established plants after one growing season
E	D * (100 / C) =	681	plants	Number of nursery plants that need to be planted
	Species Mix			
F	Ponderosa pine (PIPO)	50	%	Percent of total established plants composed of PIPO
G	Quaking aspen (POTR5)	30	%	Percent of total established plants composed of POTR5
H	Serviceberry (AMAL2)	20	%	Percent of total established plants composed of AMAL2
I	E * F / 100 =	340	plants	Number of PIPO to order
J	E * G / 100 =	204	plants	Number of POTR5 to order
K	E * H / 100 =	136	plants	Number of AMAL2 to order

10.2.6.4 Determine Plant Needs

Early in the planning stages, a general idea of plant needs is developed based on the desired future condition for each revegetation unit. The information required to determine the quantities for each revegetation unit includes:

- Area to plant,
- Plant spacing (density),
- Survival potential, and
- Species mix.

Using calculations similar to those presented in Figure 10.77, an estimate of the number of seedlings to order from nurseries can be determined. Calculations should be performed for each revegetation unit, since species mix, plant spacing, and survival will change considerably between units.

Planting Area **–** Summarize the acreage of all planting areas within each revegetation unit.

Target Plant Spacing **–** The target plant spacing is the desired distance between established plants. The spacing or density of established plants is an estimate that should be based on the site productivity and project objectives. A review of the reference sites can be a guide to determining the densities and species mix a site will support. Be sure to note how the different plant species are naturally spaced on each reference site. Some grasses and forbs exhibit uniform spacing but many woody plants have a more random or clumped pattern (See Figure 10.119 in Section 10.3.4, Installing Plants, for more discussion).

For example, an undisturbed reference site description shows that an average density for an established stand of trees is 500 trees/ac, with a species mix of 80% ponderosa pine and 20% quaking aspen (Density can be converted to plant spacing by taking the square root of 43,560 divided by plants per acre).The selection of species often determines the planting densities. Shrubs, for instance, grow at much closer spacing than trees, and this should be taken into consideration when species mixes are determined for a revegetation unit.

Revegetation unit objectives often require higher plant densities than typically occur on reference sites. Quick visual screening as the overriding objective will require high-density planting. Selecting a higher plant density than typically occurs in the project area should be done with some projection of how the area will appear many years later. High-density planting can create overstocked stands of trees within ten or twenty years of planting (Figure 10.78). Overly dense stands often lead to stressed trees and high fire hazard conditions, and might require some thinning at a later in time.

Figure 10.78 **–** *Determining plant spacing should be based on short- and long-term objectives. Where the short-term objective is quick visual screening and site stabilization, high density plantings of 1,500 trees/ac (A) will produce the short-term desired outcome. These trees may need to be thinned to reduce competition to avoid creating an unhealthy stand of trees with a high fire risk. Reducing tree densities to 250 trees per acre will produce a mature stand of trees similar to (B). Planting at these lower densities will reduce the need for thinning, but tree cover will take longer to dominate the site.*

Survival Potential **–** The survival potential is an estimate of the percentage of planted seedlings that will survive and become established. There are many factors that determine how well nursery-grown plants will survive after outplanting. Factors that you can control include:

- Selection of appropriate species and seed source for the site,
- Quality of nursery plants,
- Appropriate storage and transportation conditions, and
- Care in stock handling and planting.

High rates of plant mortality are usually due to an oversight or neglect of one or more of these factors. Projects with high plant mortality are an indication of poor planning or implementation; in other words, you have missed the mark on one of these factors. However, aiming for 100% survival is often unreasonable because of the high associated costs. Most projects should aim for a plant establishment rate of 85% to 90%, but plan for 75%.

Species Mix **–** Good survival and establishment of plants fundamentally rests on selecting the most appropriate species from locally adapted seed sources. Selecting the species mix for each revegetation unit should be based on an evaluation of disturbed and undisturbed reference site descriptions, which includes an understanding of the site limiting factors that will affect plant survival.

10.2.6.5 Select Stocktypes

Plants are grown, or cultured, in a variety of ways – indoors or outdoors, in native soil or artificial media, for several months or up to several years. The nursery industry defines how a plant is grown and its size, or morphology, in groups called "stocktypes." Although there is no standard terminology for describing the variety of possible stocktypes (Landis and others 1993), individual stocktypes can be defined by:

- Propagation environment (bareroot or container),
- Years in the nursery, and
- Size or shape of the container for container stock.

Propagation Environment **–** Plants are grown either in containers (container) or in native soil in open fields (bareroot). Bareroot stocktypes are harvested and packaged without soil around the roots, whereas the root systems of container plants are held together in a plug of rooting media. In many cases, container seedlings can be planted at any time of the year if appropriate

Figure 10.79 *– Native plants have differing growth habits and rates, so it is important to match container size with species growth characteristics. Shaded blocks represent recommended container sizes for each species type in years 1, 2, and 3.*

Container Sizes		Years in Containers									
		1				2				3	
Cubic Inch	Gallon	Evergreen Trees	Deciduous Trees	Shrubs – fast growing	Shrubs – slow growing	Evergreen Trees	Deciduous Trees	Shrubs – fast growing	Shrubs – slow growing	Evergreen Trees	Shrubs – slow growing
10-20		■			■						
30	1/8	■	■	■					■		
60	1/4		■	■					■		
115	1/2		■	■		■			■		
230	1		■			■		■			■
460	2		■			■		■		■	■
925	4						■	■		■	

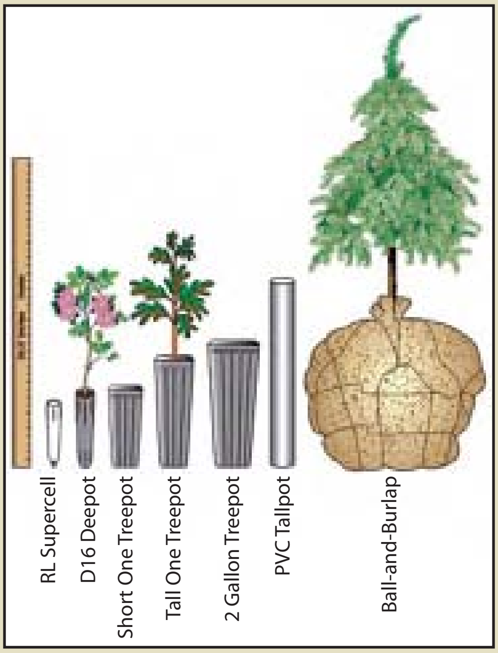
planting methods are used. Bareroot seedlings, on the other hand, are typically lifted in the winter months and held in storage for several months, limiting the planting window from early winter through later spring. Container plants can be grown in large pots for more than two years to very large sizes. Bareroot plants are limited to the depth of the growing beds, which is typically less than 12 inches. Depending on the species, bareroot plants can usually be held in beds for only 1 to 2 years. While container plants have many advantages over bareroots, bareroot seedlings are often much less expensive to purchase and plant. However, for most roadside revegetation sites, we recommend container stock.

Container Size – The size and age of a nursery-grown plant is controlled by the size of the container. Typically, the larger the container, the larger the plant and the longer it takes for roots to fill the container. In Figure 10.79, plants are grouped into broad categories based on how fast they typically fill out various container sizes. Many deciduous tree species, which include willows, cottonwood, maples, alders, and ash, tend to be very fast growing species and can fill out a range of container sizes in just one growing season. Conifer species (firs, pines, cedars, and hemlocks) will fill smaller containers the first year and can be transplanted into larger containers for another one or two growing seasons. Faster-growing shrub species (ceanothus, bitterbrush, mountain mahogany) are often grown in small containers in the spring and transplanted into larger containers several months later. They will fill a 1/8 to 1/2 gallon in one growing season. Slower growing shrub species must remain in the smaller cells for a full growing season before transplanting.

Container Design – Container shape is also an important consideration in stocktype selection because it determines how easily the root plug is extracted from a container, the degree of root spiraling, what planting methods are used, and ease of handling. The depth and taper of the container walls govern how easily a root plug can be extracted from its container. Generally, the greater the taper, the easier a root plug can be extracted from its container. Taper becomes more critical as container walls become longer with respect to the diameter of the opening. Straight-walled "tall pots," made from PVC pipe, are very long in comparison to the diameter of the opening. Root plugs from this container are difficult to extract without the placement of Vexar tubing inside the container. Pulling the Vexar tubing during extraction brings out the entire root plug without undue stress to the stem or root system. Other nurseries offer tall pots with the PVC pipe cut in half lengthwise and held together with electrical ties. Before planting, the ties are cut, which allows easy access to the root system.

Several container design features affect root development and plant quality. When plant roots grow out and hit the sides of the container, they often grow downward in a spiral pattern. When roots reach the bottom holes, they should "air prune." In poorly designed containers, the circling roots will eventually form a tight mesh which, after outplanting, can continue to circle and "strangle" the plant. Most containers have vertical ribs that guide roots down the sides of the container walls to prevent root spiraling. Some smaller containers feature copper coating on their walls to chemically prune the roots as they grow. Other container walls have vertical air slits which air prune the roots. When container roots are so cultured, the root system is more fibrous with more root tips.

Figure 10.80 – *Nurseries can produce plants in all shapes and sizes. The best stocktype for your project will depend on site conditions and time and method of planting.*



Root condition is a critical factor to discuss at the time that growing contracts are being developed. Roots that have excessive spiral growth must be pruned before they are planted (See Figure 10.128 in Section 10.3.4). This is most easily done at the nursery during harvesting. This extra processing step must be stipulated in the growing contract.

Matching Nursery Plants to Outplanting Site – A wide variety of nursery stocktypes are available (Figure 10.80). Site factors should be considered before placing an order. The depth and width of containers are very important for seedling survival and growth. Sites with low precipitation during spring, summer, and fall should be planted with larger container sizes. Where soil moisture-holding capacities are low or vegetative competition for soil moisture is high, long containers should be considered. Where rock content is high and it is hard to excavate a planting hole, shorter container stocktypes should be used. Additional post-planting care must be implemented to compensate for shorter roots (See Section 10.3.4). The planting method dictates the size of the root plug. For instance, the expandable stinger and power augers require plug diameters no greater less than 4 inches. Large seedling stems and tops are required where animal damage is expected.

Stocktype selection often determines seedling survival rates and how fast they grow in the first years after planting. Typically the larger the root system, the better the survival and growth. Larger stocktypes cost more, so it is important to target the stocktype to the needs of the site and revegetation objectives. For instance, if quick establishment of vegetation for visual screening is an important objective, then a large stocktype would be ordered. On the other hand, if a revegetation unit is relatively unseen and the site has few limitations to plant survival, a small, less expensive stocktype would be ordered. While larger stocktypes are generally more expensive than smaller stocktypes, the total costs of establishing seedlings should be considered before settling on a smaller plant. Costs for replanting a site where smaller seedlings died in the first year can be far more expensive than planting larger plants in the first place.

Years in the Nursery – Bareroot stocktypes are often defined by the years they are grown at the nursery, whereas container plants are typically described by the size of the container. This is important when ordering plants because many species take longer than one year to grow to the desired plant size. If plants are needed for a project within one year, the revegetation specialist will need to order smaller size containers to assure that the roots can fill the plug.

Unbalanced or Holdover Stock – A common mistake is growing container plants with tops larger than the root system can support. This is often the result of poor planning, delay of projects, or poor selection of stocktype. For example, road projects are frequently delayed for a year, leaving the revegetation specialist with the problem of what to do about the seedlings

Figure 10.81 *– The shoots of these pine seedlings have grown too large for the size of the root system which increases moisture stress after planting. In addition, the buds have broken dormancy, which means the plants will not tolerate rough handling (A). Poorly balanced or conditioned nursery stock will struggle to survive and grow after planting and exhibit signs of "transplant shock" (B).*

that are being grown. Typically under these circumstances the nursery manager is asked to hold the seedlings in the same containers an extra year. While most will comply, they will do it reluctantly. The result is plants that are "top heavy" – the shoots are too large for the root system to support (Figure 10.81A). The results are often deceiving. The plants have not shown stress because they have been pampered under greenhouse conditions and care. Yet, once seedlings are outplanted on a typical harsh site, it will be a struggle to grow enough roots to keep the tops healthy and alive. Plants respond to the lack of moisture in what is referred to as "transplant shock" (Figure 10.81B) by shutting down growth and often turning yellow or "chlorotic." Roadsides are stressful sites that require the very best quality plant material. A good example of the difference between well-balanced and poorly-balanced nursery stock is shown in Figure 10.82.

Delays are common in roadside projects, so two viable options can be considered: 1) transplant the stock into larger containers, 2) reject the plants and place a new order. Option one is appropriate if the plants are being grown in small containers and a larger container is available for transplanting. If you are growing plants in a large container, it makes little sense to transplant into a still larger one. This option is often more costly than option two, which is simply starting over with the order. But starting over assumes available seeds and other starter plant materials, and enough time to reorder. And what can be done with the plants that are not being used? You or the nursery manager can contact land managing agencies and landowners in the general geographic area to see if they are interested in these plants. If they are not, there are often watershed councils or environmental groups that would appreciate the donation for their projects.

10.2.6.6 Obtain Seeds or Other Starter Plant Materials

Nursery-grown plants begin from source-identified seeds or other "starter" plant materials (cuttings, smaller seedlings for transplants) that must be supplied at the beginning of the

***Figure 10.82 –** The ponderosa pine seedling in the photograph (A) was grown for four or five years at a nursery and outplanted on a semi-arid site. The photograph was taken one year after outplanting and shows the seedling has undergone transplant shock due to the imbalance, or high shoot to root ratio, of the seedling when it was planted. The seedling was root-bound when it was planted. The tree responded by dropping most of its nursery needles and grew very little in height in the first year. Photograph B shows a ponderosa pine seedling that was grown in a one-gallon container for one year, then outplanted. Because this seedling had good balance and was not root-bound, it did not undergo transplant shock after it was outplanted. After two years, this seedling is well established. The brackets in both A and B show the current year leader growth.*

contract (Figure 10.83). Since starter plant materials can take a year or more to obtain, it is important that these needs are identified early in planning, and collection contracts are put into place as soon as possible. Locally adapted seeds of some trees can take years to obtain because some species do not produce a crop every year. The benefits and drawbacks of each type of starter plant material are discussed below.

Seeds – Starting plants from seeds is usually the least expensive method of plant propagation and offers the greatest genetic diversity. The downside is that, for most species, seed propagation is slower than growing from cuttings or transplants. Crop production times will vary with species and nursery practices. Most woody plants take two to three years to grow into large plants from seeds and must be transplanted at least once. Other faster-growing species can reach shippable size in one growing season with good culture.

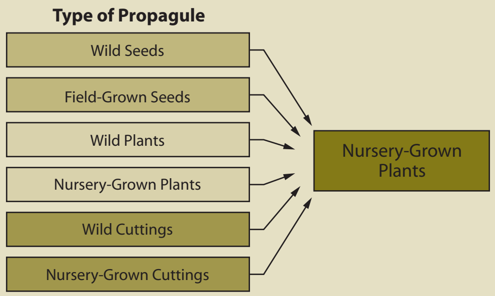
Seeds are either collected in the wild by seed collectors, or field-grown in an agricultural setting from tree and shrub seed orchards or from grass and forb seedbeds (See Section 10.2.4). Both wild-collected and field-grown seeds are sometimes available from federal seed extractories, federal nurseries, Forest Service district offices, or BLM resource areas. These agencies usually have tree seeds for most seed zones that cover federal lands, and often some selection of shrub, grass, and forb seeds are available. It is worth checking to see if these sources are available before you decide to collect seeds from the wild. Seed dealers do carry inventories, so be sure to inquire as to species and collection source. The single best resource for seeds or nursery stock is the Plant Materials Directory, which is published yearly as a special issue of the Native Plants Journal:

Indiana University Press
Journals Department
601 N Morton Street
Bloomington, IN 47404-3797
TEL: 800.842.6796
Website: http://www.nativeplantnetwork.org

Seeds obtained through federal facilities or seed dealers must report: 1) seed source – location of collection or seed zone; 2) year of collection; 3) seeds per pound; 4) % purity; 5) % germination, or tetrazolium (TZ) tests, from recent testing facilities; and 6) amount of noxious weed or other non-crop seeds. If seeds are not available through either of these sources, wild seed collection will be necessary. This can be done under the direction of district or forest botanist or by contract.

Once a plant production contract is awarded, nurseries will request information on each of the seedlots they will be sowing, including the latest purity and germination test results to determine the amount of pure live seeds. In addition, they will require the number of seeds per pound to calculate how many pounds of seeds from each seedlot will be needed to meet your order. They will also factor in the difficulty of growing each species, called the nursery factor, which will be different for each species, stocktype, and nursery. The nursery factor is a prediction of what percentage of seeds sown will become "shippable" seedlings, and considers losses during the growing season as well as those plants which are "culled" during harvesting. Nursery factors typically range from 30% to 50%, which means that they will need to sow 2 to 3 viable seeds for each plant they produce.

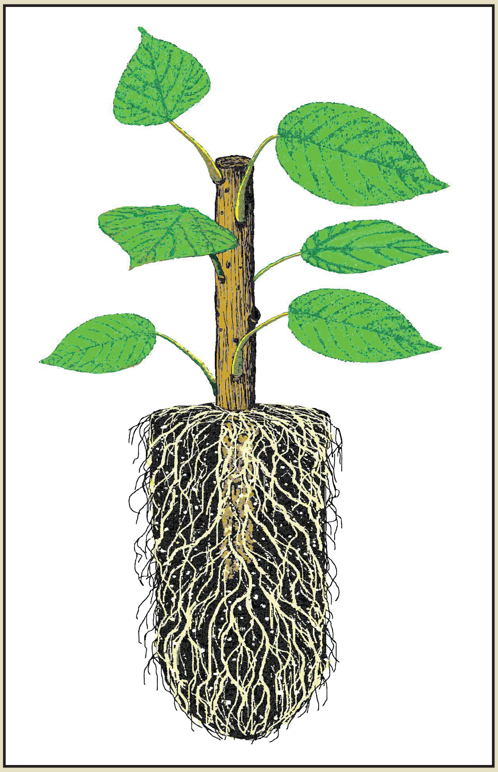
Figure 10.83 – *Nursery grown plants are propagated from source-identified seeds or other starter plant materials. Usually, seeds or starter materials must be secured prior to the award of a plant production contract.*



You can get a rough idea of how many seeds should be acquired by using the seed tests and a nursery factor of 30%. If the nursery requests significantly more seeds, then it is appropriate to inquire why more seeds are needed.

Starter Plants – Most large container stocktypes are started by moving smaller plants into larger containers

Figure 10.84 – Rooted cuttings are the quickest and easiest way to produce some woody plants, such as cottonwoods and willows.



or into bareroot growing beds. This practice is called transplanting, and it produces quality plants with large, fibrous, healthy root systems and large stems. Starter plants are typically grown from seeds or cuttings into small plants and then transplanted. In some cases, wildlings can be salvaged from the construction site and brought back to the nursery for transplanting. When ordering large containers, it should be specified that there will be at least one, and sometimes two, transplanting operations. Growing starter plants large enough for transplanting usually takes a year. They are then transplanted, usually in the spring or fall, and grown for another year or two. If seedlings or rooted cuttings are available from other sources, these can be sent directly to the nursery for transplanting, which would decrease production time by a year.

Rooted Cuttings – Rooted cuttings (Figure 10.84) can be shipped directly from the nursery for outplanting or serve as starter plant material for transplanting into larger containers. One big advantage of this stocktype is that cuttings can be collected each year, whereas seeds may be more difficult to procure. While cuttings of most species are derived from stems or branches, some species like, quaking aspen (*Populus tremuloides*) must be started from roots. Rooted cutting production is discussed in detail in Section 10.2.5.

10.2.6.7 Develop Growing Contract

All nurseries experience weather extremes, insect or disease losses, equipment failures, and other production problems that can severely decrease the quantity and quality of the stock. Therefore, it is a good strategy to reduce these inherent risks by growing plants at more than one nursery. In doing this, you will begin to see the strengths and weaknesses of each nursery. Future ordering can use this information to decide where to grow each species.

Nursery Selection – The western United States has an abundance of nurseries that grow native plants, but few will offer plants from source identified plant materials specific to your project. Obtaining genetically appropriate plants will require finding nurseries willing to grow seedlings from specified genetic material. A current list of native plant nurseries can be found in the Plant Materials Directory (See Section 10.2.6.6).

When considering a nursery for plant production, there are some basic factors to consider:

- ***Proximity.*** Is the nursery close enough to visit occasionally?
- ***Service.*** Is the staff easy to contact? Do they promptly return phone calls or e-mails? Are they friendly and helpful?
- ***Expertise.*** Are they knowledgeable in restoration and revegetation?
- ***Years in business.*** Has the nursery been in business for at least 3 years?
- ***Seedling quality.*** Is the overall seedling quality high?
- ***Seedling quantities.*** Are the orders regularly met or do they consistently run short?

- ***Price.*** Are prices competitive?
- ***Willingness.*** Will the nursery try new things?

If there are doubts about one or more of these factors, you might consider growing at another nursery. Ultimately, the selection comes down to personal experience with nurseries and word-of-mouth from other revegetation specialists.

Seedling Orders – A plant production contract must detail the information you have developed in previous sections of this chapter:

- Species,
- Genetic source,
- Starter plant material,
- Stocktype,
- Net amount of plants,
- Month and year for plant delivery,
- Minimum seedling specifications, and
- How they will be processed and stored.

A few phone calls to nurseries will give you some idea which ones will grow the species, stocktype, and quantities necessary for your project. Nurseries can still be utilized if they can only meet a portion of the order. Other nurseries can produce the remainder because there is less risk by sending plant orders to several nurseries. Contracts can be developed once you have some idea of what portions of an order a nursery can produce.

Plant Processing and Storage – Once seedlings have reached the target size and age at the nursery, they are harvested, stored, and processed for shipping. If the plants are bareroot seedlings, they are lifted from the soil, graded, and packaged. Container seedlings can be extracted from the containers, graded, and packaged, or sent to the planting site in containers and extracted immediately before planting. Either way, most stocktypes will be held at the nursery for one to six months, depending on when they are needed for planting. "Planting windows" are discussed in more detail in Section 10.3.4.

Storage times are longest for seedlings planted in the late winter and spring. For these orders, plants are extracted from their containers or lifted from the soil in the winter when they are least susceptible to the stress or damage associated with extraction, handling, and packaging. Plants in this condition are dormant. The onset of plant dormancy for deciduous plants is often around the time when plants have lost their leaves in late fall; the end of dormancy begins just before the buds begin to swell in the late winter to spring. The dormancy period for conifer species is not visibly discernible, but typically follows a similar time frame as deciduous species. Seedling dormancy in the western United States typically extends from December through February, but the dates will vary by nursery. If plants are to be extracted and held in cold storage for long periods, it is important to known when the nursery is extracting and handling the seedlings to be sure these operations are done when seedlings are dormant. Seedlings that are extracted or lifted outside the seedling dormancy period and stored for any length of time will survive and perform poorly.

When plants are lifted from bareroot beds or extracted from containers, they are also being graded for size and appearance. Unless otherwise agreed, the size specifications stated in the contract will be the grading criteria (Figure 10.85). It is good to be at the nursery during lifting/extraction and grading to see which seedlings are being thrown away and which seedlings are considered shippable. Bareroot and smaller container plants are graded and boxed for refrigerated or freezer storage. Storage containers will have important information about the plants, such as seedlot, date packed, client name, and the number of seedlings in the container. Plants are typically held in cooler storage (32 to 35 °F) from a few weeks to two months. If longer storage is required, freezer storage (28 to 31 °F) is recommended to maintain seedling quality and reduce the chance for storage molds.

Large container stocktypes (typically those equivalent to a half gallon or larger) are stored and transported in the containers in which they are grown. They are typically stored in shadehouses or other sheltered storage. In cold climates, the roots should be insulated to protect against

Inset 10.18 – Assessing Poor Quality Nursery Stock

Poor quality planting stock can be caused by biotic (e.g., diseases, insects) or abiotic factors (e.g., imbalance of soil moisture, temperature, nutrients, and pesticides) in the nursery resulting in detrimental, and sometimes devastating, effects on seedling survival and growth when outplanted. Infection with various pathogens, or biotic causes, may not necessarily be manifested in a nursery, but may cause stunting or mortality once seedlings are under stress following outplanting. Revegetation specialists should be aware of the possible nursery diseases in order to either recognize or discuss with nursery personnel during visits to inspect their seedlings.

Diseases caused by fungi, water molds, bacteria, and viruses can often be difficult to distinguish from damage caused by abiotic events or factors. If damage or chlorosis of seedlings is noted, it is recommended to check with the nursery manager to determine the history of the seedlings, what pathogens are traditionally a problem at the nursery, and what, if any, have occurred during the current growing season. Hamm and others (1990) and Landis and others (1990) provide more detailed information on nursery pests.

Shoot and foliage diseases can be caused by a variety of organisms, with various levels of impact on seedlings. Fusarium hypocotyl rot (caused by *Fusarium oxysporum*) can cause large losses in the nursery from July through October. Gray mold (caused by *Botrytis cinerea*) can cause significant damage to densely grown bareroot and container seedlings, as well as nursery stock stored in less than optimal conditions (Hamm and others 1990). The mycelium and gray spore clusters are often easily visible to the naked eye. Botrytis can girdle infected seedlings, increasing mortality rates following outplanting. Minor shoot and foliage diseases, such as shoot blight (caused a number of organisms including *Sirococcus* spp., *Phomopsis* spp., and *Phoma* spp).and needle-casts and other foliage diseases tend to deform or stunt seedlings, but do not result in significant mortality in the nursery or in an outplanting situation.

Root diseases may be the most insidious of nursery seedling diseases. Since seedlings are cultured under optimum conditions for growth, symptoms are often masked throughout the growing season, manifested only during outplanting stress or drought stress in succeeding years. Most conifers, and many native species, are susceptible to root diseases and root rots caused by *Phytophthora* spp., *Fusarium* spp., and *Cylindrocarpon* spp. These diseases will be manifested in the nursery in pockets of symptomatic seedlings or mortality, particularly in areas of poor drainage or previous infestation. Outplanting seedlings infected with these pathogens will result in reduced survival. In addition, transfer of these organisms to outplanting sites may result in infection of the planting area. This specifically is a problem with the root disease, *Phytophthora lateralis*. The spread of this disease from infected seedlings can devastate populations of established Port Orford cedar.

Not all seedling quality problems are caused by biotic factors – many are one-time damaging events that occur during a short time span with a regular distribution throughout the field or greenhouse (Mallams 2006). If foliage discoloration, foliage or stem wilting or die-back, seedling stunting, or mortality occur in large patches or over large areas in the nursery, the causes are often abiotic. Outplanting seedlings that have been stunted or damaged in the nursery can reduce seedling growth and survival, as well as increase the time required for site recovery. However, the symptoms of abiotic damage are often more apparent, and the consequences more easily predictable, than damage caused by pathogens.

Although restoration personnel have little to do with nursery cultural practices and disease mitigation in the nursery, several options exist to prevent or control disease problems on restoration sites. Disease mitigating measures are similar to insect mitigating measures: 1) only plant healthy stock because weakened or stressed seedlings are more susceptible to diseases both in the nursery and on the outplanting site, 2) plant a variety of species to avoid outplanting failure due to infestation of any single disease, 3) create a healthy soil environment – seedlings grown on poor sites or on sites outside of the species environmental ranges will be placed under stress and more susceptible to disease infection.

cold injury. During unseasonably warm periods during the late winter or early spring, large container stock should be monitored for drying and irrigated if necessary.

***Grading Specifications* –** There are no nursery-wide minimum nursery standards for the size and appearance of nursery grown plants because of the wide variety of ages, stocktypes, and growth patterns of native species. Nevertheless, you must establish some criteria for accepting or rejecting plants or you might be receiving marginal plants. Being present at the time of packing is the most effective way to negotiate grading standards with the nursery and assure that you receive quality plants.

Typical grading standards fall into the following categories (Figure 10.85):

Stem diameter at root collar ("caliper") – Stem caliper is the single most important morphological measure of nursery plant quality and has been consistently correlated with outplanting survival and growth. Diameter is not necessarily a good measurement for rooted cuttings since the size of the stem is dependent on the original diameter of the cutting. A typical grading specification for many bareroot and container stocktypes is a minimum diameter of 3.5 to 4.0 mm for one-year-old seedlings, and greater than 4.0 mm for plants grown for two years. Discuss these specifications with the nursery, since not all species will grow to these sizes in this time frame.

Shoot height – The height of the plant is measured from the root collar, or original ground line, to the top of the terminal bud. Some species do not form a terminal bud, so the swollen meristem tip or even the average top of the crown is used.

***Root system* –** The root system of the plant should be examined carefully. For bareroot stock, the roots should be well developed and fibrous and approximately the same area as the crown. For container stock, the root "plug" must be firm but not too root-bound. If the roots have spiraled and formed a tight mass at the bottom of the plugs, they should be trimmed during harvesting.

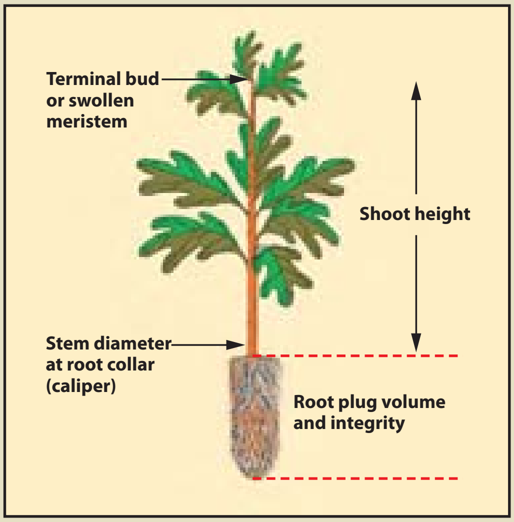
Seedling Balance – Nursery stock should have a good ratio between the amount of foliage and the root system. This is traditionally expressed as a shoot-to-root ratio (S:R), and typically ranges from one or two part shoots to one part roots (an S:R from 1:1 to 2:1). This grading standard is a qualitative determination to whether the root system is large enough to support the above-ground portion of the plant.

General plant health – During grading, nursery stock should be inspected for physical injury or disease. Root disease is a particular hazard of container stock, and soft or moldy roots should be suspect. Scraping the roots with the blade of a knife should reveal white healthy tissue.

10.2.6.8 Administer Contract

The nursery manager should be required to maintain records on how the plants were cultured. The basic information should include: date plants were started; the type, rates, and timing of fertilizer applications; irrigation schedules; greenhouse settings (temperature, lighting,

***Figure 10.85** – Grading criteria for seedlings are based primarily on stem diameter, height, terminal bud, root volume, and integrity.*



humidity); pesticide applications; and any significant problems that might have occurred with the seedlot. The nursery is also required to give an accounting, or inventory, of your plant orders by late summer.

It is important to visit nurseries at least once a year, but more often is better. These visits will give you an indication of the quality of the stock you will be receiving and whether the number of seedlings you ordered is being met. It also helps strengthen the relationship between you and the nursery manager, which often leads to more attention being given to your orders. One of the best times to visit is during the initial plant establishment phase, which is during the late spring or early summer after seeds have germinated or seedlings and cuttings have been planted. If there are stock problems, they are most likely to be observed at this time. If for some reason there is a fall-down in the inventory or the seedlings look unhealthy at this time, you have an opportunity to discuss it with the nursery manager. If caught early enough, there can be time to start more plants. At the minimum, identifying problems early will give you time to adjust your planting plans as well as adjust other contracts that depend on the plant inventory.

Another good time to visit is during the processing of plants for storage or shipment. Your presence at this time helps the nursery manager with questions that might arise about grading specifications, packaging materials, pruning, and other operations that occur at this time. It gives you a good picture of what type of stock you will be receiving when it is shipped to the planting areas. It is never an enjoyable experience to open up a box of seedlings, with planters standing around, and be surprised to find that the seedlings are not at all what you were expecting.

10.3 INSTALLING PLANT MATERIALS

Once the project site has been prepared (See Section 10.1, Soil and Site Treatments) and the plant materials have been obtained (See Section 10.2, Obtaining Plant Materials), the vegetation can be installed on the project site. The following implementation guides cover the methods for installing seeds, cuttings, and plants. Section 10.3.1, Seeding, discusses the different methods of seeding, how to formulate seed mixes, determining seeding rates, and assuring quality. A specialized form of seeding, hydroseeding, is discussed in Section 10.3.2. Section 10.3.3, Installing Cuttings, outlines cutting installation techniques most commonly used in biotechnical engineering designs. Section 10.3.4, Installing Plants, discusses techniques for planting bareroot and container plants. It also discusses seedlings, plant handling, storage, and quality control measures.

10.3.1 SEEDING

10.3.1.1 Introduction

Seeding is the distribution of seeds for the purpose of establishing seedlings at a desired density and species composition. Optimal seeding operations must take into consideration: 1) how seeds are uniformly distributed over an area, 2) where seeds are placed vertically (that is, in, on, or under the soil surface), 3) species composition in the seed mix, and 4) when seeding takes place. These factors must be adapted to each revegetation unit to account for the unique climate, soils, and species requirements of each site.

Seeding is often coupled with other operations, such as fertilization, soil amendment applications, and soil stabilization treatments. While accomplishing these objectives at the same time as seeding often makes practical sense from an economic and scheduling standpoint, it might not always be best for the short-term establishment of native vegetation. It is important to consider the effects of combining too many operations into the actual sowing operation. It may be necessary to plan some of these operations at different times. For example, fertilizing, which is often done during the seeding operation, might best meet objectives if applied separately from seeding (See Section 10.1.1).

This section will cover the different steps in developing a seeding plan: 1) identifying seeding areas, 2) determining seed application methods, 3) developing seed mixes, 4) determining sowing rates, 5) preparing seed mixes, 6) selecting sowing dates, and 7) applying seed and assuring quality.

10.3.1.2 Identify Seeding Areas

It is important to visit the project site as soon after road construction as possible and specifically identify seeding areas on the ground. If road construction is a multi-year project, finished slopes should be assessed for seeding while the remaining construction continues. While most of the seeding areas will conform to the revegetation units developed during planning, sites always look different after construction. A field review should note where topsoil has been placed, presence of surface rock, surface roughness, accessibility by equipment, microclimate, soil compaction and other site factors. These factors will be used to develop: 1) seeding methods, 2) sowing dates, 3) seed mixes, and 4) seeding rates for each of the seeding areas.

Seeding areas are located on a map and by road station. For each seeding area, acreage can be calculated using methods described in Figure 9.2 in Chapter 9, Implementation. These calculations must consider the areas where seeding will actually take place. For instance, seeds should not be applied in areas where herbicides will be used for maintenance. At the end of the field survey, total acreage for each seeding area will be summarized and this information will be used in developing seed mixes for each seeding area (See Section 10.3.1.6 and Section 10.3.1.7).

10.3.1.3 Determine Seeding Methods

There are a variety of methods for applying seeds available to the revegetation specialist. The challenge is matching these methods to the sites encountered in mountainous terrain. Typically, the site characteristics of each seeding area will dictate the type of seeding method used. For example, a road project has three revegetation units – a steep, north-facing slope; an obliterated road; and a rocky south slope. Hydroseeding could be planned for the steep, north-facing slope where other equipment cannot reach. On the obliterated road, several ground based seeding methods could be used, including mixing seeds into the soil, or broadcasting on the surface and covering with a mulch. The south-facing slopes could be hand-seeded or hydroseeded, then covered by a mulch to keep the seeds from drying out during germination. Each project needs to approach seeding with a strategy that is the most efficient and will provide optimal conditions for seed germination.

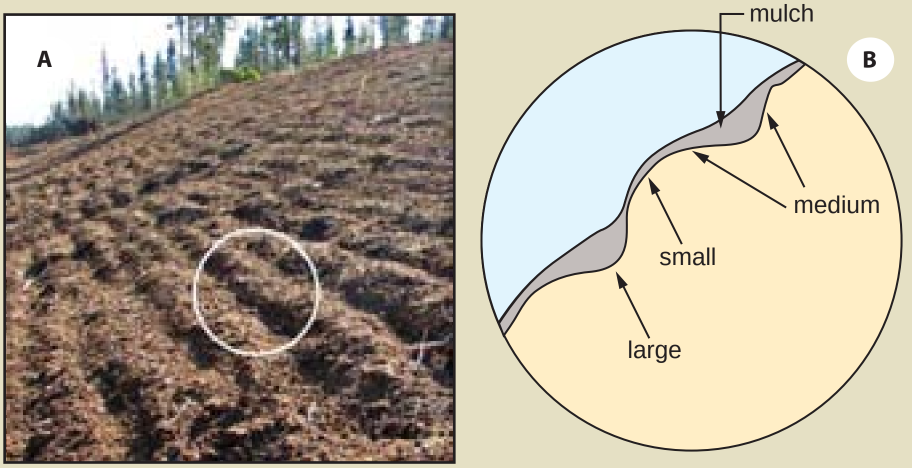
Each species has a unique seed covering requirement. While seeds of most species must be buried in the soil or covered by mulch to germinate, some species actually require some exposure to light to germinate and must not be covered very deeply. A general rule for seed covering is to bury seeds at depths from twice (Munshower 1994) to three times (Monsen and Stevens 2004) the seed diameter. The deeper the seeds are covered, the less likely they will dry out during germination. The tradeoff, however, is that seedlings will have to expend more energy to emerge from deeply buried seeds. This can ultimately affect early seedling establishment.

The ideal seedbed, as defined by Monsen and Stevens (2004), is "one in which the seed is firmly enclosed within soil particles to provide hydraulic conductivity of moisture to the seed. Seeds should be placed deep enough to prevent rapid drying but shallow enough to allow natural emergence." Creating an ideal seed environment is an important practice, especially in nurseries, farms, or gardens where the objective is to create a uniform plant crop. All operations in these settings must be standardized and uniform (e.g., correct seed depth, optimum lighting, uniform irrigation, uniform seed densities, etc.). While uniformity and standardization can be applied to wildland revegetation, an alternative strategy might be considered. This strategy starts from the premise that we really cannot know much about the specific germination and early seedling growth requirements of different native species at each seeding site. For this reason, we should be creating a variety of environments, or "regeneration niches" (Grubb 1977), where seeds might find the right conditions for germination (Figure 10.86). Further, we should apply a range of native species to fill these environments. With wildland revegetation, uniformity is not the objective. In fact, non-uniformity will most likely fit with the surrounding plant communities.

Vertical seed placement, where seeds are vertically distributed in soil or mulch layers, can be grouped into the following categories:

- Broadcast onto the surface,
- Pressed into the soil surface,
- Mixed under the soil surface,

***Figure 10.86** – When a seed mix, ranging from small to large seeds, is applied to an uneven surface (A) and covered by a long-fibered mulch (B), a range of germination environments are created. Optimum germination environments for large seeds occur in depressions where deeper seed cover occurs; optimum germination environments for small seeds, needing less cover, occur on the ridges where mulch is not as thick.*



- Drilled under the soil surface,
- Covered with long-fiber mulch,
- Mixed into long-fiber mulch, and
- Mixed into hydromulch.

Vertical seed placement methods will be discussed in the following sections in the context of how they affect germination and seedling establishment.

Seeds Sown on the Soil Surface – One of the most common forms of seeding is broadcast seeding, which is casting seeds on the surface of the soil with a rotary spreader or by hand. Broadcast seeding is almost always the least expensive form of seeding. Rotary spreaders can be attached to most types of vehicles, including all-terrain vehicles and pickups, and used where vehicle accessibility is good. Where slope gradient or accessibility limits mechanical seeding, using a hand-held broadcast seeder is an option. While manual broadcast seeding might be considered a very low-tech method, it still has an important place in revegetation.

Manual broadcast seeding offers the opportunity to spot-seed microsites at different seed rates and seed mixes. For example, two people could hand seed a steep cut slope requiring two different seed mixes – the lower portion of the slope sown with a grass and forb seed mix and the upper portion with a shrub and seed mix. In another instance, a fill slope composed of rocky outcrops interspersed among deep soils has two distinct microsites that could be seeded separately with different seed mixes. With knowledge of the road objectives, several hand seeders can apply seeds across a project area that mimics the vegetative patterns of the landscape. Spot-seeding can also be a method of applying valuable seeds or "unique" species to strategic locations. For instance, showy forbs that are expensive to obtain or require a specific habitat can be spot-seeded in those locations.

The disadvantage of broadcast seeding is that seeds are not covered by soil or mulch (Figure 10.87). Since seeds need intimate contact with the soil to germinate, broadcast seeding typically leads to low establishment of seedlings. If greater quantities of seeds are sown; however, some seeds will find microsites with high humidity (between surface gravels or rock) or will be covered by soil particles that have been moved through erosion processes. Estimates of 50% to 75% more seeds must be sown to compensate for the inability of seeds to germinate or the loss of seeds to rodents (Monsen and Stevens 2004). Survival factors must be adjusted downward when calculating sowing rates for seed mixes (See Section 10.3.1.6). Broadcast seeding on roughened surfaces can potentially increase germination rates, especially if seeds are sown in the fall. The probability that seeds will be covered by sloughing soil over time is increased (Stevens and Monsen 2004), so it is important that the soil surface be left as rough as possible where broadcast seeding will be used.

Seeds Pressed into the Soil Surface – Seed that is sown on the surface and pressed into the soil increases germination rates over broadcast sowing. Seeds are in firm, intimate contact with the soil, which increases available water to the seeds (Stevens and Van Epps 1984) (Figure 10.88). Imprinting produces a variety of microsites which may benefit the germination of a mix of species (Stevens and Monsen 2004). This type of seeding is accomplished with imprinting equipment (See Section 10.1.2.4). In this operation, seeds are dropped from a seeder mounted in front of the imprinter and then pressed into the soil. Imprinting works well for small to medium sized seeds; seeds are in firm contact with the soil but not buried too deeply to affect seedling emergence. In some cases, imprinting small- and medium-sized seeds can result in germination

Figure 10.87– *Broadcast seeding leaves seeds exposed on the soil surface where they are not in contact with the soil.*

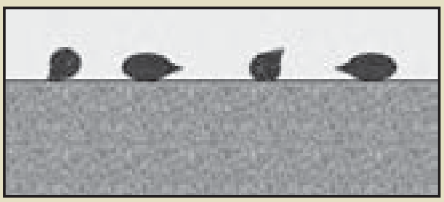
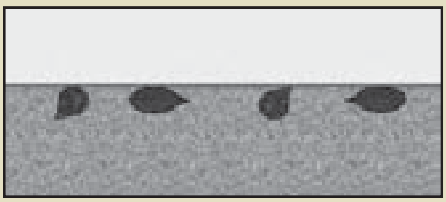


Figure 10.88 – *Pressing seeds into the soil surface improves germination by increasing soil contact.*



as good as, or better, than drilling seed (Haferkamp and others 1985). Larger seeds must be covered by soil or mulch for adequate germination. Imprinting seeds cannot occur on steep slope gradients or slopes with high rock content. Sites that are too steep for tractor access are too steep for current imprinting equipment.

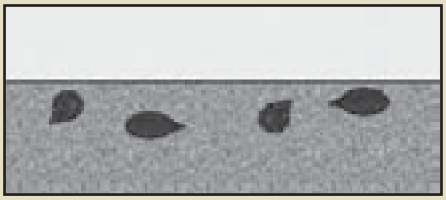


***Figure 10.89** – Seeds mixed under the soil surface puts them in direct contact with the soil, greatly improving germination.*

Seeds Mixed Under the Soil Surface **–** Mixing seeds into the surface of the soil is one of the best ways to achieve optimum germination (Figure 10.89). Mixing is done in two stages – seeds are applied on the soil surface by either broadcast seeders or by using a seedbox and drop tubes; seeds are then incorporated into the soil by dragging anchor chains, disk chains, cables, pipe harrows, or other implements behind a tractor. Equipment has been developed for wildland conditions that will seed and incorporate in one operation. The "ripper-seeder-harrow" (Figure 10.90) is a specialized seeder that subsoils, broadcasts seeds, and mixes in one operation. Use of this equipment is limited to slope gradients of 3H:1V or less and non-rocky soil surfaces.

When mixing seeds into the soil on steeper slopes, any method that scarifies the soil surface after seeds have been broadcast will mix the seeds into the surface. Using a hand rake to incorporate broadcast seeds into the surface works well, and can be used in areas where expensive or valuable seeds have been applied. This type of seed placement requires that the seed depth be monitored to assure that it is not buried too deeply. Seeds should not be mixed deeper than one inch.

These application methods allow seeds to be mixed evenly through the soil and not concentrated in rows, as they are with drilling (see below). However, soil is left loose around the seeds, which decreases water-holding capacity. If seeds are sown in the fall and do not germinate until the following spring, natural packing of soil around the seeds will occur.

Seeds Drilled Under the Soil Surface **–** Using a seed drill is another method for covering seeds with soil. Seeds are not actually drilled into the soil, as the name implies, but sown just under the surface in rows. Seed drills 1) open the surface of the soil with a disk or tine; 2) drop seeds from a seedbox, through tubes, into the open furrows; 3) close the furrows with a disk; and 4) pack the soil firmly around seeds with a press wheel. Cropland drills have been developed for the agricultural industry. However, this equipment has limited applicability on highly disturbed sites because rocky soils and uneven soil surfaces create difficulties in placing seeds at proper soil depths. Several drills have been developed for rangeland restoration that compensate for these limitations. The Rangeland and Truax® drills were specifically developed for seeding rocky, uneven surfaces. The Truax® drill was an improvement on the Rangeland drill, and includes

***Figure 10.90** – The "ripper-seeder-harrow" equipment was developed by the Umatilla National Forest. This equipment prepares the soil surface and mixes the seeds into the surface in one operation. Soils are loosened using subsoil tines, leaving a roughened soil surface (A). Seeds are metered from a seedbox through drop tubes onto the soil (B), where seeds are mixed into the soil using a chain harrow (C). Blueprints for this equipment can be obtained from the USDA Forest Service, Missoula Technology Development Center (MTDC).*

***Figure 10.91** – Seed sowing and mixing equipment can be attached to most types of ground based equipment, including all-terrain vehicles. A seed spreader attached to the back of an all-terrain vehicle broadcasts seeds on the soil surface and a chain harrow mixes seeds into the soil.*

three seed boxes that can independently distribute seeds at different depths corresponding to the size and shape of the seeds (Stevens and Monsen 2004).

Seed drills concentrate seed into rows (Figure 10.92), creating a greater potential for competition between emerging seeds within rows than if seeds were broadcast. For example, a seed mix with an aggressive species will emerge and dominate the row of seeds at the expensive of less aggressive species. The three seedboxes on the Truax® seed drill can be used to compensate for this potential problem. The less aggressive species are placed in separate seedboxes and sown in separate rows. If more than one seedbox is used, separate sowing rates must be calculated for each box. Typically, lower seed rates are used in drilling operations because the seeds are concentrated in rows and closer together. Where rodents are present, drilled seeds are more prone to being excavated by rodents that simply follow a row of seeds (Stevens and Monsen 2004).

Seeds Covered With Long-Fibered Mulch **–** Optimum seed germination is obtained under long-fibered mulch. The mulch provides a moisture barrier that protects seeds and keeps soil from drying (Figure 10.93). Soil moisture is maintained longer around seeds than if they were strictly covered by soil. This is a two-stage operation in which seeds are broadcast on the soil surface and then covered by mulch. The thickness at which the mulch is applied depends on the seed size and the type of mulch. Small seeds will require less cover than large seeds. The rate at which mulch can be applied varies by the characteristics of each type of mulch. Wood strands and straw, for instance, can be applied at higher rates (thicker layers) than composts or chips because more light is able to penetrate these mulches, allowing seed germination and seedling establishment. See Section 10.1.3 for further discussion of mulches.

Sowing seed mixes that contain a variety of seed sizes will require that the mulch not be uniformly applied. One strategy is to begin with a roughened seedbed as shown in Figure 10.86. Because the surface is not even, mulch will settle in depressions and be thicker than on the ridges. Monitoring the application rates is important to assure that seeds are covered with the proper mulch thickness. While covering seeds with long-fibered mulch is the most favorable method for optimum seed germination, it is also the most expensive.

***Figure 10.92** – Seed drills place seeds in rows under the surface where they are in direct contact with the soil.*

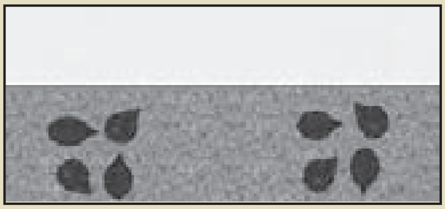
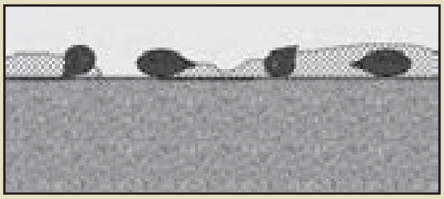


***Figure 10.93** – Covering broadcast seeds with long-fibered mulch is very effective in conserving moisture around the seeds.*

Figure 10.94 – Seeds mixed into long-fibered mulch have less contact with soil, which can reduce germination.

Figure 10.95 – Applying seeds in a hydromulch places a portion of seeds on the soil surface and some suspended in the hydroseeding matrix above the surface.



Seeds Mixed into Long-Fibered Mulch – Seeding and mulching are often combined into one operation (Figure 10.94). Most mulch blowers have seed metering systems which distribute seeds with the mulch as it is being applied to the soil surface. Seeds in this operation are distributed within the mulch, as opposed to being placed between the soil surface and mulch layer. Although one operation is more efficient, seed germination and seedling emergence rates are typically lower than when seeds are broadcast on the surface and covered with mulch. Seeds are not in contact with the soil when mulch and seed are mixed. Unless the mulch has a high water-holding capacity, moisture around the seeds will be limiting during germination and seedling emergence. It is important to know how much moisture a mulch can hold when deciding whether seeds will be mixed with the mulch or broadcast applied first then covered with mulch (See Section 5.2.2.1 for determining moisture holding capacities of mulches). Composts, for instance, have high water-holding capacities, and seeds will germinate well in this material; ground or shredded wood mulch and wood strands have very little water-holding capacity and seed germination will be poor. Seed rates should increase relative to how much moisture the mulch is expected to hold. For low water-holding capacity mulches, seeds in the upper portions of the mulch will not germinate or will germinate poorly. Seed rates in this type of mulch should be increased by 25% to 50%.

Seeds Applied in Hydromulch – When seeds are applied through a hydroseeder (See Section 10.3.2), they will lay on the soil surface surrounded by a thin covering of fine-textured wood fibers (Figure 10.95). At rates of 1,000 lb/ac hydromulch, seeds will be covered with less than 0.25 inch of mulch, with some seeds not covered. As rates approach 3,000 lb/ac, mulch thickness increases to over 0.25 inch, with most seeds being covered. Hydromulch has a high water-holding capacity, maintaining up to two and a half times its dry weight in water. This can be beneficial to seeds during germination. However, unless very high rates of hydromulch are applied, many seeds in the slurry are not covered by the hydromulch. Some hydroseeding operations try to compensate for this by applying a slurry containing seeds first, and covering the seeds with hydromulch with a second pass. The thin seed cover is favorable for only small seeded species. Seeds can be damaged in the hydroseeding operations through the pumps and agitators, or by hitting the ground at very high speeds during application.

Even with these limitations, hydroseeding is still one of the most common methods of applying seeds to road construction disturbances. It is often the only way to place seeds on steep, rough terrain encountered in mountainous regions. Compensation for these limitations has had varying degrees of success. Possible variations include: 1) increasing the amount of seeds, 2) applying seeds in the first pass, then covering with hydromulch in the second pass, and 3) applying higher rates of mulch. Fall hydroseeding also increases establishment rates. Over-wintered seeds are ready to germinate on the first warm days of late winter or early spring when humidity levels are high. In addition, hydraulic mulches are more likely to stay moist for longer periods of time. Hydroseeding is simpler than dry seeding because there is no seed metering system; seed mixes are simply mixed into the hydroseeder tank and applied. See Section 10.3.2 for more discussion on hydroseeding.

10.3.1.4 Formulate Seed Mixes

The seed mix refers to the species composition being applied over a seeding area. It is important to avoid applying a single species to a site. Since highly disturbed sites typically are extremely variable in soil temperatures, fertility, soil moisture, solar radiation, and other site factors, it is important to apply a number of species in a seed mix to assure that all possible microsites are populated (Monsen and Stevens 2004). Microsites that are unfavorable to one species might be favorable to others. Applying a mix of species also assures that if there is a problem with the germination of one species, the other species will fill in. The composition of seed mixes and sowing rates should be based on the growth habits of each species and the soils and climate of the site.

It is preferable to avoid mixing slow-growing species with fast growers, because the fast growers will out-compete the slow growers for space and resources (Monsen and Stevens 2004). Separating slow growers from fast growers is not always possible. The seed quantities must therefore reflect higher ratios of slow growers to fast growers to achieve some degree of success. Shrubs and trees are typically less aggressive than grasses during the establishment phase, and should be applied in a separate mix or planted as seedlings. Grasses tend to be more aggressive than forbs. However, if the Truax® seed drill is used, they could be applied in the same area but in different rows using the separate seed boxes. Some species take several years to develop. A mixture of fast-growing annuals and slow-growing perennials will assure that there is cover the first year, yielding to more robust perennials in the succeeding years.

Disturbed reference sites can be good indicators of species that are adapted to the climate and soils of the project area. Vegetative surveys conducted during the planning stages should show the proportions of species that can be expected, and these findings should become the basis for developing species composition and ratios of each species. Prior to determining sowing rates, the proportion of each species within each seed mix should be set. This information will be used to determine seeding rates for each species.

10.3.1.5 Determine Sowing Rates

The sowing rate is the amount of seeds of each species in a seed mix that are applied in a given area. Sowing rates are calculated for each species that compose a seed mix. These calculations are performed twice – once during the development of seed increase contracts to obtain an approximate quantity of seeds to propagate for the entire project, and several months prior to actual seeding when seed inventories are known and exact seeding areas are

***Figure 10.96** – Assembling a seed mix requires sowing calculations for each species in the mix. This figure shows one way to calculate the quantity of seeds for one species (e.g.* Elymus glaucus *[ELGL]) in a mix. These calculations must be made for each of the remaining species in the mix.*

A	Number of seeds/lb:	128,000	seeds/lb	From seed tests
B	Purity:	92	%	From seed tests
C	Germination:	89	%	From seed tests
D	A * B / 100 * C / 100 =	104,806	PLS/lb	Number of PLS per pound of bulk seed
E	First year survival:	20	%	The estimate of PLS of ELGL that become seedlings
F	Target 1st year seedling density:	20	seedlings/ft^2	Desired number of seedlings (per ft^2) of all species in seed mix after 1 year
G	Target composition:	35	%	Target percent of total 1st year plants composed of ELGL
H	(F / E) * G =	35	PLS/ft^2	PLS of ELGL to sow per ft^2
I	43,560 * H / D =	14.5	pounds/acre	Pounds of ELGL to sow on a per acre basis
J	Area to seed:	5.5	acres	Total area for seed mix
K	I * J =	80	lbs	Total ELGL needed for seed mix
L	Quantity of containers:	4	bags/acre	For handling
M	I / L =	3.6	pounds/bag	Total weight ELGL to put into each seed mix bag

located. The calculations made prior to seeding will be used to assemble the seed mixes for each seeding area.

Each species requires a set of data to calculate the total pounds of seeds needed in a seed mix which includes:

- Pure live seeds per pound of bulk seeds,
- Estimated first year survival,
- Target first year seedling density for all seeded species,
- Percentage of density composed of each species, and
- Area that will be seeded with seed mix.

Figure 10.96 shows one method for calculating the amount of seeds needed of each species in a seed mix. Since a seed mix is made up of several species, calculations must be performed on each species. In this example, blue wildrye (*Elymus glaucus*) is one of several species included in a seed mix. The end result of these calculations is the number of pounds of blue wild rye seeds that must be added to each seed mix bag.

Pure Live Seeds Per Pound (PLS/lb) – When purity and germination are multiplied together and divided by 100, the resulting value is the % pure live seeds (PLS). It represents the percentage of the gross seed weight that is composed of viable seeds (See Figure 10.65 in Section 10.2.4). For example, if germination is 89% and purity is 92%, the PLS would be 82%. When PLS is multiplied by the number of seeds per pound, the result is the pure live seeds per pound of gross seeds (PLS/lb). This value is often used in seed and sowing calculations, and it states the approximate number of seeds that will germinate in a pound of gross seeds under ideal (test) environments. For example, the PLS in Figure 10.96 is 82%, and the number of seeds per pound is 128,000. The total PLS/lb is (82/100) * 128,000 = 104,806 (Line D in 10.96). Tests for purity, germination, and seeds per pound are run by State Certified Seed Testing Laboratories and obtained from the seed producer or supplier.

First Year Survival – Not all viable seeds develop into established seedlings after being sown on a disturbed site. The conditions encountered on revegetation sites are generally unfavorable for germination and plant establishment. The first year survival factor reflects the effect of the harshness of the site on plant establishment (Line E of Figure 10.96). It is a prediction of the percentage of PLS that germinate and become established plants after the first growing season. A favorable site, for instance, will have a high survival factor because a high percentage of live seeds will germinate and establish into plants; a harsh site will have a low first year survival factor because seeds will germinate poorly, resulting in plants less likely to survive over the dry summer months. Unfortunately, there are currently no established field survival factors for the western United States. Therefore, the revegetation specialist will have to make estimates based on experience and an understanding of site factors, seed handling, and sowing methods.

How much fall down actually occurs? Even under very controlled growing environments, such as those found in seedling nurseries, survival factors are much lower than most would think. It is not uncommon for bareroot seedling nurseries to set first year survival values between 65% and 75% (USFS 1991). Compare the highly controlled environment of a nursery to seeding in the wild, where precipitation is intermittent and soils are depauperate. It should be no surprise to find that only 10% to 20% of the live seeds sown in the wild actually turn into live plants the first year after seeding (Monsen and Stevens 2004; Steinfeld 2005).

Estimating the first year survival is always a guess. It is interesting that very exact data from seed tests are used for a portion of the sowing calculations, followed by a broad approximation of how well viable seeds will actually germinate and become established in the field. Unfortunately, this information is hard to obtain. Monitoring data collected in the spring and fall, after the completion of each seeding project, can be used to develop a basic understanding of how seeds perform in the field under various soils, climates, and mitigating treatments. First-year monitoring that measures seedling density is useful in this regard. The number of seedlings can be counted in a series of photoplots, and the average number of seedlings per square foot can be calculated. The average seedling density, divided by the average number of PLS sown per square foot (line H of Figure 10.96), gives the survival factor for that project area. Steinfeld (2005) performed this type of monitoring for several seeding projects six months after sowing on southwest Oregon sites and found the results to be very low (15% of viable seeds became established plants). If this type of assessment is conducted over a range of seeding projects,

Table 10.16 *– First year seedling survival is dependent on the quality of the germination environment. This table is a guide to setting first-year survival rates based on factors that influence germination. High first-year survival rates might be closer to 20%: low survival is often less than 5%.*

	Estimated Field Survival	
	Low	**High**
Seed cover	none	mulch
Spring rainfall	low	high
Humidity	low	high
Water-holding capacity	low	high
Sowing method	poor	good
Season sown	fall	spring
Seed treatments	poor	good
Freeze thaw	high	low
Surface erosion	high	low
Aspect	south	north
Fertility	low	high

survival factors could be developed for a range of soil and climate conditions. It would be good to understand how survival factors change with different types of seed covering methods.

Factors to consider when estimating survival factors are shown in Table 10.16. Chapter 5 discussed how these factors affect plant growth. Sites with low first year survival would have a large number of limiting factors. Very poor sites can have survival factors below 5%, whereas favorable sites can have factors as high as 20%.

Target First Year Seedling Density **–** The target first year density is the number of plants/ft^2 desired the first year after sowing (Line F of Figure 10.96). Establishing target density factors is often based on the objectives of the project. For example, projects where the objective is fast plant establishment for either erosion control or weed prevention would usually require the target first year densities to be relatively high. Target densities are also based on the growth habits of the species to be sown. Fast-growing species with large spreading growth habits would have low target densities. Shrubs and trees would have target first year densities of less than 1 plant/ft^2, whereas grasses might have densities up to 25 seedlings/ft^2. Monitoring sites after one year can give a good indication of what densities can be expected from each species and what densities are most appropriate for meeting project objectives.

It should be recognized that there is a point of diminishing returns, where applying more seeds does not necessarily produce more seedlings. There is a limit to how many seedlings can survive on a site, and no amount of seeds applied will change this fact. While applying excess seed errs on the conservative side, it can be wasteful and costly. It can also favor the aggressive species over the less aggressive species (Monsen and Stevens 2004). When using high seeding rates, it is important to reduce the ratio of aggressive species to non-aggressive species in order to assure that non-aggressive species can become established.

Target Composition **–** The target composition is the proportion of each species that will comprise the seedlings found in a given area (Line G of Figure 10.96). An example of a target seed mix composition is one that would produce a stand of grass and forb seedlings made up of 35% blue wildrye (*Elymus glaucus*), 35% California fescue (*Festuca californica*), and 30% common yarrow (*Achillea millefolium*). See Section 10.3.1.4 for further discussion.

Area to Seed **–** The area to seed is the total acreage of a seeding area to which a seed mix will be applied (See Section 10.3.1.2 for a discussion on how seeding areas are determined.)

10.3.1.6 Prepare Seed Mixes

Once sowing calculations are completed for each species, seed mixing operations can begin. The objective of these operations is put together seed mixes in packages that are organized, easy to handle, and ready to use. This is an important step, because there can be no room for confusion in seeding operations or time for reorganizing seed mixes. The seed mixing operation involves weighing seeds from each species or seedlot, mixing seedlots, placing seeds in bags, and labeling.

The seed bag is the basic handling unit used in seeding. Before mixing begins, you must determine how much area a bag of seed mix will cover. This will depend on the seeding method. For hydroseeding contracts, the seed bags can be no larger than the area a slurry unit will cover (See Section 10.3.2). For example, if a 1,000 gallon hydroseeder tank covers a quarter acre, then the bags of seed mix would have enough seeds to cover a quarter acre. In this example, the seed mix is divided into four bags per acre (Line L of Figure 10.96). The most typical seed bag coverage is a quarter of an acre because of the increased flexibility, reduced weight, and ease of handling.

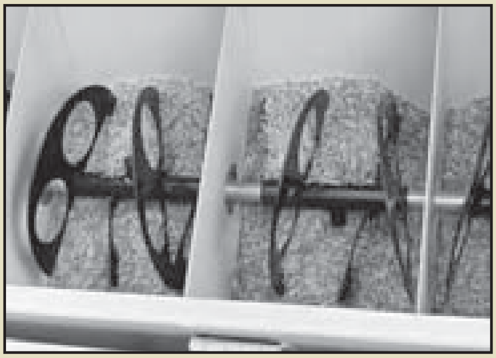
The sowing method is an important factor in assembling the seed mix. If the mix is to be used in a seed metering system (Inset 10.19), each seedlot must be thoroughly mixed together to ensure a uniform distribution of seeds of each species on the site. On the other hand, if the seed mix is placed in a hydroseeder, it is not necessary to mix the seeds since all seeds will eventually be mixed in the hydroseeder before application. Other packaging will be required if more than one seedbox is used (e.g., the Truax® seed drill).

Inset 10.19 – Seed Metering and Delivery Systems

The seed metering system is key to uniform application of dry seed mixes. Seed boxes should contain a mechanical seed agitator (as shown in picture) that constantly mixes the seeds to prevent seed bridging. The rate of seed flow must also be easy to adjust to allow for changes in sowing rates. Some systems, such as those found on mulch blowers, have remote controls that allow the applicator to turn the metering system on and off.

There are several types of seed delivery systems available, and the choice of the system will depend on project objectives. Some systems have more than one seed box to keep several species separate. This might be necessary when working with seed mixes that include chaffy or fluffy seeds. Specialized seed boxes that are manufactured with a semicircular seedbox, auger agitator, and pickerwheel, as developed by the Texas Agricultural Experiment Station (USDA/USDI 2005), can be used for these types of seeds.

Drilling different sized seeds may also require two or more seed boxes. The Truax® seed drill has three seedboxes that are adjusted to sow various seed sizes and shapes.



Other materials can also be included in the assembly of the seed mix. Mycorrhizal inoculum can be mixed with the seeds, as well as dyes to make seeds easier to see after seeding. Mycorrhizal inoculum and dye will change the rates that seeds will flow. Seed metering systems will have to be calibrated for these materials. Very small-seeded species may need to be sown with carriers, such as rice hulls (Stevens and Munson 2004). For small, fluffy seeds, wheat bran can be added to help prevent them from migrating upward in the seed mix (Dixon and Carr 2001b).

When calibrating seeds for mulch blowing operations, it will be necessary to create more small seed bags that represent smaller calibration areas (Inset 10.20).

10.3.1.7 Determine Seeding Date

The best date to sow varies by site, but typically it is in the fall. On cool, arid sites, seeding later in the fall is better to prevent premature germination prior to the onset of the winter (Monsen and Stevens 2004). On warm, moist sites (e.g., the west side of the Cascade Mountains), sowing can take place in the late summer and early fall, anticipating that seeds will germinate with early fall rains and become established prior to winter. If seeds are sown in the spring or early

Inset 10.20 – Calibrating Seed Densities for Mulch Blowing

Calibrating seed metering systems on mulch blowers to obtain the target seed density can be accomplished by laying out several plots of identical area (e.g., 1,000 square feet) with flagging. The seed required for each plot is determined and measured:

seed weight = plot area (sq ft) * (target pounds of seed mix/acre) / 43,560.

For example if the seed mix application rate is calculated at 30 lb/ac and the plot size is 1,000 ft^2, the weight of seed to apply per plot is 1,000*30/43,560, or 0.69 lb. Make at least 6 seed calibration bags. Prior to applying mulch, place the seeds from the calibration bag into the seed metering bin. Apply the mulch to the plot at the target depth while one person monitors the seeds being metered out. When all seeds are dispensed, stop the application and estimate the area covered by mulch. If the mulched area was approximately half of the 1,000 ft^2 plot (500 ft^2), the seed densities would have been doubled. Adjustments to the seed metering controls would need to be made to deliver 50% of the seeds. After these changes are made, mulch would be applied to another plot to determine if seeding rates were closer to the target rates.

summer, seed mixes should be composed of species that germinate quickly and do not require a long natural stratification period.

10.3.1.8 Assure Quality

There are several factors to monitor during seeding to assure operations are administered correctly. Depth of seed placement, uniformity in application, target seed densities, and seed handling must be monitored throughout the process. It is important to periodically measure seed depths, especially at the beginning of the operation or when any new site being seeded. Seed dyes are sometimes applied to make seeds more visible. However, these are not useful when seeds are applied through hydraulic seeders or mulch blowers. Uniformity of seed application can be monitored as seeds are being distributed through seed metering or delivery systems. Sometimes seed systems plug or malfunction, resulting in sporadic application of seeds. Poorly applied seeds, where the applicator either misses spots or applies over seeded areas, will also results in an uneven application.

Seed densities can be monitored indirectly by measuring the area where a known weight of seed has been applied and matching it to the estimated acreage it was targeted to cover. For example, on a project where a seed mix is split into a quarter-acre bags, the area seeded with one bag of seed mix would be measured. If a quarter-acre bag covered only 0.2 acres, the seed was sown more thickly and the density was increased by 25% (0.5/0.2). If the seed bag had been applied over 0.30 acre, the seeds would have been spread across more area and the seed density would have decreased by 17% (0.5/0.3). These measurements should be done as each seed mix is being applied. If there is a significant change in density, adjustments to the seeding operations can be made.

Measuring a seeding area unit is important not only for determining if seeding rates are being applied correctly, but also for accurately paying the seeding contractors. Contract administrators should be measuring the area that each seed bag or known seed quantity is being sown during, or immediately after, seed application. Figure 9.2 in Chapter 9 describes a method to measure area by measuring the slope length that has been seeded at each road station marker and multiplying it by the distance between markers.

Proper seed handling should also be monitored. Seed bags should stored in suitable conditions and always handled with care. Seed bags should not be thrown or dropped or left in unsuitable conditions.

10.3.2 HYDROSEEDING

10.3.2.1 Introduction

Hydroseeding is a method of hydraulically applying seeds, stabilizers, and soil amendments to the surface of the soil for the primary objective of revegetation. The term hydromulching is often used interchangeably with hydroseeding, but there is an important distinction; hydromulching is the application of hydraulic mulch and surface stabilizers for the primary purpose of erosion control. Hydromulching is typically conducted on multi-year construction projects, when surface soils need to be temporarily stabilized for soil erosion or dust abatement. While hydromulching and hydroseeding operations both must stabilize the soil surface, hydroseeding has the additional and overriding goal of placing viable seeds in a surface environment to germinate and grow into healthy plants. Meeting the dual objectives of erosion control and plant establishment in one operation is often a balancing act. The best methods for soil stabilization are not always optimal for seed germination and plant growth. In this section, we will focus on hydroseeding, not hydromulching. We will discuss how to best meet the needs of early plant establishment using hydraulic sowing methods and leave the discussion of stabilizing the surface through hydromulching to the many articles on this subject and to the manufacturers of these products.

Hydroseeding equipment is composed of: 1) a tank that holds a slurry of water, seeds, soil amendments, and stabilizing products; 2) paddles or agitation jets in the tank to mix the slurry; 3) a high pressure pumping system; and 4) a hose and nozzle (Figure 10.97).

Tanks come in a variety of sizes, from a few hundred to over 3,000 gallons. As the size of the tank increases, the speed and efficiency of the operation improves. Because the travel time is the same for any size hydroseeding unit, the farther the water source is from the project site, the more efficient larger tanks become.

The hydroseeding tank is analogous to a large mixing bowl filled with various ingredients and blended together with water to make a slurry. Typical hydroseeding ingredients fall into these categories:

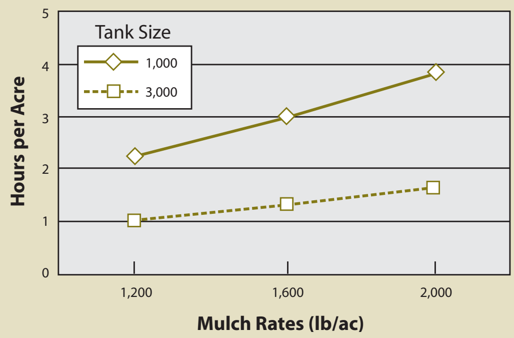
- Seed,
- Hydraulic mulch,
- Tackifier,
- Fertilizer,
- Soil amendments, and
- Dye (typically in the hydraulic mulch).

The mixture of ingredients is called a slurry. When a slurry is applied to an acre, it is referred to as a slurry unit. The quantity of each material added to a slurry tank is only limited by the ability of the mixture to be pumped through a hose and shot through a small nozzle without clogging. The tank can only hold so much material before the mixture becomes too thick to pump. Finding the right mix and rates of ingredients is important for efficient use of the equipment. The applicators and manufacturers of these products can recommend optimum product rates.

Hydroseeding ingredients must be thoroughly blended prior to application to achieve uniform seed coverage. There are two types of hydroseeding mixing systems – those that mechanically stir and those that mix using a hydraulic jet. The first system employs rotating paddles to blend the slurry in the tank and a centrifugal pump or positive displacement gear pump for slurry delivery. The second system uses a centrifugal pump to both agitate the slurry and deliver the slurry to the site.

Figure 10.97 – *The hydraulic seeder is composed of a tank that holds and mixes a slurry, and a pump system that moves the slurry through a nozzle for application to the soil surface.*

***Figure 10.98** – Hydromulch application time can be roughly calculated from the size of the mixing tank and the application rate. Cycle time (the time it takes to drive from the water source to the spray area, discharge the slurry, and return) used in this analysis was 60 minutes for a 3,000 gallon tank and 45 minutes for a 1,000 gallon tank (figure modified after Trotti 2000).*



During application, the slurry is pumped to the nozzle for application. The applicator has a choice of nozzles, use of which depends on the site and slurry conditions. Slurry application can be from a "gun" mounted on the top of the hydroseeding unit or from a hose pulled manually to the application site. Stationary application (using a hydroseeding gun) is accomplished where the hydroseeding equipment can easily access the site. These areas are typically cut slopes and fill slopes. Depending on the consistence of the slurry, the pumping system, and wind conditions, slurry can be shot 200 feet or more. Hoses are laid out for sites that cannot be reached this way. Depending on the diameter of the hose and the pumping system, hoses can reach sites over 300 feet from the hydroseeding unit.

Hydroseeding is used when other seeding methods are impractical (See Section 10.3.1, Seeding). Typically, these are steeper sites where ground based seeders are limited. Hydroseeding has the advantage over other seeding methods of applying soil amendments, fertilizers, soil stabilizers, and seeds together in one operation, making this a one pass operation. In addition, seeds that are used in hydroseeding operations do not have to be as clean (that is, free of straw, awns, chaff) as for other seeding methods. This can reduce costs and time associated with seed cleaning operations.

The time it takes to hydroseed is a function of the size of the mixing tank and the amount of hydraulic mulch that is applied on a per acre basis (Figure 10.98). The greater the amount of hydraulic mulch applied per acre, the longer it will take. For example, it takes almost twice as long to apply 2,000 lb/ac of hydraulic mulch through hydroseeding equipment as it does to apply 1,200 lb/ac. For this reason, determining the appropriate amount of hydraulic mulch is important from a cost standpoint. Cost includes not only the costs of purchasing the product, but also the time to apply it. Tank size is also an important factor in application rates; the larger the tank size, the less application time it takes. A 3,000 gallon mixing tank for example, takes less than half the time to cover an acre than a 1,000 gallon tank.

Hydroseeding in wildland revegetation has a number of limitations (Stevens and Monsen 2004):

1) Seeds are not placed in the soil
2) Seeds and seedlings can dry out
3) Some seedlings cannot grow through the hydraulic mulch
4) Seeds can be damaged by agitators and pumps
5) Precocious germination can occur as a result of moisture in the hydraulic mulch
6) Hydroseeding requires large quantities of water

With good planning, implementation, and monitoring, many of these limitations can be managed, resulting in successful revegetation. Ultimately, the success of any hydroseeding project comes down to the availability of water during germination and seedling establishment. Hydroseeding is successful in the landscaping business because seeds are irrigated after hydroseeding until a stand of grass has become established. As one applicator stated, "what people don't understand is you can do the best hydroseeding job in the world but if they don't water it, it's not going to grow" (Brzozowski 2004). The challenge in wildland revegetation is that, for most projects, irrigation is not available. To make hydroseeding successful, strategies must be developed that maintain moisture around the seeds and in the soil during early plant establishment.

10.3.2.2 Integrate Hydroseeding into Revegetation Strategy

From a revegetation standpoint, hydroseeding serves as: 1) a method of seed placement, 2) a means of stabilizing the soil surface for controlling erosion and to allow seedlings to become established, and 3) a way to apply fertilizers and other soil amendments. These objectives cannot always be met in one hydroseeding operation. It often requires that each objective be considered independently, and then integrated into an overall strategy. Clarifying objectives, based on the site specific conditions of the project, and determining the best way to achieve them using hydroseeding equipment as part of the approach, will lead to the best revegetation results. For example, seed placement and fertilizing are different objectives, yet meeting both objectives is often accomplished in one hydroseeding operation out of convenience. However, the best time to apply fertilizers on many projects is after the seeds have germinated (See Section 10.1.1). Instead of meeting fertilizer and seeding objectives in one hydroseeding operation, separating them into two different applications would be a better strategy for meeting overall project objectives.

On a site with high surface rock, for example, the main objective would be seed placement. Little importance would be placed on surface stabilization since the rock has already created a stable surface. The best potential sites for seedling germination on this harsh surface would be between the surface coarse fragments, where seeds are protected and moisture collects. Yet a common mistake that occurs in many hydroseeding projects is to include the same rates of tackifiers as would be used on a soil surface. Under these circumstances, tackifiers adhere seeds to the rock surface, preventing the seeds from washing between the gravel and cobbles that cover the surface. The objective of stabilizing the surface is not only unnecessary in this example, it would negatively affect placement of seeds.

Hydroseeding should always be accomplished within a strategy of creating an optimum seed environment. The hydroseeding operation places seeds on the surface of the soil which is often a poor environment for germination. Hydraulic mulch is inferior to long-fiber mulches in reducing surface temperatures, maintaining soil moisture, and moderating surface temperatures (See Section 10.1.3). The term "hydraulic mulch" is misleading because most materials that fall into this category lack many of the important properties associated with mulches (See Section 10.3.2.5). By their nature, hydraulic mulches are more like a growing medium than mulches because of their capacity to absorb water (Most hydraulic mulches hold greater than 1,000 times their weight in water). As a growing medium, hydraulic mulch maintains high moisture around the germinating seeds. But once the hydraulic mulch dries out, which is often very quickly on dry sites, it no longer protects the seeds from drying as a mulch would and germination rates are compromised.

The literature is scant and inconclusive on the benefits of hydraulic mulch to seed germination and seedling establishment in wildland conditions. Carr and Ballard (1980) found no difference in plant establishment when seeds were applied with and without hydraulic mulches, but only low rates of hydromulches were compared. One approach to increasing seed germination that is often used in drying climates is a two pass application system, where seeds and a minimum amount of hydraulic mulch are applied in the first pass, then covered by a thick application of hydraulic mulch in a second pass. While this application method appears to have some advantage over a one pass operation because the seeds are covered with a greater thickness of hydraulic mulch, it is not known what the difference in germination and seedling establishment rates might be. The benefits from a germination standpoint are probably not seen until the hydromulch rates are high (3,000 lb/ac or greater). Even then, on arid sites receiving less than 6 inches precipitation, higher hydraulic mulch rates can intercept the low amount of precipitation that is received, preventing moisture from reaching the seeds (See Section 5.2.2). Since it is uncertain whether hydraulic mulches improve germination, it is better to base mulch rates on surface stability objectives than on seeding objectives and use other methods to improve seed germination. For example, it might be more effective to reduce the amount of hydraulic mulch to the minimum amount necessary to apply seeds and, with the costs savings, apply a long-fibered mulch in a second operation.

10.3.2.3 Identify Hydroseeding Areas

Hydroseeding should take place after the final slope shaping and topsoil placement have been completed. Several months before hydroseeding is to take place, the site must be visited to finalize an implementation plan that includes the locations of where the plants or cuttings are to be installed and where seeding will take place. While most of the hydroseeding areas will conform to the revegetation units developed during planning, things always look different after construction. In this field review, the exact locations of the areas that will be hydroseeded are drawn on a road map and areas are identified where different seed mixes, fertilizer types/ rates, or hydraulic mulch rates will be applied.

The acreage for each hydroseeding area is calculated using methods described in Figure 9.2 in Chapter 9. This method partitions the cuts lopes and fill slopes into rectilinear units by road stations and calculates acreage between each unit. This information is then summarized in a hydroseeding table (shown in Figure 10.107) that is used to develop task orders. It can also be used in the field for keeping record of acreages and location of hydroseeding operations.

The proximity to streams must be considered when locating hydroseeding areas. If hydroseeding areas are adjacent to ditches or waterways that drain into live streams, a buffer should be included around these features to avoid entry of fertilizers into the stream system. Fertilizers applied to these sites have the potential of entering the ditches during rainstorms and eventually reach a stream course as nutrient pollution. Road runoff can be a significant contributor of nutrients to water systems (Reuter and others 1998).

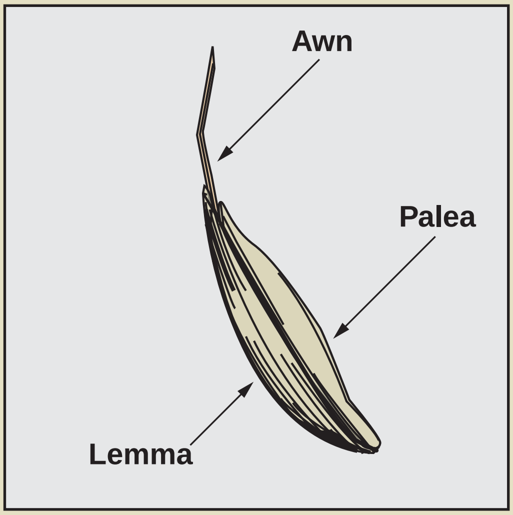
10.3.2.4 Determine Seeding Rates

Sowing rates for hydroseeding are calculated using the same method outlined in Figure 10.96 in Section 10.3.1. The reader is referred to this section for determining seeding rates for any type of sowing method. These sowing calculations assume that the method of sowing does not cause damage to seeds. This might not be a good assumption with hydroseeding, which has been shown to increase the risk of seed breakage in the hydraulic seeder tank during mixing (Kay and others 1977; Wolf and others 1984; Pill and Nesnow 1999). Additions of fertilizers further increase the risk by exposing seeds to high salt levels when seeds are in the slurry tank and also after they are applied to the soil surface (Brooks and Blaser 1964; Carr and Ballard 1979; Brown and others 1983). Taking precautions to reduce the risk of seed damage during hydroseeding will increase the seed germination rates and reduce the amount of seed needed for the project.

Considerations that can reduce the risk of damaging seeds include:

- Type of hydraulic seeder,
- Seed condition,
- Duration in slurry,
- Seed moisture,
- Hydraulic mulch,
- Nozzle and nozzle position, and
- Fertilizers.

***Figure 10.99** – Grass seeds are protected by sets of bracts called the lemma and the palea (the lemma is the larger, outer covering, and the palea is the shorter, interior sheath). The awn is a fibrous bristle that extends from the midrib of the lemma. The awns for most grass species are removed during cleaning for easy sowing. The lemma and palea should be kept on the seeds to protect them from seed damage during sowing, especially in hydroseeding operations.*



Hydraulic Seeders – Hydraulic seeders that use centrifugal pumps for agitation and delivery can have a higher potential to damage seeds than systems with paddles and rubber-coated gear pumps (Kay 1972a; Kay and others 1977). Kay (1972a) found that germination of intermediate wheatgrass (*Agropyron trichophorum* [Link Richt.]) seeds was reduced from 80% (control) to 10% germination after one hour in a centrifugal agitation system; after two hours, germination was reduced to 1%. There was no reduction in germination after one hour using paddle agitation, but germination declined to 59% after two hours. Pill and Nesnow (1999), however, found that centrifugal pumps did not reduce germination rates of Kentucky bluegrass (*Poa pratensis*) and perennial ryegrass (*Lolium perenne*) after mixing for an hour in a slurry tank.

Seed Condition – Grass seeds are enclosed by sets of bracts, called the lemma and palea. These structures provide a protective covering (Figure 10.99) and are believed to reduce seed breakage during hydroseeding agitation and application. In the aforementioned study, Pill and Nesnow (1999) believed that one of the primary reasons there was no decline in germination after an hour of mixing in a slurry tank was because the lemmas and paleas were still intact around the seeds. The association between presence of these seed structures and protection from seed breakage during hydroseeding should be considered when cleaning seeds for hydroseeding. Seed cleaning is necessary for storage and seeding (See Section 10.2.1 and Section 10.2.4). However, seeds for use in hydroseeding operations do not have to be as clean as seeds used in other seeding methods. Each species has different cleaning requirements for hydroseeding. Some require thorough cleaning, while others might require very little cleaning. It would be beneficial to discuss the level of seed cleaning for hydroseeding with your seed extractory personnel and seed increase contractors.

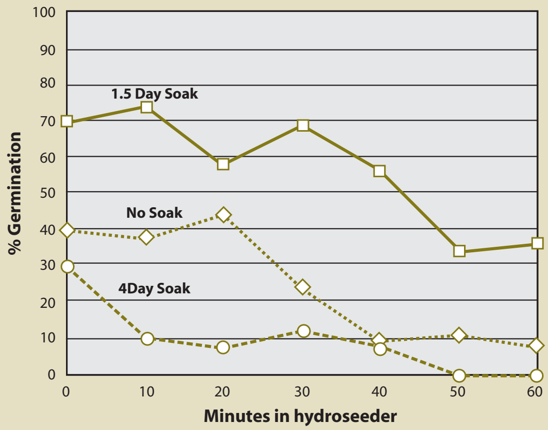
Duration in Slurry – The longer seeds are mixed in the slurry tank, the greater the potential for breakage. Kay and others (1977) found that after 20 minutes of agitation, seed germination decreased significantly (Figure 10.100). For this reason, it is important to add seeds immediately before application.

Seed Moisture – As a general rule, moistened seeds have less potential for breakage than dry seeds because they are more flexible when impacted. Kay and others (1977) found that soaking seeds for 1.5 days prior to application significantly increased germination over dry seeds (Figure 10.100). Longer soaking periods (4 days) had negative effects on germination because radicles were emerging and were damaged with mixing.

Soaking seeds prior to hydroseeding will unfortunately initiate seed germination, which is not usually desirable for hydroseeding projects. Pill and Nesnow (1999) suggest seed priming as an alternative to soaking. Priming is a seed treatment that partially moistens seeds without initiating seed germination (Pill and others 1997). Seed is mixed at one part seed to 10 parts moist vermiculite (although peat could be used as a substitute) and stored at cool temperatures for up to 10 days prior to hydroseeding.

Hydraulic Mulch – Hydroseeding without hydraulic mulch can increase seed damage (Kay 1972a, 1978). Using a minimum rate of 500 lb/ac hydraulic mulch is suggested for protecting seeds (Kay 1978).

Figure 10.100 – *Using a centrifugal hydroseeding pump system, Kay and others (1977) found a reduction in germination of Bermudagrass (Cynodon dactylon) seeds after 20 minutes in the slurry tank. Seed germination improved when the seeds were soaked in water for 1.5 days prior to placing in a hydraulic seeder tank. However, soaking for longer than 1.5 days reduced germination more than if the seeds were not soaked (modified from Kay and others 1977).*



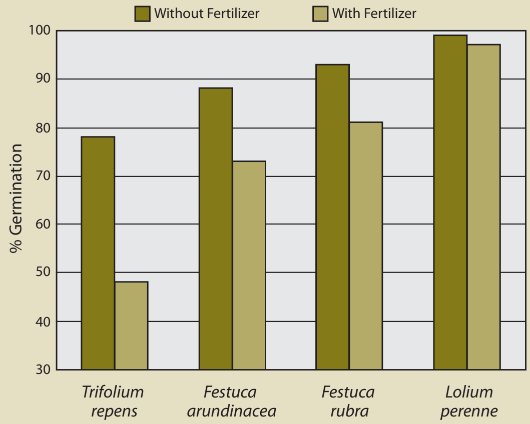


Figure 10.101 – *Incorporating 10-30-10 fertilizer into hydroseed slurries can reduce the germination of some species (Carr and Ballard 1979).*

Nozzle Type and Nozzle Position – Shooting slurry straight at the soil in close range can damage seeds. The impact at high speeds can cause seed coats to break. As one hydroseeding operator describes the action, "we just shove that seed right smack in the ground with a lot of force...the gun was slamming straight to it" (Brzozowski 2003). Describing this action to a Forest Service seed extractory specialist, his reaction was, "that can't be good for the seed" (Barnar 2007). In the seed production and seed extraction businesses, handling seeds carefully is a high priority. This attitude and practice should not stop with the seed producers, but follow through to the application of seeds. One application practice that could reduce seed damage is to aim nozzles so the slurry is not hitting the soil surface with full force at close range. Arching the slurry stream so the spray hits with lower force is more desirable. Using less pressure or lower pressure nozzles, such as fan nozzles, can also reduce seed damage (Figure 10.102). Some soils are very loose or powdery after construction, which can cushion the seeds, as opposed to very compacted surfaces. Seeds applied to these surfaces can be buried under the loose soil when the slurry is shot straight at the surface, offsetting the effects of seed breakage and increasing germination potential (Mast 2007).

Fertilizers – Adding fertilizer to the slurry can reduce germination of certain species due to the effects of fertilizer salts on seed imbibition, or uptake of water (Brooks and Blaser 1964; Carr and Ballard 1979; Brown and others 1983). This is not just a problem when seeds and fertilizers are mixed together in the slurry tank; it can also negatively impact the seeds after they are applied to the soil surface and before the first rains dilute the surrounding salts. Effects of fertilizer salts will be more detrimental on sites with low rainfall. Carr and Ballard (1979) found white clover (*Trifolium repens*) and, to a lesser degree, *Festuca* spp. had the greatest reduction

Figure 10.102 – *Hydraulic seeders are equipped with several types of nozzles. The nozzle shown in photograph (A) shoots long, high pressure, streams while the fan nozzle shown in (B) spreads the slurry out for closer applications.*

in germination. They suggest white clover should be applied by hand, separate from the hydroseeding operation.

Assuming that most native seeds, especially legume species, are affected by fertilizer salts, it is important to understand what the effects of different types and rates of fertilizers will have on the salt concentrations in the slurry. Brooks and Blaser (1964), Carr and Ballard (1979) and Brown and others (1983) used inorganic, fast release fertilizers, which dissolve quickly in solution (See Section 10.1.1). Organic and control release fertilizers, on the other hand, dissolve slowly and therefore should have lower salt levels in solution. Whichever fertilizers or rates are used, testing the slurry for soluble salts should be conducted to assure that concentrations are not lethal (See Section 5.5.5).

The effect of hydroseeding operations on seed viability is an important issue and deserves more research attention. Monitoring information can be used to broaden our understanding on how to properly use this important tool.

10.3.2.5 Select Hydraulic Mulch and Determine Rates

Hydraulic mulch is a low bulk density material applied through a hydraulic seeder to increase surface soil strength and reduce erosion. At high application rates, seeds are covered, thereby increasing the potential for increased seed germination. Commercial hydraulic mulches are derived from wood fiber, recycled paper (wood cellulose), sterilized grass straw, or a combination of the three. Wood fiber mulches are manufactured from wood chips thermally treated by a steam and high pressure shredding process; wood cellulose mulches are made from waste paper materials such as recycled newspaper and cardboard (Trotti 2000). Hydraulic mulches typically have very high water-holding capacities (over a 1,000 times their weight in water). A pound of wood fiber mulch, for instance, absorbs between 1.5 to 2.5 gallons of water and, inversely, a gallon of water holds between 0.40 and 0.66 lb hydraulic mulch. This is important information to know when determining how much hydraulic mulch to add to a slurry tank. Most operators will not exceed a ratio of 0.4 to assure they do not clog their system with a slurry that is too thick. At this proportion, a 1,000 gallon tank would hold 400 pounds of wood fiber mulch. Product specification sheets should indicate the ratio of hydraulic mulch to water for hydroseeding equipment.

The depth and cover of hydraulic mulch depends primarily on the quantity and properties of the mulch placed in the tank. Typical hydroseeding projects range in application rates from 500 to 3,000 lb/ac. At low application rates (<1,000 lb/ac), wood fiber mulch will not cover the entire soil surface, leaving most seeds and much of the soil surface exposed. At high rates (>3,000 lb/ac) the soil surface and seeds are usually completely covered (Figure 10.103). With the appropriate mix of tackifiers, hydraulic mulch rates above 3,000 lb/ac can bond together

***Figure 10.103 –** Hydraulic mulch applied at high rates and with specialized tackifiers will hold together as a sheet and is referred to as a "bonded fiber matrix," or BFM. The application rate of wood fiber mulch in this picture was 3,000 lb/ac.*

to form a continuous sheet, called a bonded fiber matrix, or BFM. A bonded fiber matrix will stabilize seeds and control surface erosion up to a year after application.

The length of the wood or cellulose fibers is an important characteristic in creating a soil cover mulch that does not restrict seed germination or plant growth. Cellulose mulches have shorter fibers than wood fiber mulches and, because of this, these materials compact much easier when they are applied. Applying too much cellulose mulch can result in a soil surface that has the consistency of "paper mache." At application rates greater than 1,500 lb/ac cellulose mulch, there is a reduction in infiltration and air exchange, and seed germination and seedling establishment are decreased (Gassman 2001). Some manufacturers have overcome this problem by mixing straw, a long-fibered material, with paper mulch. Typically, cellulose mulch requires 20% to 40% more material to achieve the same uniformity of coverage as wood fiber mulch (Trotti 2000) (Figure 10.104). While recycled paper mulches are typically less expensive than wood fiber, the cost savings are partially offset by the increased amount of paper mulch used. Blended mulches (those with equal portions of wood fiber with recycled paper) are an effort to improve the characteristics of recycled paper by adding wood fiber.

The use of hydraulic mulch for seed germination becomes less important on wetter sites, especially in climates where there is little soil drying during germination (Carr and Ballard 1980). These conditions are found from fall through early spring on many sites in the Coast Range and Cascade Mountains, and microsites that include north aspects and sites shaded by vegetation. On these sites, 1,000 lb/ac or less might be sufficient for seed germination. In areas with high rainfall and erosive soils, higher hydraulic mulch rates or even a bonded fiber matrix might be needed to keep seeds and soil in place until seeds have germinated and grown into established seedlings.

10.3.2.6 Select Tackifier

Tackifiers are sticking agents that bind soil particles together and protect the surface from wind and water erosion. When applied with hydraulic mulch, tackifiers increase the effectiveness of the mulch as a soil cover by binding the hydraulic mulch fibers and the surface soil particles together. Tackifiers create water-stable surfaces, which means they are capable of repeated wetting and drying and do not lose strength after a series of rainstorms. Hydraulic mulch and tackifiers can remain effective even through a winter with high precipitation (Figure 10.105).

Selecting a tackifier can be difficult. There are numerous commercially available products on the market from which to choose. Unless you have used these products side by side in the field, it is difficult to know the difference. A hydraulic seeder operator can offer advice on tackifiers and

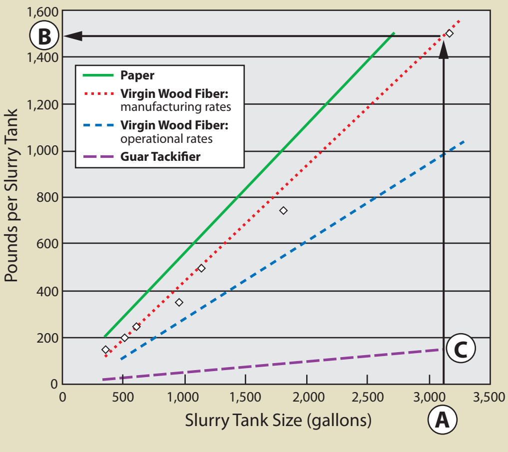


***Figure 10.104** – The slurry tank can hold only so much material before the slurry becomes too thick to pump through the system. This graph gives a general relationship between the size of the slurry tank and the maximum amount of hydraulic mulch it can hold (modified from http://www.bowieindustries.com).*
Since virgin wood fiber mulch holds more moisture than paper mulch, less virgin wood fiber mulch can be added to a slurry tank. For a project utilizing a 3,200 gallon slurry tank (A), a maximum of 1,500 lb virgin wood fiber mulch (B) can be placed in the tank with 150 lb guar tackifier (C). Guar tackifier rates are based on a ratio of 1:10 guar to wood fiber mulch. At a prescribed rate of 1,000 lb/ac of wood fiber mulch, this slurry tank will cover approximately 1.5 ac. If the application rate is 3,000 lb/ac virgin wood fiber mulch, it will take 2 tanks.

other hydraulic seeding products, since they have tried a variety of products and would usually have a good idea of effectiveness.

There are two general types of tackifiers commonly used in hydroseeding – organic and synthetic. Organic tackifiers are derived from plant materials which include guar, plantago, and other plant starches. Synthetic tackifiers are manufactured polymers and copolymers that include polyacrylamides (referred to as PAM), acrylic polymers and copolymers, methacrylates and acrylates, and hydro-colloid polymers. Organic tackifiers break down biologically and are typically effective for at least three months, depending on site conditions and product type. Synthetic tackifiers are photo and chemically degradable and have somewhat greater longevity than organic tackifiers, lasting up to a year on many sites (CASQA 2003b).

***Figure 10.105** – Hydraulic mulch with tackifiers remain effective for up to a year. This hydraulic mulch and tackifier slurry was applied nine months prior to this picture, and was still partially effective.*

Revegetation specialists and operators usually develop a preference for tackifier products based on: 1) ease of handling and storage, 2) ease of application, 3) toxicity to plants, 4) environmental concerns, 5) weather restrictions, and 6) application rates.

Handling and Storage – Tackifiers are available as dry powder or liquid formulations. Most organic and some synthetic tackifiers are packaged as dry powders. These products are easy to handle and store because they weigh less and have less bulk than liquid containers. Liquid tackifiers must be stored in areas that will not freeze if stored over the winter. Handling and disposal of plastic containers is also a consideration when using liquid tackifiers.

Ease of Application – An important property of tackifiers is viscosity. Viscosity is the measure of the "stickiness" of a tackifier, or the propensity of the tackifier to hold a slurry together when it is applied. Tackifiers with high viscosity, such as guar based tackifiers, will hold the slurry together as a fine stream when pumped from the nozzle (Figure 10.106A), and the stream of slurry will shoot farther. When a slurry with high viscosity hits the soil surface, it sticks and does not easily run off. A slurry with low viscosity, on the other hand, will separate as it is comes out of the nozzle and drift, especially if there is a breeze, resulting in uneven application (Figure 10.106B). If low viscosity slurries are applied at rates that are greater than the soil infiltration rates, the slurry will run off the surface. Not only will seeds be lost, but other materials in the slurry (including fertilizers) have the possibility of moving into surface drainage systems (Figure 10.106C).

Tackifiers act as lubricants and create less friction through the hydraulic equipment. With high viscosity tackifiers, equipment runs smoother and nozzles do not plug as frequently. This will enhance the overall performance and longevity of the equipment.

Toxicity to Plants – One reason organic tackifiers are sometimes preferred over synthetic tackifiers is the belief that these materials are better for seed germination and seedling establishment. They are organic substances that break down into non-toxic compounds. While organic tackifiers are sometimes advertised as being better for plant health, there is nothing in the scientific literature to indicate that synthetic tackifiers are any more harmful or toxic to plant establishment than organic tackifiers.

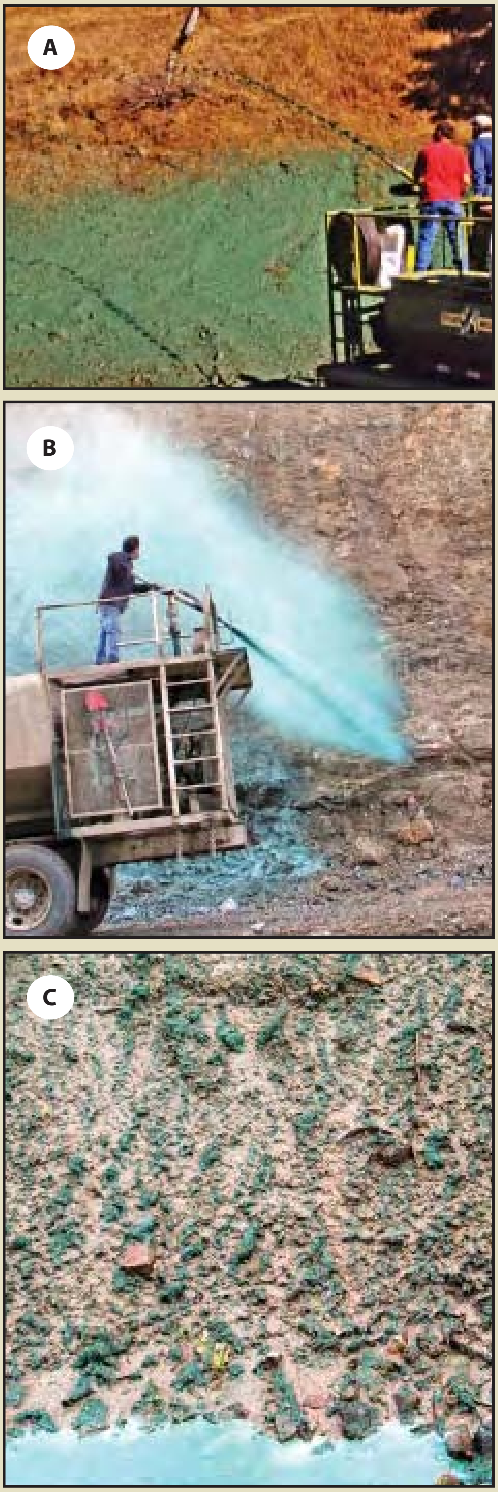
Environmental Concerns – There have been concerns about the use of polyacrylamides (PAM) on human health and the environment. Acrylamide, a known neurotoxin to humans, is the main ingredient of this polymer. Polyacrylamides alone have low toxicity – LD50 of 5,000/kg oral dosage (Peterson 2002). However, in the manufacturing of the polymer, some acrylamide is formed. The US Food and Drug Administration has set a maximum allowable acrylamide content in PAM of 0.05%. While PAM does not appear to break down in the environment to acrylamide, if released during decomposition, it is thought to be quickly decomposed by soil microbes (Peterson 2002). Furthermore, since PAM degrades slowly in the environment, there should not be an accumulation of acrylamide in the soil (Claassen and Hogan 1998). Evans (2006) cites reviews by Barvenic (1994) on health hazards and Goodrich and others (1991) on aquatic macrofauna, edaphic microorganisms, or crop species. When polyacrylamides were applied at recommended rates, the materials were found to be safe for the environment. The reader is referred to Barvenik (1994) for a comprehensive discussion of PAM in the environment.

As with all products used in revegetation, a material safety data sheet should be requested from the manufacturer of the product and reviewed for possible human effects and effects to the environment. Some states have regulations on the use synthetic polymers in landscaping. It is important to be abreast of the latest environmental regulations (Peterson 2002).

Weather Conditions **–** Tackifiers have limitations and conditions for proper application, including: soils must be moistened prior to application; there must be a 1- to 3-day drying period after application; the site cannot freeze during or immediately after application; or they must be applied between a certain temperature range. It is important to understand which environmental restrictions apply to the tackifier you are using and how it might affect the hydroseeding operations. A site that is expected to be wet in the fall, for instance, will require a tackifier that needs a minimal curing period.

Tackifier Rates **–** When tackifiers are used with hydraulic mulches, tackifiers are applied at rates at 5% to 10% of the weight of the hydraulic mulch (CASQA 2003a). Refer to manufacturer labels for specific rates.

Figure 10.106 – *High viscosity tackifiers, mixed at manufacturer recommended rates, keep the slurry together during application using a "stream" nozzle (A). Low viscosity tackifiers, or slurries with low concentrations of tackifiers, do not hold together when applied and will drift with wind (B) or run off slopes (C).*



Introduction

Initiation

Planning

Implementation Guides

Monitoring & Management

Summary

***Figure 10.107 –** Prior to hydroseeding, review the areas to be hydroseeded in the field. For each road station (column C), the length of the slope (column D) that will be hydroseeded is measured (or estimated) and recorded. This information is placed in a spreadsheet as shown in this figure and acreage for each station is made by multiplying slope length by distance between stations (column E) and converting to area units (columns F and G) (e.g., acres). During hydroseeding, the stations and percentage of area to be covered (column B) within the station are recorded for each slurry tank (column A). Partial station coverage is estimated and acreages adjusted, as shown in the last entry in this example. When the slurry is completed, the total acres for that slurry tank are summed.*

A	B	C	D	E	F	G
Tank	% Covered	Station	Slope Length (m)	Distance between stations (m)	Area (m^2)	Acres
4	100	20+1000	27	20	540	0.133
4	100	20+1020	24	20	480	0.119
4	100	20+1040	25	20	500	0.124
4	100	20+1060	24	20	480	0.119
4	100	20+1080	25	20	500	0.124
4	100	20+1100	27	20	540	0.133
4	100	20+1120	26	20	520	0.128
4	50	20+1140	28	20	560	~~0.138~~ 0.069
		20+1160	23	20	460	0.114
		20+1180	21	20	420	0.104
		20+1200	26	20	520	0.128
		20+1220	22	20	440	0.109

Acres covered by Tank 4 = 0.95

10.3.2.7 Select Other Slurry Components

The remaining components of the hydroseeding slurry can include dyes, fertilizers, biostimulants, and mycorrhizae.

Dyes – Dyes are used as markers for the applicator to indicate where the slurry has been applied. Most hydraulic mulches include dyes, so it is not usually necessary to include dyes in the slurry when using these mulches.

Fertilizers – Fertilizers are often applied through hydroseeders. Determining the type and amount of fertilizers to use is discussed in Section 10.1.1.

Biostimulants – Biostimulants are sometimes applied to the slurry.

Mycorrhizae – Mycorrhizae are often included in the slurry (See Section 10.1.7, Beneficial Soil Microorganisms).

10.3.2.8 Locate Water Source

It should go without saying that you cannot hydroseed without a water source, yet a common mistake is to wait until the last minute to locate a source. For many parts of the western United States, water sources can be long distances from the project site. It is important to establish early where water will be obtained for hydroseeding early in the planning process.

Considerations when selecting a water source include:

Distance – On projects where the water source is a long distance from the hydroseeding site, large slurry tanks will increase the efficiency of the operation. Conservation of water should be a priority in these circumstances. Covering more area with each slurry tank is one way to reduce water needs. This can be accomplished by applying lower rates of hydraulic mulch and tackifier per acre.

Water Quality **–** The quality of the water for hydroseeding must be low in salts and other potentially toxic compounds. If in doubt, send a sample to a water quality lab for testing or, at minimum, run pH and conductivity measurements on a sample.

Water Use Permits **–** Always check with the agency or landowner for permits to use their water.

10.3.2.9 Develop Hydroseeding Contract

Once a basic hydroseeding plan is developed, a contract is developed. The contract usually contains most of the following elements:

Site Location and Description **–** A general description of the site, slope gradients, location, and time of year the hydroseeding will occur should be addressed.

Products and Rates **–** The hydroseeding products or equivalent products (hydraulic mulch, tackifiers, fertilizers, and so on) are identified, and the rates per acre for each product are stated for each hydroseeding mix or mixes. The total number of acres for each hydroseeding mix must be tabulated.

Water Source **–** The location and distance to each water source are described. The contract should indicate whether it is the responsibility of the contractor to obtain agreements from owners for use or any required water permits.

Storage Area **–** The contractor will want a site to store hydraulic mulches, tackifiers, fertilizers, and other materials associated with the hydroseeding operation. The site should be in close proximity to the hydroseeding areas and relatively safe from vandalism.

Equipment **–** If specific types of hydraulic seeders are required for the job, they should be specified in the contract. Using hoses to access portions of the project site will often be necessary. The contract should specify how many feet of hose are needed and what percentage of the project will be applied by hose.

Cleaning Equipment **–** The contract must state that the tank and hoses will be cleaned from all previous hydroseeding or hydromulching projects. The equipment will be inspected and, if it does not pass inspection, the contractor will be required to clean equipment at an approved offsite location.

Weather Conditions **–** The weather conditions, based on manufacturer specifications, should be stated. The contract should specify acceptable temperature ranges and wind velocities. It should also state whether rain or freezing temperatures can occur within a specified period after application. A provision should be stated that applications will not occur on frozen ground. Some tackifiers also require that the soils be moistened before application.

Mixing **–** The contract should state that the seeds be mixed into the slurry immediately before application. It should further state that the slurry must be applied within 30 minutes after the seeds have been placed in the tank. When the seeds are in the slurry, it should be moderately agitated only enough to mix the seeds and keep the slurry from separating.

Application **–** The slurry should be applied at a rate that covers 85% of the soil surface. Slurry should not run off the soil. If it does, adjustments to application speeds or nozzles must be made. Figure 10.102 shows the spray pattern of two types of nozzles. Avoid applying slurry at a range that causes slurry to splash off the surface and soil to dislodge. A two pass method is preferred to obtain good seed coverage. In the first pass, 50% or less of the slurry is applied, followed by the second pass that applies the remainder of the material. Each pass is applied in a different direction (bidirectionally), which reduces the "shadow effect" created by just one pass and may serve to better lock the matrix together (Bill Mast personal communication).

Traffic Control **–** The contract must state how traffic safety will be ensured during application. Will the contractor be required to supply signs, warning lights, or flaggers?

10.3.2.10 Keep Good Records

Hydroseeding is a complex task. Not only are several products being applied at different rates at one time, but they must be evenly applied over large complex areas. A skilled hydroseeding operator must be at the helm, and you must keep track of what is being applied and the acres on which it is being applied. This will assure that you are getting the target amount and enable accurate payment to the contractor.

Inset 10.21 – Keeping Track of the Numbers

Hydroseeding might look easy, but keeping track of the numbers is not. Most hydroseeding operators have learned to do calculations in their heads on the run. However, unless you do this kind of work all the time, you probably will not be able to manage this along with the other requirements of being a contract inspector. As fast as this operation goes in the field, you cannot afford not to have a good record-keeping system. After all, it is your responsibility to make sure that the contract is being fulfilled.

Planned Application Rates. A hydroseeding plan is developed during the preparation of the contract that locates hydroseeding areas and defines general rates of materials to be applied. The Table 1 shows how planning information for hydroseeding can be displayed. In this example, 3 hydroseeding mixes are defined by different rates of tackifier, mulch, and seed mixes in a slurry unit. Hydro mix 1 will be applied on gentle slopes requiring only a light covering of mulch (MulchRite) at 1,000 lb/ac. Hydro mix 2 is for steeper slopes and requires 2,000 lb/ac mulch and more tackifier. Hydro mix 3 is for very erosive slopes and requires 3,000 lb/ac mulch and a different seed mix. The hydro mix locations are designated on a road map. From this table, a total quantities list of materials for the project can be made by multiplying the per acre rates by the acres for each hydro mix.

Table 1

				Slurry Unit (per Acre Rates)				
				Seed	MajiTack	MulchRite	MycoAlive	SlowGro Fertilizer
Hydro Mix	Reveg Units	Seedmix	Acres	Bags/ac	Buckets/ac	Bales/ac	Bags/ac	Bags/ac
1	A2, B1	A	2.0	4	100	1,000	10	1,000
2	B1	A	5.0	4	200	2,000	10	1,000
3	D1, D2	B	3.5	4	200	3,000	10	1,000
				Total Quantities:	1,900	22,500	105	10,500

Conversions to Product Units. When you are in the field, you do not think in terms of pounds per acre because every product comes in packages. For example, MulchRite is packaged in 45 pound bales. To make it a simple, all rates must be converted from pounds per acre to product units (Table 2).

Operational Plans. Table 3 converts the planned application rates to operational loading rates by 1) converting "pounds per acre" to "product units per acre" and 2) converting "product units per acre" to "product units per slurry tank." The key to these calculations is knowing approximately how many acres each slurry tank will cover. This is a function of the size of the slurry tank and the amount and type of mulch and other materials being mixed in each tank (See Figure 10.104 for calculating acres per slurry tank). In this example, it was estimated that hydro mix 1 would cover approximately 1.5 acres. Hydro mix 2 would cover half the area (0.75 ac) because twice the hydromulch is being applied. Hydro mix 3 would cover one third of the

Table 2

	MajiTack	MulchRite	MycoAlive	SlowGro Fertilizer
Pounds per	50	45	10	50
Product Unit:	Bucket	Bale	Bag	Bags

Table 3

				Per Slurry Tank				
				Seed	MajiTack	MulchRite	MycoAlive	SlowGro Fertilizer
Hydro Mix	Tank Size	Ac/Tank	Seedmix	Bags	Buckets	Bales	Bags	Bags
1	3,300	1.5	A	6	3	33	1.5	30
2	3,300	0.75	A	3	3	33	0.8	15
3	3,300	0.5	B	2	2.0	33	0.5	10

Keeping Track of the Numbers (Cont.)

area as hydro mix 1. The math, using the tackifier MajiTack in hydro mix 1 as an example, is 100 (shaded cell in Table 1) /50 (shaded cell in Table 2) * 1.5 (shaded cell in Table 3) = 3 (circled cell in Table 3) buckets per slurry tank. Notice the difference in some of the product unit rates, such as the "SlowGro Fertilizer."

Operations Diary. Table 4 covers the minimum amount of information that must be collected during hydroseeding operations. It captures date, time, and quantity of product units placed in the slurry tank. It is also a record of the acres that were covered by each slurry tank (See Figure 10.107 for a quick way of determining acreage). Notice that the application rates in this example (ac/tank) were variable, especially for Tank 2. This is not uncommon for hydroseeding projects. At the end of each day, Table 4 is used to summarize the amount of materials used each day and to track inventory. This table is the basis for contract payment.

Table 4

								Products				
								Seed	MajiTack	MulchRite	MycoAlive	SlowGro Fertilizer
Tank	Map Unit	Date	Start	Finish	Ac/ Tank	Water (gal)	Seed Mix	Bags/ ac	Buckets/ac	Bales/ac	Bags/ac	Bags/ac
1	A2	10/18/07	9:15	9:50	1.20	3,300	Mix 1	6	2.0	33	1.5	30.0
2	A2	10/18/07	10:10	10:50	1.80	3,300	Mix 1	6	2.0	33	1.5	30.0
3	B1	10/18/07	11:20	11:55	0.70	3,300	Mix 1	3	5.0	33	1.0	15.0
4	B1	10/18/07	13:00	13:35	0.95	3,300	Mix 1	3	5.0	33	1.0	15.0
5	B1	10/19/07	14:15	15:15	0.80	3,300	Mix 1	3	5.0	33	1.0	15.0
							Toal Quantities:	21	19	165	6	105

Actual Applied Rates. Tables 5 and 6 convert what was actually applied back to pounds per acre to compare what was originally planned from Table 1. For example, 33 bales of MulchRite was applied in Tank 4 (shaded cell in Table 4). It is converted to actual pounds per acre as follows: 33 * 45 (shaded cell in Table 5) * 0.95 (shaded cell in Table 6) = 1,563 lbs/ac (circled cell in Table 6). Compared to the original plan, this was three quarters of the planned rates because the slurry tank was applied over a greater area than originally planned. For seed rates, this means that a quarter fewer seeds were applied.

Table 5

	MajiTack	MulchRite	MycoAlive	SlowGro Fertilizer
Pounds per	50	45	10	50
Product Unit:	Bucket	Bale	Bag	Bags

Table 6

								Products				
								Seed	MajiTack	MulchRite	MycoAlive	SlowGro Fertilizer
Tank	Map Unit	Date	Start	Finish	Ac/ Tank	Water (gal)	Seed Mix	Bags /ac	Buckets/ac	Bales/ac	Bags/ac	Bags/ac
1	A2	10/18/07	9:15	9:50	1.20	3,300	Mix 1	5.0	83	1,238	12.5	1,250
2	A2	10/18/07	10:10	10:50	1.80	3,300	Mix 1	3.3	56	825	8.3	833
3	B1	10/18/07	11:20	11:55	0.70	3,300	Mix 1	4.3	357	2,121	14.3	1,071
4	B1	10/18/07	13:00	13:35	0.95	3,300	Mix 1	3.2	263	1,563	10.5	789
5	B1	10/19/07	14:15	15:15	0.80	3,300	Mix 1	3.8	313	1,856	12.5	938

The records begin with the original hydroseeding prescription. These are the planned application rates of each hydroseeding material. It is not enough to know what you want as a finished product on the site; you must understand how it will be accomplished. This means that you must translate the prescribed product quantities per acre into how it will actually be applied. These calculations can be challenging, especially when the hydroseeding operation is in full swing. It is better to have some idea how this will work before you arrive in the field. Inset 10.21 is a guide through a process of determining how much of each hydroseeding material must go into a slurry tank. These calculations, along with the contract specification, become the operation plans.

During the hydroseeding operations, the contract inspector must keep track of each slurry tank that is applied. This includes the time, amount of water, quantities of products, location, acreage, and weather conditions. Calculating the acreage of each slurry tank is important in the field to assure that the rates of materials are being applied as prescribed. This can be accomplished using a method shown in Inset 10.21, Table 4. When this information is collected, the actual applied rates of materials per acre can be made using methods shown in Inset 10.21, Table 6. This will tell you how close each slurry tank came to the prescribed rates. This is important feedback for the hydroseeder operator. If the application rates were off significantly, adjustments can be made quickly. These records can be summarized at the end of the project to determine total quantity of materials used and the number of acres covered. This information can be the basis for contract payment.

10.3.3 INSTALLING CUTTINGS

10.3.3.1 Introduction

Live cuttings have a variety of uses in revegetation projects, from stream restoration to roadside stabilization. When live cuttings are used as slope reinforcement, barriers to soil movement, or integrated into retaining structures such as rock gabions, crib walls, or rock walls, they form the living component of a soil biotechnical engineering system (Sotir and Gray 1992). In slope reinforcement, live cuttings initially play a structural role by increasing soil strength and preventing surface erosion. As cuttings establish into plants, soils are stabilized through a dense network of interlocking root systems. Soils are further stabilized during the growing season as soils dry due to increased evapotranspiration and rainfall interception.

Soil biotechnical engineering techniques are well documented. Gray and Leister (1982), Sotir and Gray (1992), and Lewis (2000) are excellent sources on road and slope stabilization, and the reader should refer to Bentrup and Hoag (1998) for streamside stabilization. Section 10.2.2 discussed how to collect and evaluate live cutting quality; this section will focus on the care and installation of live cuttings to optimize the success of biotechnical engineering and other roadside revegetation projects. For simplicity, live cuttings are grouped by general application in biotechnical engineering projects: 1) live stakes, 2) live brush layers, and 3) live fascines.

10.3.3.2 Live Stakes

Live stakes are individual cuttings that are inserted into the slope to physically stabilize the soil and, with time, grow into individual plants with dense, interconnecting roots that further increase soil stability. Live stakes are used to repair small earth slips and slumps (Sotir and Gray 1992) and as pole plantings for stabilizing streambanks (Bentrup and Hoag 1998). Joint planting refers to live stakes inserted into voids or openings between large rocks. The live stakes can take root and revegetate rock riprap sites or portions of fractured bedrock (Sotir and Gray 1992). Live stakes are also used in live fascine installations and to anchor erosion mats to the soil (Lewis 2000). In gullies, draws, or intermittent streams, live stakes are placed in rows as live silt fences (Polster 1997) to slow water velocities and catch sediments and other debris. In saturated soil conditions, where excavation for brush layering or fascines is not feasible, live stakes can be densely stuck by hand.

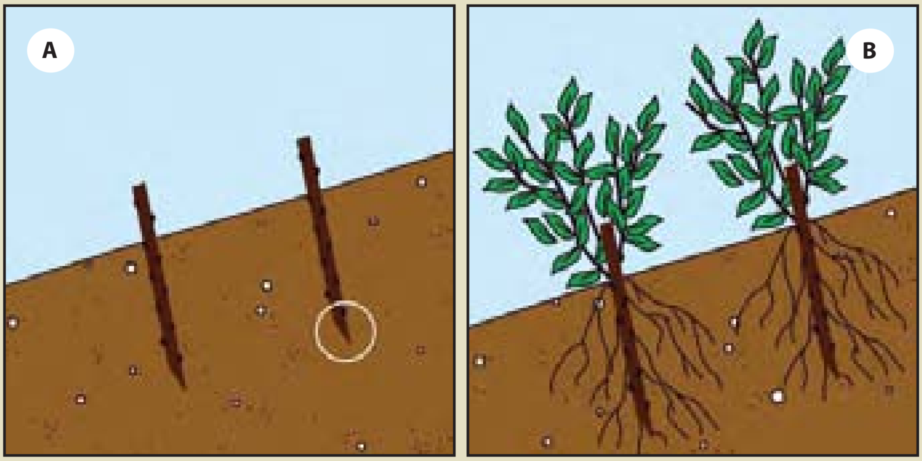
Collection **–** Live stakes are collected from the main stems of donor plants located in the wild (See Section 10.2.2) or from stooling beds in nurseries (See Section 10.2.5). The optimum period to collect cuttings is during the dormant period, after the plants have lost their leaves. If cuttings are collected outside this period, testing the viability of the cutting material is essential (See Section 10.2.2.4). It is important to collect cuttings with several dormant buds because this is where shoots will originate (Figure 10.108).

Figure 10.108 – The vertical orientation of buds on older willow (Salix spp).*stems can be visually difficult to discern (see arrows). Keeping track of the orientation of the bud from collection to installation is very important.*

When preparing stakes, all side branches are removed, leaving just the stem. Only stems with diameters between 1 and 3 inches are used. Stems are cut into lengths of 1 to 3 feet, depending on how the materials will be used. It is important to select the appropriate cutting length. Stems that are too short will affect the success of the project, and cuttings that are too long will increase the costs of the project. During collection, basal ends of the cuttings are always oriented in the same direction to assure that the buds will be aligned. This will help avoid confusion later when the stakes are being installed. Finding the orientation of the buds is often difficult (Figure 10.108) and having to reorient in the field takes time. As individual stakes are made, the top of the stake is cut flat, while the basal end is cut at an angle (Figure 10.109). This makes the stake easier to insert into the soil and orients the live stake so the buds are facing up and away from the soil surface. If buds are facing down, the live stake will not root.

During collection, live stakes are wrapped in small bundles with twine. The size of the bundle must be light enough to be easily carried. Once the bundle size has been determined, the numbers should not vary in order to track cutting quantities. Stakes should be cut from healthy donor plants. Stems that have obvious insect or disease damage should not be used. It is often easy to forget that live cuttings are plant materials, like seeds and seedlings, and must be handled and stored with care.

***Figure 10.109** – Live stakes are cut at an angle on the basal end (circle) for easier installation and to assure the stake is placed with buds facing up. Cuttings with buds installed upside-down will not develop into plants.*



***Storage* –** It is recommended that live, dormant stakes be collected and installed the same day (Sotir and Gray 1992; Lewis 2000). This is not always possible in a road construction project. When it is not, temporary storage in Forest Service district tree coolers is an option. Temperatures in these facilities should be set below 40°F and, if humidifying equipment is available, it should be kept on high. For longer-term storage (over two weeks), cuttings should be wrapped in plastic or moist burlap to prevent the vegetative material from drying out and temperatures should be set just below freezing. Lower temperatures can result in damage and even death (Wearstler 2004). As a last resort, cuttings can be temporarily stored outside, provided: 1) daily temperatures are low (<50 °F) and humidity is high, 2) cuttings are completely wrapped in plastic, 3) temperatures will not drop below 25 °F, and 4) the site is shaded from the sun.

***Preparation* –** Studies of black willow (*Salix nigra*) have shown that soaking dormant cuttings prior to installation can increase survival (Schaff and others 2002; Martin and others 2005; Pezeshki and others 2005; Pezeshki and Shields 2006). Soaking for approximately 10 days appears to be the optimum period for black willow (Schaff and others 2002; Pezeshki and Shields 2006). Soaking non-dormant cuttings, however, appears to be detrimental to survival (Pezeshki and others 2005; Pezeshki and Shields 2006). Species native to the western United States might respond similarly to the black willow. The effects of soaking can be tested in other willow species using a method outlined in Section 10.2.2.4. If live stakes are soaked in streams, it is important to be sure they are sufficiently protected from being swept downstream during high precipitation or snowmelt.

***Installation* –** For most applications, live stakes are installed perpendicular to the soil surface. When installed, no more than one quarter to one fifth of the cutting is exposed (Sotir and Gray 1992; Darris and Williams 2001). Buds are always pointing up and away from the soil surface with at least two healthy buds above the soil surface. It is essential that soil be firmly packed around live stakes so there are no large air spaces surrounding the cutting. Live stakes can be installed using techniques described in Section 10.3.4, Installing Plants. These include a shovel, auger, or expandable stinger. In addition to these methods, several techniques are available specifically for live stake installation, which include a hammer, stinger, or waterjet stinger.

Hammer or Mallet. Live stakes can be pounded into the ground using a hammer or mallet. The angled basal end of the stake is placed on the soil surface and the top of the cutting is struck. A small two by four wood block can be placed on the top to absorb the impacts and reduce the risk of splintering the stake. If splintering does occur, the splintered ends should be cut (Lewis 2000). After cutting, there must still be several viable buds above the soil surface. Using a hammer or mallet works best when soils are loose and low in rock fragments. It becomes more and more difficult as rock content or compaction increases. Smaller stem diameters are often not sturdy enough for this installation method.

Stinger. The stinger is a good method for installing live stakes on rocky or compacted soils. A pilot hole is created by mechanically pushing a metal rod into the soil. A live stake is inserted into the hole and tamped to the bottom using a hammer or mallet, as discussed above. Some operators will create the hole with the stinger and, after placement of the stake, use the face of the excavator or backhoe bucket to push the stake further into the soil. The hole created by the stinger is often larger than the diameter of the stake, and the soil must be tamped in around the cutting to reduce air space and create good soil contact. A stinger can be made by welding a long piece of rebar to the bucket of an excavator or backhoe. The stinger is limited by slope gradient and terrain accessibility.

Waterjet Stinger. The Waterjet Stinger hydraulically creates a hole for installing live stakes. A pump draws water from a stream, lake, or water truck for delivery through a hose to the stinger nozzle. As the tip of the nozzle is pushed into the ground, high-pressure water is injected into the soil, creating a slurry (Figure 10.110). When the Waterjet Stinger is removed, a stake is quickly pushed into the resulting slurry at the desired depth. As water drains from the slurry, soil settles around the cutting, resulting in good soil contact.

The advantages of using the Waterjet Stinger are: 1) it is simple to operate and transport; 2) little training is necessary; 3) production rates are high; 4) holes are deep, assuring that cuttings are planted directly into a wet environment, 5) soils are saturated around the cutting for a long period of time; and 6) the soil slurry settles around the cutting, eliminating air pockets in the rooting zone (Hoag and others 2001). The disadvantage of the Waterjet Stinger is that it requires a source of water. If the project is not near a body of water, it can be brought in using a water truck or large water storage containers placed in the back of a truck (Figure 10.111). The

Figure 10.110 – *The Waterjet Stinger (A) injects high-pressure water into the soil, turning it to a slurry (B) into which a live stake can be inserted (Photos courtesy of Chris Hoag).*

Waterjet Stinger is also limited by the amount of rock present in the soil. This equipment does not work well in soils containing gravels, cobbles, and boulders that obstruct the downward movement of the probe (Hoag 2007). Sandy soils drain quickly, so installation of cuttings with the Waterjet Stinger must be done quickly and with a little more effort. Steep slope gradients and rough terrain also limit equipment and the transportation of water. For more information on the Waterjet Stinger refer to Hoag and others (2001).

Expandable Stinger. The expandable stinger can install live stakes into all soil types and soil conditions, from rocky to compacted. It can plant long cuttings (> 4 ft), and stems of most diameters (including very small diameters). The stake is placed into the stinger, which is inserted into the soil and released, leaving the cutting at the desired depth (See Section 10.3.4.3, Select Planting Tools and Methods). This installation method can leave large air spaces around cuttings. It is therefore recommended that soils be tamped around the cutting after placement.

Hand-Sticking. Hand-sticking is appropriate in areas where soils are mucky or saturated, including recent landslides and wetlands, and cuttings can easily be inserted into the soil. Because this installation method can be done quickly, areas can be planted at very high densities (Figure 10.112).

Figure 10.111 – *A 250-gallon water tank with pump can be installed in the bed of a pickup truck to supply water for Waterjet Stinger sticking.*

Figure 10.112 – Hand-sticking cuttings at high densities is an option for saturated soils where the soils are too wet for installation of fascines or brush layers. This photograph shows leaves forming on cuttings several months after installation.

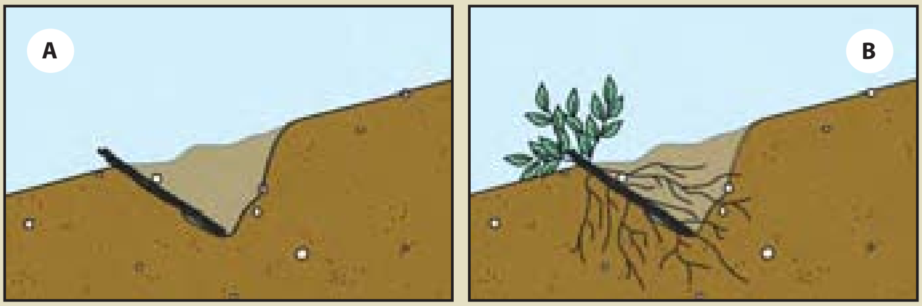
10.3.3.3 Live Brush Layers

Live brush layers are cuttings that are spread on excavated benches and covered by soil (Figure 10.113). This practice is used in several biotechnical engineering applications, including brush layers and modified brush layers. Constructing brush layers is a three-step process in which contour benches are excavated, live branches are spread across the bench surface, and branches are covered with soil from constructed benches directly upslope. The process begins at the bottom of the slope and is repeated until the entire slope is installed with brush layers. In a modified brush layer system, the brush layers are resting on, and supported by, logs or live fascines (Sloan 2001).

Brush layers and modified brush layers increase slope stability and reduce erosion by breaking slope length, reinforcing soil, trapping sediment, increasing infiltration, acting as horizontal drains, and reinforcing soil as cuttings develop roots (Sotir and Gray 1992). Live brush layers can also be used to vegetate crib walls, rock gabions, and rock walls. In this application, live branches are placed on benches that are created as these structures are built. For crib walls (Inset 10.22), live layers are placed on the bench created behind each layer of logs; in rock gabions, live layers are placed on each layer of gabion baskets.

Collection – Materials for live layering are obtained from branched cuttings collected in the wild or from stooling beds. Stems up to 2 inches in diameter can be used (Sotir and Gray 1992). The basal end of the cuttings are always oriented in the same direction during collection and bundling. Cuttings for brush layers should be long enough that the growing tips are just exposed at the soil surface, while the basal portion of the cuttings reach to the back of the bench (Sotir and Gray 1992). For rock gabions, rock walls, and crib walls, cuttings should be

Figure 10.113 – Live brush layers are cuttings that are placed on benches and covered with soil (A). The basal end of the cuttings should extend back to the base of the bench, and the growing tip should just show out of the soil. When placed on the contour and at regular intervals, live brush layers form a network of roots and vegetation that tie the slope together in a series of strips, increasing slope stability and reducing erosion.

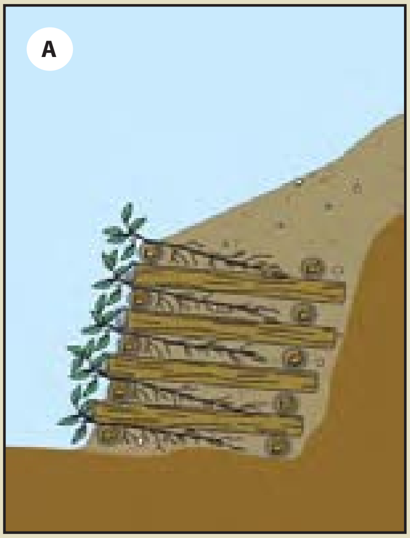


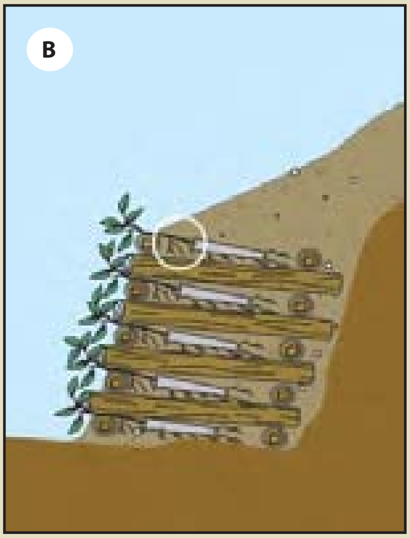
Inset 10.22 – When Should Seedlings or Rooted Cuttings be Substituted for Live Cuttings?

Live cuttings are widely used in biotechnical engineering projects. Sometimes, however, it is more practical to substitute rooted cuttings or seedlings in place of live cuttings. This is especially the case when the road project calls for cuttings to be planted in the summer or fall, when dormant, live cuttings are not available, or when live cutting material is not available in large enough quantities.

For example, a road near a wild and scenic river is being widened. Biotechnical engineering techniques using live willow cuttings are being planned for retaining walls to increase slope stability in areas adjacent to the river. The design looks good on paper (A). However when discussing the details with a revegetation specialist, question arises: where will the cuttings be collected and what time of year will the willows be installed? Upon inventorying the willow stands on the district, they learn there is not a supply of willows great enough to meet the needs of the project. To obtain this volume and size of cuttings would require the establishment of stooling beds at a nursery (See Section 10.2.5), which would take at least two years prior to project implementation. More disturbing, they learn that the contract can only be implemented in the summer due to water quality and wildlife restrictions. While some cuttings installed in the summer would sprout, most would not, as was determined through rooting potential testing (See Section 10.2.2.4). Referring back to the project objective, the design engineer and the revegetation specialist realize that going ahead with the project, as designed, would compromise revegetating the retaining wall. The decision was made to adopt an alternative design to install rooted cuttings grown in long tubes (at a nursery) instead of unrooted cuttings. The rooted cuttings would be planted at very high densities where the brush layers were to be installed (Figure B). Since only a small amount of cuttings would be necessary to start rooted cuttings in containers at the nursery, there was no need to develop stooling beds, eliminating the extra time and costs to produce these plant materials.

The stems of the long-tube rooted cuttings can be set back several feet into the soil (see circle in Figure B) as long as a portion of the foliage is above ground. This will add length to the rooting area and the stems will initiate roots (C).





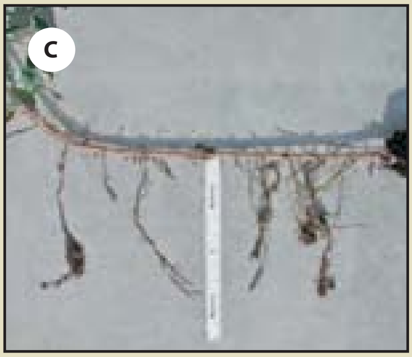
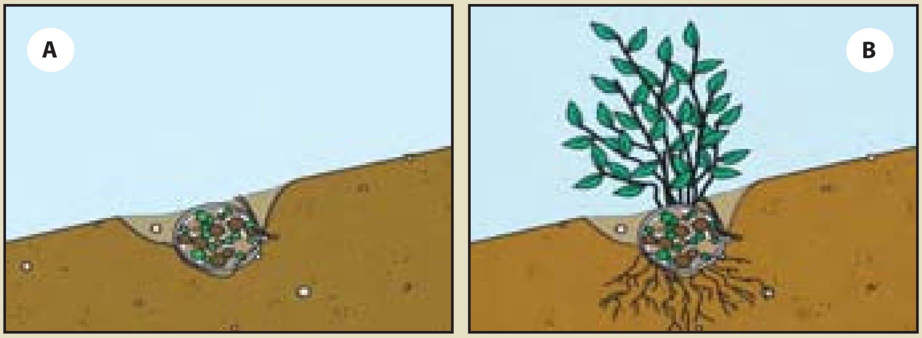


Figure 10.114 *– Live fascines are long bundles of cuttings placed in trenches constructed perpendicular to the slope. The bundles are placed in contact with the soil, with the upper portion of the fascine covered by a thin layer of soil (A). Fascines initiate shoots and roots in the spring, and are established by early summer (B).*



long enough to extend into soil or backfill behind the structures. During collection, cuttings are placed in bundles and secured with twine. Bundles should be light enough to carry. The optimum period to collect cuttings is during the dormant period, when the plants have lost their leaves. If cuttings are collected outside of this period, then testing the viability of the cutting material is essential (See Section 10.2.2.4). Fine branches dry out quickly if exposed to warm dry temperatures. Cuttings must be protected during transportation, storage, and handling to avoid drying.

Storage **–** See discussion under Live Stakes, Section 10.3.3.2.

Installation **–** Branched cuttings are laid out on benches so the basal end of the cutting reaches to the back of the bench and the growing tips extend just beyond the front. Soil is placed over the cuttings and tamped to assure there are no large air spaces. Excessive compaction is unnecessary for plant establishment and is often detrimental for long-term plant growth (See Section 5.3.3). The material used to cover live branches in or behind crib walls, rock gabions, and rock walls is often low in water-holding capacity, nutrients, and organic matter. Soil amendments, such as compost, can be incorporated into backfill material to improve water-holding capacity and to serve as a long-term source of nutrients and organic matter. These amendments can increase establishment and improve plant growth (See Section 10.1.5, Organic Matter Amendments). Waiting until after the construction of crib walls, rock gabions, and rock walls to amend the soil is not practical or feasible.

10.3.3.4 Live Fascines

Live fascines are cuttings bound together to form a long continuous bundle (Figure 10.114). When installed on the contour, live fascines slow runoff, increase infiltration rate, capture sediments, reduce slope length, and revegetate the site (Sotir and Gray 1992). Live fascines have a good potential for quick establishment because of the high density of buds near the surface of the soil. Live fascines can quickly send out shoots and roots early in the growing season and become established before summer (Figure 10.114).

Fascines are used in the construction of live pole drains to drain saturated slopes, small slumps, or gullies (Polster 1997). Live pole drains are designed to intercept surface water from unstable slopes or seepage areas, and transmit it through a system of interconnecting bundles to more stable areas (See Section 5.7.3). The constant supply of intercepted water encourages vigorous growth of the cutting material into a continuous stand of vegetation. Fascines are also used as the base or support in the construction of modified brush layers. Live fascines have great potential for establishment because of the high density of buds just under the surface of the soil. These buds can emerge quickly in late winter and early spring. Because they are installed at the soil surface, live fascines are more prone to drying out than live brush layers or live stakes. For this reason, live fascines are more successful on moist sites or in conjunction with live brush layering or live staking.

Collection **–** Branches and stems up to 2 inches in diameter are collected from the wild or from stooling beds and gathered to form a long continuous bundle. Fascines vary in length

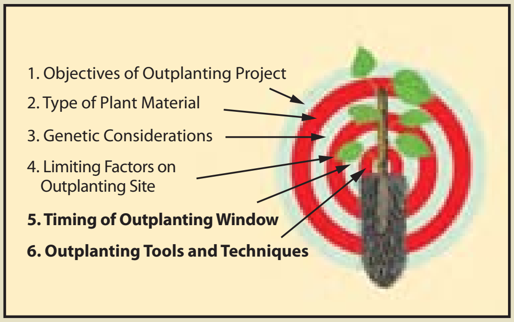


Figure 10.115 – *The final two steps of the Target Seedling Concept, the Outplanting Window and Planting Tools and Techniques, must be considered before initiating planting projects (adapted from Landis and Dumroese 2006).*

from 5 to 30 ft, and from 6 to 8 inches in diameter. For large projects, constructing a series of sawhorse-type structures makes this operation easier and more efficient (Sotir and Gray 1992). At frequent intervals, bundles are secured with twine to hold the fascines together. Cuttings should be collected during the dormant season, when the plants have lost their leaves. Fine branches dry out quickly if exposed to warm dry temperatures and must be protected during transportation, storage, and handling.

Storage – See discussion under Live Stakes, Section 10.3.3.2.

Installation – Prior to installation, trenches should be created at the proper depth so the top of the fascine is flush to the surface of the slope when installed. The shape of the trench should allow soil contact with all portions of the bundle. Soil is tamped down around the sides of the bundles to assure soil contact, and the upper fifth of the bundle is covered by a thin layer (<1 inch) of soil. A very small portion of the fascine should be exposed, but not enough to dry the stems. If the fascine is buried too deeply, vegetative growth will be restricted.

10.3.4 INSTALLING PLANTS

10.3.4.1 Introduction

Although a wealth of information exists about planting for reforestation, very little information has been published about planting nursery stock on roadsides. Several references can be found discussing harsh site reclamation. Ashby and Vogel (1993) is an excellent source for planting on restored minelands.

Before beginning a planting project, the revegetation plan and plant production contract should be reviewed carefully, as should the Target Seedling Concept (Figure 10.115) which was considered during the planning process (See Section 6.4). The first four steps were covered when plants were ordered during the planning process. The timing of the outplanting window and planting tools must be considered at this time.

Timing of the Outplanting Window – The outplanting window is the period of time in which environmental conditions on the outplanting site are most favorable for survival and growth of nursery stock (Figure 10.116). The outplanting window is usually defined by limiting factors, and soil moisture and temperature are the usual constraints. In most of the continental United States, nursery stock is outplanted during the rains of winter or early spring when soil moisture

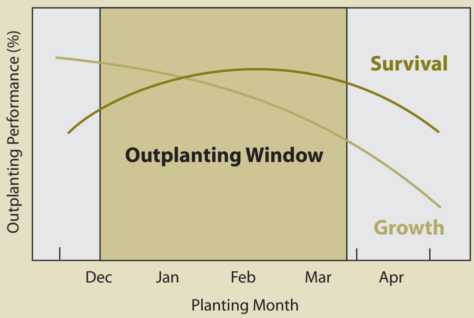


Figure 10.116 – *The best time to plant your project site (the "outplanting window") will depend on local weather and soil moisture conditions. In the Pacific Northwest, this is typically during late winter or early spring, when soil water content is high and atmospheric drying potential is low (modified from South and Mexal 1984).*

Figure 10.117 *– This type of spreadsheet helps calculate how many plants of each species are needed and should be developed for each planting area. This example includes quaking aspen (POTR5), ponderosa pine (PIPO), and Saskatoon serviceberry (AMAL2), but can be extended to accommodate more species.*

	Revegetation Unit	Plant Species			Units	Definition
	2	PIPO	POTR5	AMAL2		
A	Planting area:	0.75			acres	Area that will be planted
B	Target plant spacing:	9	14	20	feet	Desired distance between established plants
C	Ave. survival potential:	95	70	70	%	Percent of seedlings that survive after one growing season
D	(43,560 ∗ A) / (B ∗ B) =	403	167	82	plants	Desired number of established plants after one growing season
E	D ∗ (100 / C) =	425	238	117	plants	Number of nursery plants that need to be planted

is high and evapotranspirational losses are low. Fall outplanting is another option on some projects, especially when dormant and hardy plants can be installed just before the normal rainy season begins. Planting during the summer is usually discouraged because the nursery stock is not dormant and will experience severe transplant shock. If nursery stock is carefully handled and plants can be irrigated, then summer plantings are possible.

Planting Tools and Techniques – Nursery stocktype and the conditions on each outplanting site must be considered before planting begins. All too often, planters develop a preference for a particular planting implement because it has worked well in the past. However, no one tool will work for all types of nursery plants and under all site conditions. Size of nursery stock, in particular the depth and width of the root plug, is the critical consideration. Tall pots, for example, have an unusually deep root plug, which makes them difficult to plant properly with standard tools. For some types of plants and especially for large planting projects, it may be necessary to buy or rent specialized equipment, which must be secured in advance. The planting tools recommended for roadside revegetation projects are discussed in Section 10.3.4.3.

10.3.4.2 Define Planting Areas

When construction is completed, the project site is assessed for planting. A detailed map showing the exact planting locations and conditions is developed by reviewing each location on the ground. Each area should be identified on a map and described in a spreadsheet by:

- Planting area acreage,
- Planting patterns,
- Plant spacing (density),
- Survival potential, and
- Species and stocktype mix.

Figure 10.118 *– This spreadsheet is a practical way to calculate the area of each planting unit.*

	A	B	C	D	D
1	Station	Slope Length (m)	Distance Between Stations (m)	Area (m^2)	
2	2 + 1000	3	20	60	= B2 * C2
3	2 + 1020	4	20	80	= B3 * C3
4	2 + 1040	6	20	120	= B4 * C4
5	2 + 1060	7	20	140	= B5 * C5
6	2 + 1080	6	20	120	= B6 * C6
7	2 + 1100	4	20	80	= B7 * C7
8	2 + 1120	2	20	40	= B8 * C8
9					
10		Totals	m^2	640	= SUM(D2:D8)
11			ft^2	6,888.90	= D10 * 10.76391
12			Acres	0.16	= D11 / 43,560

With this information, a planting strategy can be developed for each planting area using calculations similar to those shown in Figure 10.117.

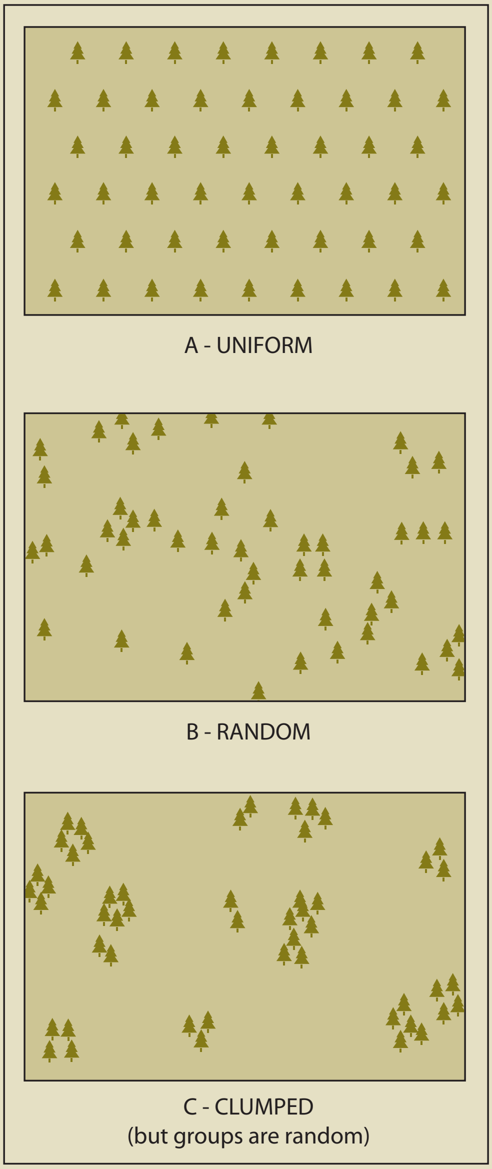
Size of Planting Areas **–** The first step is to measure the area of each planting unit. Although they could be calculated from blueprints, the true planting areas should be measured on-site. A practical method is described in Figure 10.118.

Planting Patterns **–** The pattern at which nursery stock is planted is critical for creating a more natural and visually pleasing roadside experience. Most planters have learned to install plants at uniform spacing and in rows (Figure 10.119A). Although uniform patterns ensure that all plants have equal growing space, it is not natural. Planting seedlings in groups (Figure 10.119B) or clumps (Figure 10.119C) is more visually appealing and more ecologically functional.

More specific considerations about planting patterns are based on project objectives and site characteristics of the area. A typical example would be using plants to screen potentially dangerous or visually sensitive areas, such as large cuts and fills or obliterated roads. Determining where trees or shrubs are to be planted to meet these objectives can only be accomplished by driving the newly constructed road and making these decisions in person.

Plant Spacing **–** The planting spacing or density (See Section 10.2.6.4) will determine how quickly an area will be screened by vegetation. The higher the density, the more plants are required. Selecting the appropriate density must be based on the existing vegetation density recorded at reference sites, as well as both short- and long-term project objectives. It must also be based on the expected survival rates of the planted stock, since not all planted stock will survive.

Figure 10.119 ***–*** *The objectives of the outplanting project and desired appearance affect planting patterns. If the objective is rapid growth and quick site coverage, the plants can be regularly spaced (A). However, plants spaced in a more random pattern mimic natural conditions (B), and a random clumped pattern where different species are planted in groups is often the most natural appearing (C) (adapted from Landis and Dumroese 2006).*



Survival Potential **–** Each planting area must be assessed for its unique site characteristics, such as rock content, soil depth, accessibility, steep slopes, and poor accessibility. These will determine the stocktype and species selection, method of planting, and the difficulty of transporting large plants to the site. The identified site limitations will determine the expected survival rates; target survival rates should be at least 70% to minimize the costs of site preparation and anticipated replanting.

Species Mix and Stocktype **–** Each planting area will have a different mix of species and stocktypes based on the site characteristics and project objectives defined during the planning stages. This is a refinement of those plans, based on site specific evaluation of the area. Trees and other large woody plants are considered "keystone species" because of their sheer size and longevity. These structurally and functionally dominant plants play a pivotal role in restoration plantings because they generate physical structure and create ecological niches for many other species. This fosters the in-seeding of other plants, resulting in a more natural and visually appealing landscape.

10.3.4.3 Select Planting Tools and Methods

One planting method will rarely work for all planting areas in a revegetation project. Roadside sites offer some serious challenges to planting nursery stock, most notably highly compacted soils and often a high percentage of rock. Road projects create the opportunity for unique situations such as planting islands.

The most common type of planting method is manual planting using a shovel. Recent developments in mechanized planting equipment have increased tools available. The most common types of planting tools for roadside revegetation sites are described below:

Shovel **–** The versatile "tile spade" shovel (Figure 10.120A) is the first choice for compacted soils and stocktypes used in roadside revegetation. Forestry supply companies sell a specialized planting shovel with a 14 by 5 inch blade, a welded reinforcement plate on the back of the blade (Figure 10.120B), and rubber padded footplates (Figure 10.120C). Shovels work well when planting both bareroot and container stock, as well as bulbs and other plant materials that do not require holes deeper than one foot. Working the shovel blade back and forth breaks up compacted soil and can create a planting hole for large container stock (Figure 10.120D). Sites must be accessible for hand planters, and the soils not too rocky or shallow. Very steep slopes (1:1 or greater) make shovel planting very slow and difficult.

Power Auger **–** Power augers can be an excellent and efficient way to excavate holes for planting (Figure 10.121A). Many types of augers are available: 1-person operated, 2-person operated, and a chain saw modification. A wide variety of auger sizes means that this one implement can work for many stocktypes. Augers are particularly good for large container stock. For example, a four-inch auger bit will create planting holes that will just fit the root plug of a "Tall Pot" container plant, ensuring good root-to-soil contact (Figure 10.121B). In a comprehensive review of planting tools, Kloetzel (2004) concluded that, when container size is larger than 336 ml (20 in^3), power augers will boost production under most soil conditions. It is most efficient to have one person operating the auger, with several people planting behind him/her. Auger planting is effective on restoration sites because one person determines the location and pattern of the planting holes. Production rates are reduced with rocky or compacted soils, but a drill

Figure 10.120 **–** *Specialized "tile spade" shovels are ideal for planting a wide variety of nursery stock on restoration sites (A). Commercial planting shovels feature a reinforced blade (B) and rubber-padded footplates (C). Working the long shovel blade back and forth breaks up compacted soil and creates planting holes deep enough for large container stock (D).*

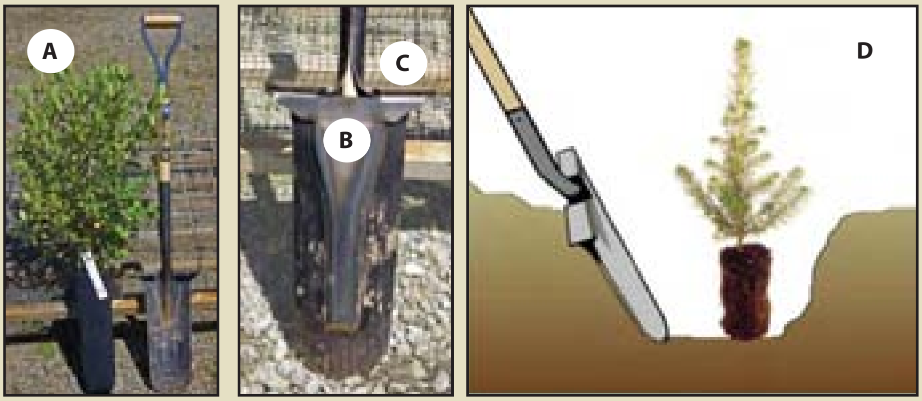


Figure 10.121 – Power augers are effective because one trained operator determines the depth and spacing of the planting holes (A). Auger bits come in a variety of sizes to accommodate the large stocktypes favored in restoration plantings (B).

auger with a special bit has been developed for planting large container stock in rocky soils (St. Amour 1998).

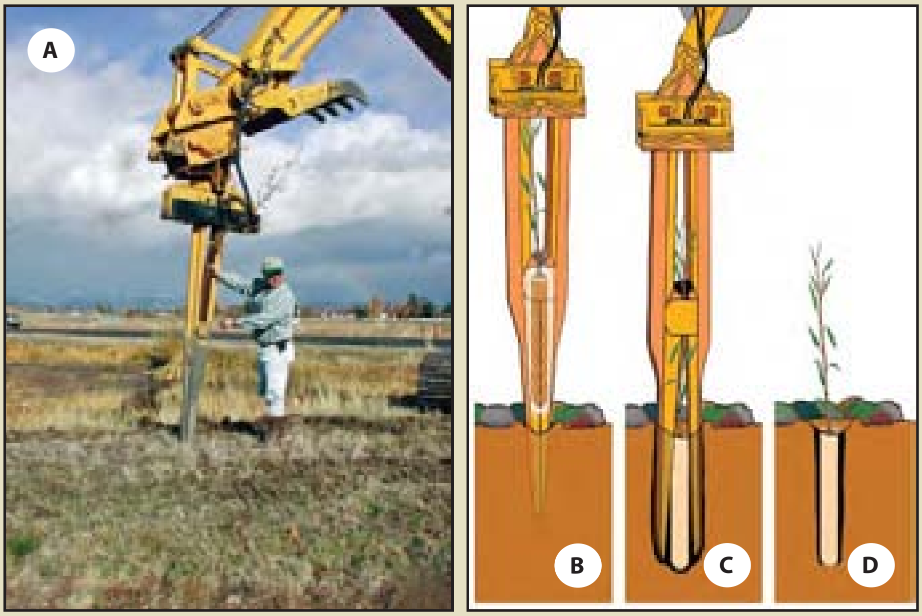
Expandable Stinger **–** Specialized planting equipment is needed for the rocky and steep slopes that are often found along forest roads. The original stinger was a pointed metal bar that was hydraulically forced into the soil to plant willow and cottonwood cuttings. The expandable stinger is a recently developed planting device attached to the arm of an excavator (Figure 10.122) that creates a hole and plants the seedling all in one operation. The planting head is composed of two parallel steel shafts, which are hinged in the middle to open and close in a scissor-like manner. Each shaft is constructed to create a long hollow chamber between them when closed. The opening and closing of the shafts are hydraulically driven. When the shafts are closed, the stinger comes to a point and is pushed into the soil by the force of the excavator arm. A long hardwood cutting or container plant is placed into the chamber. The expandable stinger is maneuvered to the planting spot, where the beak is inserted into the soil. When the beak opens, the seedling drops to the bottom of the hole leaving, the seedling in place (Figure 10.122B-D).

Two expandable stinger models are currently in use. The single-shot model inserts plants one at a time and averages between 50 to 80 seedlings per hour. The 50-shot model contains a rotary magazine that can hold fifty plants of up to three different species and can double the planting rate of the single-shot model (Kloetzel 2004).

The advantage of this equipment is that it can reach very steep cut and fill slopes, sites that are inaccessible by other planting methods. Smaller excavators can reach 25 feet, while larger machines extend planting up to a 50 foot radius, which is adequate for most cut and fill slopes. This equipment can also plant in very rocky soil conditions, including rip-rap and gabions, and can insert plants up to 6 feet. With the typically compacted soils on roadside sites, the action of the beak of the expandable stinger breaks up the compaction around the planting hole. While soil typically falls back around the root plug after the expandable stinger has planted the seedling, it is still important to determine whether additional soil needs to be filled and tamped around the plant. Poor soil contact with the root system can reduce survival and growth during establishment.

The major drawback to the expandable stinger is the expense. Because of the high hourly rate of an operator and equipment, the expandable stinger must be working at full capacity at all times. Good planning is essential. This means that all the planting sites are laid out before the

Figure 10.122 – The expandable stinger is operated by placing a long container or hardwood cutting into the chamber (A). The arm of the excavator pushes the point of the stinger into the soil to the appropriate planting depth for the root system (B) and the beak opens, shattering the soil (if it is compacted) and creating a hole (C). The stinger is removed and the plant remains in place as soil collapses around the sides of the plug (D).



equipment arrives, there is a clear understanding of species mix and planting for each planting area, seedlings are on the site and ready for loading into the equipment, and there is enough personnel to keep the equipment going. In a well-planned operation, the expandable stinger can plant up to 200 seedlings in an hour. In addition to the hourly operating costs, the mobilization costs can be very high, especially if the excavator and expandable stinger must be transported across several states. These costs must be spread across all seedlings being planted for a true cost. The more seedlings that are planted by the expandable stinger at one construction site, the less it will cost per planted seedling. Larger planting projects (>1,500 seedlings) spread these costs over more seedlings and make expandable stinger projects economical.

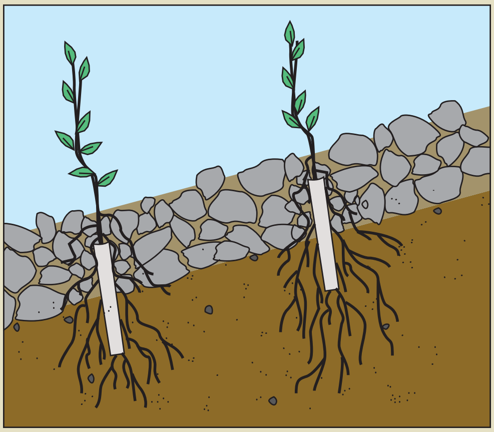
Pot Planter – The pot planter is a modification of the waterjet stinger (See Section 10.3.3, Installing Cuttings) that creates planting holes large enough for container plants. Like the waterjet stinger, it draws water from a water source (e.g., a lake, stream, water truck) and hydraulically creates a planting hole as the tip of the high pressure nozzle is pushed into the soil (Figure 10.123A). The pot planter has 3-inch vanes attached to the sides of the nozzle, which create holes large enough for containers up to one gallon (Figure 10.123B). The hole that is created by the pot planter is actually a soil slurry that is displaced when the root plug is pushed into it at the desired planting depth. Once the water drains from the slurry into the surrounding soil, the soil settles in around the root plug, assuring good soil-to-root contact.

The advantages of using a pot planter include: 1) container plugs are thoroughly moistened at outplanting, 2) there are fewer air pockets in the soil and better root-to-soil contact, and 3) soil around the planting hole is moistened, allowing roots more time to move out of the plug and into the native soil. These advantages create the opportunity for earlier fall planting dates, even as early as late August to early September in some areas. The earlier the fall planting, the greater the chance for rooting to occur before winter sets in. This rooting will be in addition to the root growth that occurs the following spring and can make the difference in whether a seedling survives the first growing season. Large containers can be planted quickly at a rate of approximately one plant per minute (Hoag 2006). The pot planter is limited by the same factors as the waterjet stinger, which include steep slope gradients, inaccessibility, high soil rock content, and poor water source availability.

Figure 10.123 – *The pot planter creates a planting hole by injecting high pressure water into the soil (A). Once the soil is liquefied, the container is pushed into the soil to the appropriate depth (B).*

Planting into Engineered Structures – There are occasions when seedlings will be planted as engineered structures are being built. These structures include vegetated gabion walls, riprap, and retaining walls (See Inset 10.22 in Section 10.3.3). Planting must be well planned and integrated into the construction schedule. Since road construction often takes place in the summer when plants are in full growth, special handling methods and irrigation must be implemented during installation to assure optimum seedling establishment (Figure 10.124). Installing plants into riprap, for example, requires good planning and integration into construction activities. Drawings and a set of planting instructions are essential. Seedlings are partially planted in the existing soil and partially in riprap. Riprap and soil is hand placed around the seedling plug to assure good root–to-soil contact and that the seedlings are handled with care. The remainder of the riprap is placed and the seedlings are irrigated. Each vegetated engineered structure will require different sets of instructions and drawings that are specific to the objectives and environmental conditions of the site.

Figure 10.124 – *Engineered structures of gabions and riprap require tall nursery stock and special installation techniques. When properly done, however, plants survive and grow well and greatly increase the visual appearance of the structure.*



10.3.4.4 Assess Plant Inventories

Depending on the size and scope of the project, there may be many combinations of species, seedlots, and stocktypes being grown at one or more nurseries. Seedling inventories from all nurseries where your stock is being grown must be consolidated into one list. Each nursery will supply a list of the quantity of seedlings in each seedlot that meet the contract specifications. Do not be surprised if this list does not exactly meet your original order. It is rare that the original seedling order ever gets filled exactly as requested. Some seedlots grow well, while others grow poorly, and this is reflected in the seedling inventory. You will find there are more seedlings in one seedlot and less in another.

Plant inventories do not always give the full story about seedlots. Prior to putting together a planting plan, a visit to the nurseries will give a full picture of the status of each seedlot. Stressed seedlings, poor roots, root-bound seedlings, disease, and other problems can only be realized by visiting the nursery months before plants are received. The visit to the nursery is not always a negative fact finding mission. It should be approached as a problem-solving trip. For example, an inventory might indicate that certain seedlots do not meet size specifications. A closer review at the nursery may show that many of the seedlings that do not meet size specifications would be suitable in certain planting areas. If inventories are low, discussions with the nursery manager might bring up the possibilities of substituting surplus seedlots from other clients for the downfall in your inventory.

10.3.4.5 Match Inventories to Planting Area

At this point, the information developed during the location of planting units, including seedling density, species, and stocktype, must be reevaluated in light of the newest seedling inventory. In other words, the seedlings from the inventory must now be divided between planting areas in a manner that still meets the project objectives.

Using the spreadsheet in Figure 10.125 is a simple way to reconcile the differences between the plants needed at each planting area and the plant inventory. In this example, three planting areas are defined (A1, A2, and B). For each planting area the number of plants of each species/stocktype are listed. The planned needs are summarized in Line A. When the seedling inventory (Line B) is received, it is discovered that there will not be enough ponderosa pine (PIPO) or quaking aspen (POTR5) to meet the planned needs. The deficits are circled in Line C. In this example seedlings can either be obtained from other sources, or the plant needs can be adjusted downward. In this example, the PIPO and POTR5 were adjusted downward because no substitute trees could be found to make up the difference. AMAL2 (Saskatoon serviceberry) was adjusted upward as a partial substitution for the shortfall of tree seedlings. Planting spacing was recalculated from Figure 10.117 with a resulting increase of approximately 1 ft for both PIPO and POTR5. The extra PUTR2 (antelope bitterbrush) and PREM (bitter cherry) were not planted (Line F), but surplused to a local landowner. Many more rows and columns can be added to this spread sheet to accommodate more species and planting areas.

Figure 10.125 *– Spreadsheets are a handy way to keep track of nursery orders and adjust plant inventories to planting needs.*

Planned Seedling Needs

	Species & Stocktype				
	PIPO	POTR5	AMAL2	PUTR2	PREM
Planting Areas	2 Gal	1T18	1T12	1STP	1STP
A1	425	238	117		
A2	75	25	35	100	
B		275			50
A Planned Needs	500	538	152	100	50
B Seedling Inventory	400	435	200	125	75
C Difference	-100	-103	48	25	25

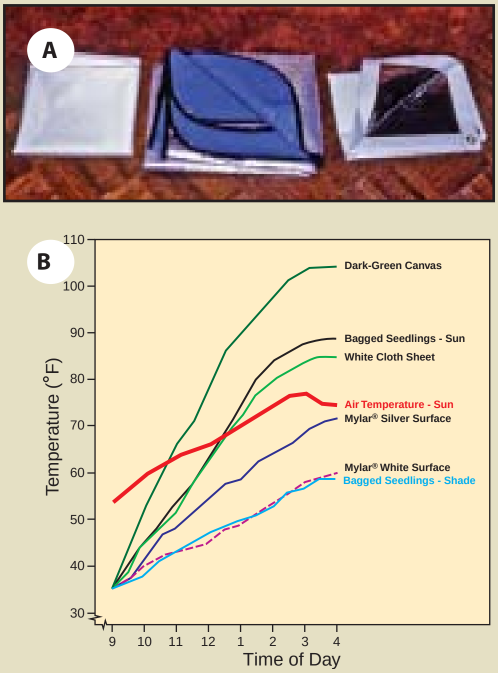
Adjusted Seedling Needs

	Species & Stocktype				
	PIPO	POTR5	AMAL2	PUTR2	PREM
Planting Areas	1 Gal	1T18	1T12	STP	STP
A1	350	200	155		
A2	50	10	45	100	
B		225			50
D Adjusted Needs	400	435	200	100	50
E Seedling Inventory	400	435	200	125	75
F Difference	0	0	0	25	25

10.3.4.6 Transport Plants

The delivery of seedlings to the planting site is not generally the responsibility of the nursery. It can be an item in the seedling production contract, a separate transportation contract, or you can transport them yourself. Whichever way you decide, remember that seedlings can be easily damaged during transportation by poor handling, hot temperatures, or drying conditions. Plants that have been packed in bags or boxes are protected from drying conditions and can be transported in most vehicles. If containers are transported in open pickups, they should be covered with a space blanket or special tarps to moderate temperatures and minimize the potential for desiccation (Figure 10.126). Specially-constructed Mylar® tarps can be purchased from forestry or restoration supply companies.

Figure 10.126 – During transportation and on-site storage, nursery stock should be covered with special reflective tarps (A) which have been proven to reduce temperature buildup (B).



Plants that have been kept in freezer storage should be thawed prior to transportation and planting. While small container stock has been shown to have satisfactory survival when planted frozen, there is no indication that large stock will perform the same. Once frozen seedlings have been thawed or cooler-stored seedlings have been allowed to warm, they should be planted immediately. Seedling viability will decrease if they are placed back into cold storage for more than a few days.

Plants that have not been packed in storage containers must be transported in enclosed units. Transporting plants in open vehicles, such as pickups, exposes foliage to strong, drying winds which can unduly stress the plants. Large container plants typically stand 2 to 4 feet tall (including the container) and require transportation with enough space to accommodate the size.

10.3.4.7 Develop Planting Contract

The following discussion outlines some of the basic components that should be addressed in a planting contract.

Location – A map of the planting areas should be included in the contract.

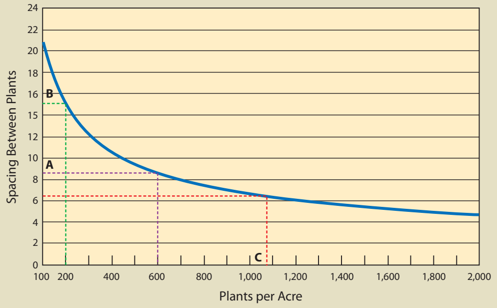
Planting Quantities – The quantity of species, by stocktype, must be presented for each planting area.

Planting Method – There might be several planting methods which should be indicated for each stocktype and planting area.

Plant Spacing Requirements – For each planting area, describe or define the plant spacing at which each species will be planted. Calculations to determine the proper spacing between plants was presented in Figures 10.117. Approximate distance between plants can be determined graphically by knowing the target plants per acre, and, in reverse, the plants per acre can be determined by knowing the target spacing between plants (Figure 10.127). For example, if the plan calls for a density of 600 seedlings to be planted per acre, the spacing between plants would be around 8.5 feet (Figure 10.127A). If the plan calls 600 seedlings to be planted in planting pockets of three plants per pocket, there would be 200 planting pockets spaced approximately 15 feet apart (Figure 10.127B). In another example, if you want to know the number of seedlings to order for a given area with a target spacing of 6 feet, the number of plants required would be just under 1,100 seedlings (Figure 10.127C).

These spacing requirements are an average. Depending on the plantability of a site, the specified average spacing may vary up to 25% in any direction to find a suitable planting spot. Where an unplantable spot is encountered, the planter will plant in the closest plantable spot. Whenever possible, plants should be installed next to stumps, logs, or other obstacles that provide partial protection from sun, wind, and animals. If planting islands are designed into the planting areas, each island should be marked within the planting area by the contract inspector and the species mix should be stated in the contract.

Figure 10.127 *– Approximate distance between plants can be determined from this graph by knowing the target plants per acre, and, in reverse, the plants per acre can be determined by knowing the target spacing between plants.*



Handling Care **–** Plants must be handled with care to prevent damage to roots and foliage. Seedlings must not be thrown, dropped, hit, or otherwise mechanically impacted. Extracting the root plug from the container must be done gently, avoiding excessive force when pulling the seedling from the container. Seedlings should not be removed from containers until the hole is excavated. The container is then removed, and the seedling is quickly planted. Excessive exposure of the root system to the air will decrease seedling survival and growth (Greaves and Hermann 1978).

Root Pruning **–** The bottoms of some containers are poorly designed, causing roots to circle or build up at the bottom of the pot (Figure 10.128A). These damaged roots must be cut prior to planting to prevent potential root strangling, especially for tap-rooted woody species (Figure 10.128B). Root pruning is best accomplished at the nursery, but must be stated in the growing contract to cover the added expense. Pruning in the field is not recommended because of the increased root exposure. However, it may be necessary when nursery stock arrives with constricted roots.

Figure 10.128 *– Roots will circle and accumulate at the bottom of some container types (A), especially if the stock has been held too long. Pruning these roots at planting will ensure that new roots will promptly grow out into the surrounding soil (B).*

Container Moisture – Root plugs that are dry must be thoroughly moistened prior to planting. Irrigating seedlings at the nursery several days before shipping and again on the day of shipping assures that root plugs are completely wet. These instructions must be conveyed to the nursery manager prior to picking up the seedlings. Provisions should be in the contract that addresses the need for wetting root systems should they be dry at the time of planting. Wetting root plugs can be accomplished by dipping seedling containers into a large water container, such as a cattle trough or trash can, prior to planting. Planting seedlings using the pot planter assures that the root plugs are wet at planting.

Temporary Storage – If container plants cannot be planted in one day, they can be stored in the field in a well-sheltered area protected from the sun and animals. Reflective tarps are recommended to keep plants cool and moist during on-site storage (Figure 10.126). If container plants are left out for several days, the root plug should not be allowed dry out. If they do lose moisture, the containers must be irrigated prior to planting. Plants that have been extracted and placed in storage boxes or bags should not be left on–site, but returned to a local cooler for storage.

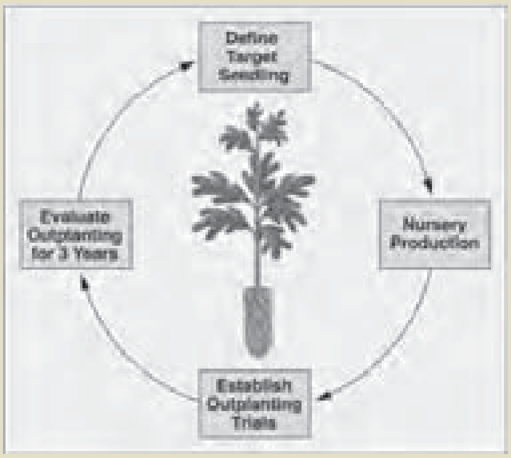
Planting – Prior to preparing the planting hole, the planters must clear the surface of the planting spot of all limbs, logs, snow, duff, litter, rocks, and other loose debris. If sod, crowns of living plants, and roots are present, they must be scalped down to moist mineral soils. Clearing and scalping dimensions must be stated in the contract. Planting holes shall be located near the center of the prepared planting spot and they should be dug vertically rather than perpendicular to the ground surface. The planting hole should be three to four inches deeper than the total length of the root system or root plug, and wide enough to fully accommodate the width of the root system. Seedlings should be placed in the hole so that the cotyledon scar (the bump or constricted area on the seedling stem that is the transition from the root system to the stem) is one inch below the ground line. Species that can be rooted from cuttings can be planted deeper, since portions of the stem will root when buried. The root plugs should not be forced into the planting hole, distorted, or broken during planting. After placing the plant in the hole, excavated soil is placed firmly around the root system so there is no loose soil or air pockets around the root plug. The root system must not be damaged during this operation. A small circular water-holding basin can be created around each seedling after planting to capture water or store irrigation water.

10.3.4.8 Administer Contract

The planting contract inspector must 1) schedule the shipment of seedlings from the nursery, 2) be certain that root plugs are moist and ready for planting, 3) have the right quantities of plants at each planting area, and 4) inspect the contract. In addition, if there are special planting patterns designed for the planting area, these may need to be marked on the site prior to planting.

The planting inspector must determine if the conditions are favorable for planting. Seedlings should not be planted into dry soil unless the planting spot is irrigated immediately after

Figure 10.129 – _Monitoring the survival and growth of nursery stock for several years after planting provides valuable information for future projects._



planting or the pot planter method is being used. Under certain circumstances, high moisture soils follow geomorphic features, such as creek or river terraces where high ground water brings moisture to the soil surface. These sites should be identified on the ground at the time of planting.

10.3.4.9 Monitor Planting Success

Valuable information can be gained by monitoring nursery stock for several years after planting. The first few months are critical because nursery plants that die immediately after outplanting indicate a problem with nursery stock quality. Plants that survive initially, but gradually lose vigor, indicate poor planting or drought conditions. Therefore, plots must be monitored during and at the end of the first year for initial survival. Subsequent checks after 3 years will give a good indication of plant growth potential (Figure 10.129). This performance information is then used to give valuable feedback to the nursery manager, who can fine-tune the target specifications for the next crop.

10.4 POST INSTALLATION CARE OF PLANT MATERIALS

The first year after plant materials are installed on a project site is typically the most critical period in a revegetation project because this is when plants become established. Applying the appropriate mitigation measures to improve the site and soil conditions prior to installation of plant materials greatly increases the chances of plant establishment. Sometimes even these measures are not enough to overcome limiting site factors. The implementation guides in this section cover several post installation measures that can be done to increase the potential of plant establishment.

Establishing plants from nursery stock is often limited by animal browsing. Section 10.4.2, Animal Protection, covers the methods available for protecting plants from different forms of animal damage. On hot, dry sites, plants need to be shaded from mid to late afternoon solar radiation. The application of shade cards, Section 10.4.3, is one method for protecting young plants from heat stresses. Moderating the climate around plants from extreme temperatures and high evapotranspiration rates is sometimes accomplished through the use of tree shelters. Section 10.4.4, Tree Shelters, outlines when these structures are used, product types, and how they are applied. Some projects require supplemental irrigation for establishing seedlings on extremely dry sites. Section 10.4.5, Irrigation, discusses two types of irrigation used in revegetation projects – deep pot irrigation and drip irrigation.

10.4.1 INTRODUCTION

The first several years after the installation of seedlings are critical for the survival of healthy nursery plants. In the western United States, nursery plants die because of animal damage, high surface temperatures, high evapotranspiration rates, lack of soil moisture, and vegetative competition. In this section, we will discuss certain steps to reduce these impacts. Where animal browsing is high, fencing, netting, and animal repellants are important to consider (See Section 10.4.2). For high surface soil temperatures shade cards can be used to protect seedlings (See Section 10.4.3). Reducing evapotranspiration rates is achieved using tree shelters (See Section 10.4.4) and shade cards. Some high visibility projects require fast growth rates and low risk in plant establishment, in which case irrigation can be considered (See Section 10.4.5). Additional measures that benefit seedling survival are covered in other sections. These include applying mulch around seedlings to conserve soil moisture and reduce vegetative competition (See Section 10.1.3), spot fertilizing (See Section 10.1.1), and applying mycorrhizal inoculum (See Section 10.1.7).

10.4.2 ANIMAL PROTECTION

Planted seedlings can be damaged by a variety of animals, including cattle, deer, elk, gophers, and voles. While some damage by animals can be expected, excessive damage should be prevented. There are a variety of methods to protect seedlings which include rigid and non-rigid netting, fencing, and animal repellents.

10.4.2.1. Netting

A common practice for protecting seedlings from browsing animals is to install a plastic netting over each seedling. The netting acts as a barrier to foraging of foliage, stems, and even root systems, without impeding plant growth. It has been used to protect seedlings from deer, elk, gophers, and other ground burrowing animals.

There are two general types of netting – rigid and non-rigid. Non-rigid netting is a soft, fine-mesh plastic material. When installed on a seedling, it fits snuggly around the foliage like a sock. The rigid netting (Figure 10.130) has larger mesh openings and holds its form when installed. Rigid netting, while typically more expensive, is usually preferred over non-rigid because it is easier to install and seedling growth inside the netting is less restricted.

Netting must be installed as soon after planting as possible to ensure immediate protection. If installation occurs after bud break, care must be taken not to break or damage the terminal leaders or buds. Rigid netting is held in place with one or two bamboo stakes woven through the netting at three places and driven into the soil at a minimum depth of 8 inches. For deer and elk protection, netting is placed so the height of the netting is several inches or more above the terminal bud. Non-rigid netting is simply placed over the foliage like a sock and

***Figure 10.130** – Rigid netting can protect seedlings from deer, elk, and gopher damage. The netting in this picture was installed 3 inches below the ground line to protect the seedling from gophers while the foliage and terminal leader is protected from deer and elk browsing.*

not secured with stakes. Rigid netting can offer some protection from gopher damage if the netting is installed more than several inches below the surface of the soil (Figure 10.130).

The effectiveness of the netting decreases as the terminal leader grows out of the rigid netting and become susceptible to browsing. At this point, the netting can be repositioned upward to protect the terminal leader, which requires annual maintenance. At some point, netting must be removed entirely to avoid restricting seedling growth and ultimately killing the seedling. Some netting has been manufactured with photodegradable material which will break down within several years, eliminating the need for removal. Nevertheless, sites that have had any type of plastic netting installed on seedlings should be visited several years after planting to determine whether the plastic netting is decomposing or needs to be removed.

10.4.2 2. Fencing

Fencing is often used to protect planted or seeded areas from wild ungulate and livestock grazing or trampling. Each group of animals requires different fencing specifications. Fence height for wild ungulates require 8 to 12 ft (Helgerson and others 1992) while fence height for livestock is 4 to 5 ft. Fences must be installed prior to seeding or planting to ensure optimal plant establishment.

Fencing entire planting or seeding areas is expensive to install and maintain. Maintenance must be given high priority because one break or opening in the fence will place the entire project at risk. It has been recommended that fences be monitored and maintained at least once a week and up to three times per week during peak browse season (Greaves and others 1978).

An alternative to fencing entire planting areas is to fence strategically located areas, such as planting islands. Fenced areas, called exclosures, range in diameter from 6 to 15 ft and are typically constructed with a 14 gauge, galvanized welded wire mesh (2- by 4-inch openings). Fence heights can be reduced around small diameter exclosures because wild ungulates are less likely to jump into small areas (Gobar 2006). Fence heights as low as 5 ft have been installed with good results (Riley 1999). In this strategy, the smaller size and greater number of exclosures reduces the risk of a failed project. After seedlings have grown high enough to withstand grazing and browsing pressures, small enclosures should be removed.

10.4.2.3. Animal Repellent

Browsing by deer and elk can be temporarily controlled by applying animal repellents to the foliage of seedlings. There are a variety of repellents on the market with varying degrees of effectiveness. Trent and others (2001) tested 20 products for effectiveness in reducing deer browse on western redcedar (*Thuja plicata*) seedlings and found that products emitting

***Figure 10.131** – Shade cards are placed on the south side of the seedling so the shadow cast by the shelter protects the lower portion of the seedling. This photo was taken two years after shade card placement.*

sulfurous odors were the most effective. These products contain active ingredients such as "putrescent whole egg solids" or "meat meal." Less effective products were those causing pain or irritation, containing active ingredients such as capsaicin, garlic, d-limonene, and thiram. Of the products tested, the least effective repellents protected seedlings for a few weeks, while the most effective protected seedlings for up to three months. Since seedlings are generally more palatable after winter dormancy, deer repellents should be applied just before bud break (Helgerson and others 1992) and at several month intervals during the active growing period as needed. Animal repellents in a hydrophilic powder formulation are reported to adhere better and last longer in climates with high rainfall than liquid forms (Helgerson and others 1992).

10.4.3 SHADE CARDS

Since high soil surface temperatures can limit seedling survival and growth, it is important that the stem of the seedling (where heat buildup occurs and causes the most damage) is shaded from the sun (Childs and Flint 1987). Seedlings can be planted next to obstructions, such as logs, to utilize the shade these structures provide. Unless the placement of obstacles is planned into the project, construction sites will usually be free of material large enough to cast shadows. An alternative, but less effective, method of creating shade is using shade cards. Shade cards are small, easy-to-install structures that shade the lower portions of the seedling from high surface soil temperatures (Figure 10.131). Tesch and Helms (1992) reviewed numerous studies that evaluated the effects of shade cards on planted seedlings and found that, while the use of shade cards can significantly improve seedling survival, they should only be considered on sites where several revegetation conditions are suboptimal, including south-facing aspects, sites with high winds, or when planting small, poor quality stock.

To be effective, shade cards should be installed in the spring after planting and before hot weather sets in. It is important to know where the shadow of the installed shade card will be cast in order to know where to place the card. The shadow must cast shade on the stem and lower portions of the seedling to protect these areas from high surface temperatures during the hottest portion of the day (Childs and Flint 1987). The length of the shadow is dependent on the longitude, date, time of day, slope angle, and height of the shade card. Improper installation of shade cards is a common mistake which typically occurs when cards are placed on the wrong side of the seedling. Card installers must be aware of the cardinal directions at all times during the day, which can be difficult on cloudy days. For this reason, contractors and inspectors should use a compass when installing cards and inspecting contracts. Another common mistake is not placing the shade card close enough to shade the base of the seedling during the hottest times of day.

Shade cards are also used to protect seedlings from strong, drying winds that create high moisture stress for establishing seedlings. Typically, shade cards are placed on the windward side of the seedling to deflect the wind. It is important to know the direction of the strongest or hottest wind in order to properly install the shade cards. For example, on a site with strong, drying winds coming up-valley in the afternoon, two shade cards would be installed at 90° angle to each other on the down-valley side to enclose the seedling.

Shade cards are made from shingles, cardboard, tarpaper, and polypropylene mesh. Selecting the appropriate shade card for your site should be based on how easy the shade card is to install, the weight, dimensions, life span, and costs. The drawbacks to the use of shade cards are the visual impact on the site and the fact that they must be removed after several years.

10.4.4 TREE SHELTERS

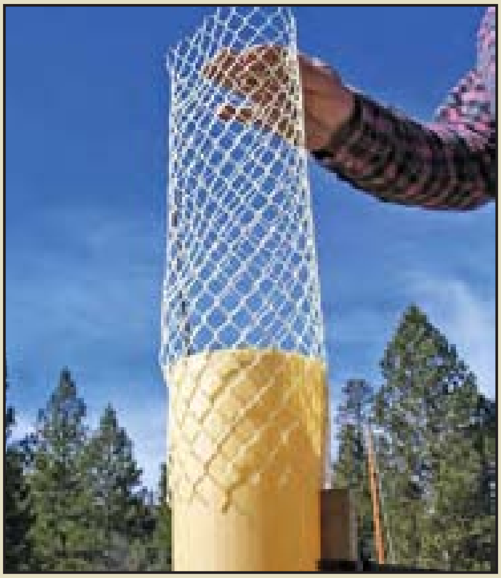
Tree shelters are translucent plastic tubes that are placed around seedlings after planting (Figure 10.132). They benefit seedling establishment by creating a favorable growing environment while shielding the seedling against animal damage. Tree shelters enhance plant growth by creating a microclimate similar to a mini-greenhouse, which has lower light intensities, higher temperatures, and higher relative humidities (Applegate and Bragg 1989; Jacobs and Steinbeck 2001). On high elevation sites, tree shelters increase above-ground temperatures and extend the growing season (Jacobs and Steinbeck 2001). Seedling survival and growth is enhanced by tree shelters on some sites because increased condensation on the inner shelter walls during the evening, drips into the soil and increases soil moisture (Bergez and Cupraz 1997). On windy sites, tree shelters protect seedlings from wind damage and blowing sands (Bainbridge 1994). In addition, tree shelters protect seedlings from large game, gophers, rabbits, voles, and grasshoppers (Tuley 1985; McCreary and Tecklin 1997; Jacobs and Steinbeck 2001).

Where to Use: Tree shelters should be considered for sites where the potential for animal damage is extreme and seedling survival and rapid seedling growth are essential. These sites include but are not limited to sites with the following characteristics:

- Gopher or vole damage,
- High elevation,
- High winds,
- Hot and dry,
- High solar intensity,
- Low water-holding capacity soils, and
- "One-shot" planting.

Figure 10.132 – *Corrugated plastic tree shelters create a microclimate around seedlings to enhance moisture and temperatures for seedling growth. In addition, they protect plants from animal browsing.*

Figure 10.133 – Rigid tubing can be installed over the top of the tree shelter to protect seedlings from larger browsing animals.



Drawbacks: Tree shelters are not intended for all species or site conditions. Several studies have shown that, under certain climates, seedlings grown in tree shelters are more susceptible to low temperature extremes than those grown in the open (Svihra and others 1993; Kjelgren and others 1997). These conditions occur in the late winter and early spring on some sites when warmer daily temperatures in tree shelters induce earlier bud break and stem dehardening, leaving seedlings more susceptible to cold temperatures. Air temperatures can also be colder at night in tree shelters on some sites because tree shelters can potentially trap cold air near the ground surface (Swistock and others 1999). On the opposite extreme, extremely high temperatures in the summer can be reached inside the shelters during mid-day, which might be detrimental to seedling growth. For these reasons, installing tree shelters should be done with some understanding of the effects that the shelters will have on each species to be planted and the climate of the site. Small trials, prior to installation, can point out potential problems.

In visually sensitive areas, tree shelters do not blend well with natural backgrounds. Depending on the species and the site, tree shelters might have to remain around plants for up to five years. In addition, long range planning for shelter removal is critical; without removal, the stem of the plant can be restricted.

Installation: Installing tree shelters may be done during or immediately after planting to protect seedlings from animal damage. Tree shelters are usually delivered in stacks of plastic sheets. They are assembled on site into cylinders that are placed over the seedling and held upright with a stake (Figure 10.132). The stake is driven into the soil so that the bottom of each cylinder is in direct contact with the soil surface. If burrowing animals are a problem, shelters can be installed several inches below the soil surface. This is an effective control of gophers and voles (McCreary and Tecklin 1997; Jacobs and Steinbeck 2001). Netting is sometimes placed over the opening of the shelter to prevent birds and lizards from becoming trapped (Bainbridge 1994). Rigid tubing can be placed over the top of the tree shelter to protect the emerging foliage from deer and elk browse (Figure 10.133). Tall tree shelters will require very strong stakes anchored firmly in the soil to withstand strong winds. As the shelters are installed, care must be taken to avoid skinned bark, damaged buds, or broken leaders. Where moisture is a limiting factor, weeding the vegetation from around the shelters is essential. Seedlings competing with weeds are unlikely to take advantage of the water saved by a tree shelter (Bainbridge 1994; McCreary and Tecklin 1997).

Maintenance and Removal: Installed properly, tree shelters require little maintenance. Nevertheless, sites where tree shelters are installed should be inspected annually to assess seedling conditions in the tree shelter and determine if any maintenance is needed. Since yellow jackets and other animals create homes inside tree shelters, it is wise to be cautious when conducting inspections.

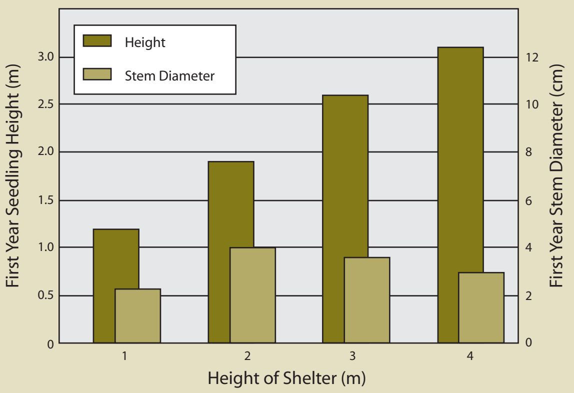


***Figure 10.134** – A study conducted with Australian redcedar* (Toona australis) *on a warm, moist site in North Queensland showed that, as taller tree shelters are used, first year shoot growth increases. Stem diameters, however, do not change (Applegate and Bragg 1989).*

Tree shelters create growing conditions that favor seedling height growth over stem diameter growth (Figure 10.134). Since tree shelters physically support the seedlings while they are growing, the seedling directs more of its energy into growing up to the light and less into the stem. Tree shelters must not be removed until a portion of the seedling crown has grown out of the shelter. If the tree shelter is removed while it is still growing inside the shelter, the seedling will not be capable of supporting itself. Once the seedling has emerged from the shelter, stem diameters will continue to increase as the foliage acclimates.

Available Products: Tree shelters are available in a variety of shapes, sizes, colors, and styles from companies that specialize in reforestation, restoration products, or grape growing.

Color. Color and translucency of the plastic are important characteristics for selecting a tree shelter. Brown-colored tree shelters greatly reduce solar radiation and, in one study on a high elevation site, was shown to drastically decrease seedling survival of Engelmann spruce (*Picea engelmannii*) (Jacobs and Steinbeck 2001). But on hot, dry sites, reduced radiation might benefit seedlings. Oak seedlings (*Quercus* spp).planted in a semi-arid environment actually performed best in short, brown-colored shelters because of reduced daily temperatures (Bellot and others 2002).

Lighter colored tree shelters allow greater solar radiation to reach the seedling, but can also heat up when they are exposed to direct sunlight. Highly translucent tree shelters should be considered where light is limiting. On the other hand, low translucent shelters might be more appropriate for sites where solar radiation and mid-day temperatures are high in order to reduce the potential for overheating.

Material. Tree shelters are made from translucent plastic for light transmission built with different degrees of sturdiness. Corrugated tree shelters are the sturdiest and are used on sites with strong winds. Corrugated materials are also used in the taller tree shelters for added support (Figure 10.132), while thin plastic can be used in shorter shelters. Tree shelters are typically designed to degrade in five years, but in many cases they do not. Many shelters can therefore be reused, which will reduce project costs.

Ventilation. Without ventilation, tree shelters will build up heat on warm days, especially if they are in direct solar radiation. Maximum daily summer temperature in shelters can be 8 to 16 °C (15 to 30 °F) higher than ambient air temperatures (Steinfeld 2005). Extreme temperatures can be reached on days where ambient air temperatures exceed 38 °C (100 °F). For these sites, shelters with some form of ventilation, such as holes, should be used. Ventilated tree shelters have been shown to reduce maximum daily shelter temperatures by 3 °C (5 °F) (Swistock and others 1999). Where ventilation is needed, taller shelters will require more ventilation than shorter shelters.

A ventilated tree shelter may restrict CO_2 in the area around the seedlings, which would be a further consideration for ventilation. Some studies have shown that CO_2 is very low in shelters (Dupraz and Bergez 1997). However, other studies that have shown higher levels of CO_2 within shelters than outside (Frearson and Weiss 1987).

Size. Selecting the size of the shelter should be based on the anticipated growth rates of the species planted and the anticipated animal damage. Shelter heights range from 1 to 9 ft, and

***Figure 10.135** – Small tree shelters can be placed around germinating seeds to enhance germination and early seedling establishment, as shown in this picture of an establishing California black oak* (Quercus kelloggii) *seedling in a tree shelter made out of x-ray film.*

diameters up to 6 inches. To obtain the greatest benefit from tree shelters, the shelter height should not exceed the maximum seedling growth in the first year. Fast-growing species should have tall shelters; shorter shelters should be used for slow-growing species. Ideally, the shelter height should be greater than the browsing level of the foraging animal. For instance, tree shelter heights in deer browse areas should be at least 4 ft tall so that new seedling growth from the top of the tube is not severely browsed back. Extending the protection of the tree shelter can be done by using a rigid netting placed over the top of the shelter. Large shelters can be cut into any height or diameter needed for the project. Very small shelters (less than 6 inches tall) can be used around germinating seeds to protect them from small animals and create a micro-climate for germination (Figure 10.135).

Costs: Tree shelters can be an expensive addition to the revegetation project. The high costs to purchase, assemble, install, maintain, and remove shelters should be considered against the benefit of increase survival and growth. On projects where smaller, less expensive seedlings are being planted, the cost savings from not planting larger stock can offset the installation of tree shelters. Assuming that tree shelters increase seedling survival, fewer seedlings would need to be planted, and these savings could offset the costs of installing tree shelters. Where quick establishment of vegetation is the objective, the use of tree shelters should be considered.

10.4.5 IRRIGATION

There is a wide range of irrigation methods and techniques available to the revegetation specialist, ranging from simple to elaborate, and modestly priced to costly. Since irrigation is often a very expensive revegetation strategy for most projects, the decision to irrigate, and subsequently the selection and design, must be integrated into the objectives of the road project during the planning stages. The most common reason for irrigating in the western United States is to aid in seedling survival during the first several growing seasons. Those sites that have low soil water-holding capacities, high evapotranspiration rates, or low summer rainfall meet these criteria. Irrigation is also used when the project objectives call for a quick establishment of vegetation for visual screening, erosion control, or slope stabilization. Wildland irrigation is almost always a temporary measure, spanning a maximum of three years. Therefore, elaborate or expensive irrigation systems are not often the best choice for these situations. Low-tech systems, requiring minimal maintenance, tend to be more appropriate for wildland restoration.

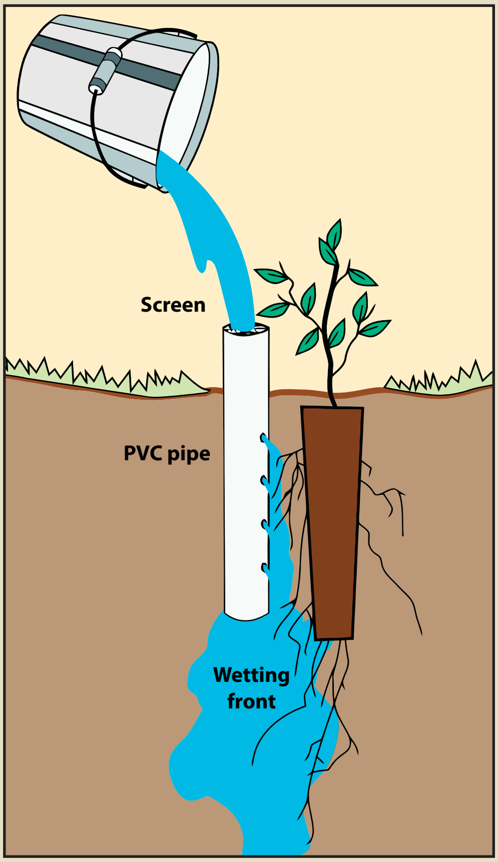
The challenge in wildland irrigation is the timing and placement of water in the soil. An irrigation system that delivers water when the plant is less likely to need it is wasteful and can be detrimental to the seedling. A system or schedule that applies water when the plant requires it for survival or growth is most cost effective and beneficial for seedling survival and growth.

Developing irrigation schedules based on plant needs is an essential part of using irrigation for establishing plants, and those needs change based on the species being established, nursery stocktype, soils, and climate.

Placing the water in the soil profile where it can be directly accessed by much of the root system is critical for efficient use of an irrigation system. Some irrigation systems moisten more of the soil profile than will be accessible by the establishing root system, and water is consequently wasted. Other ineffective systems barely wet the soil surface, leaving the applicator satisfied, but the roots without water. The objective of an efficient and effective irrigation system in wildland settings is to deliver only the amount of water needed, when and where it is needed for seedling survival and growth.

Tree and shrub seedlings survive by growing roots down into the soil profile, accessing moisture at deeper portions of the soil profile than annual grasses and forbs. Deep placement of water for these species is far more important than surface soil moisture. Yet many irrigation systems, such as drip, basin, and overhead sprinklers, deliver water through the surface, wetting soil where it is not needed, and encouraging weeds and other competitive plants to establish and thrive. Furthermore, surface irrigation does not always assure moisture will be evenly delivered to the deeper portions of the soil where the roots of trees and shrubs are growing. Soil structure and texture affect the wetting-front patterns of surface-applied irrigation water. If the soil is compacted, the amount of water that is delivered to the lower rooting zone can be reduced. A better method of water delivery to the root zone of trees and shrubs is to bypass the surface of the soil completely.

***Figure 10.136** – Deep pot irrigation uses an open-ended PVC pipe placed next to a planted seedling. Small holes (1 mm) are drilled 2 to 3 inches down the pipe and positioned toward the root system. A screen is placed over the top of the pipe to keep animals out. The size of the pipe and placement is designed to deliver the appropriate amount of water to actively growing roots (modified after Bainbridge 2006b).*



10.4.5.1 Deep Pot Irrigation

There are several irrigation methods developed for arid land revegetation that bypass the soil surface and deliver water directly to the root zone. These systems include deep pot, porous hose, and wick irrigation methods (Bainbridge 2006a). Because these systems deliver water directly to the soil profile where roots are actively growing, far less water is required. Deep pot irrigation (Figure 10.136) appears to be the most effective and practical method for irrigating planted seedlings in arid environments (Bainbridge 2006b). This system has been found to be three times more effective at increasing seedling survival than surface irrigation using the same amount of water (Bainbridge and others 2001).

Deep pot irrigation delivers water to the root system through a pipe positioned next to the seedling (Figure 10.136). The pipe is either filled periodically by hand or through an installed drip irrigation system. The soil is moistened as water drains through both the bottom of the PVC pipe and the holes drilled in the sides. The amount of water delivered to the soil depends on the size of the pipe and how much water is applied. Deep

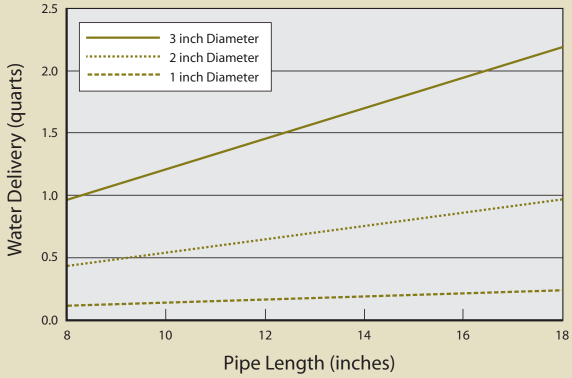


Figure 10.137 *– The maximum amount of water that can be delivered to a root system in a single irrigation (y axis) is determined by the pipe length (x axis) and the diameter of the deep pot (lines). For example, a 14-inch pipe with a 1-inch diameter will hold approximately 0.15 quarts of water; a 2-inch diameter pipe will hold 0.75 quarts; a 3-inch diameter pipe will hold 1.7 quarts of water.*

pot irrigation pipes are typically made from PVC pipes, though most pipe or tubing material can be used. Pipe diameters range from 0.5 to 3 inches. Pipe lengths range from 8 to 18 inches, depending on the stocktype and water volume to be delivered. A seedling with a short root plug will require a shorter pipe, whereas a longer root plug will require a longer pipe. The bottom of the pipe should be positioned no deeper than the length of the root plug so the wetting front moves around the bottom and lower portions of the plug where it can be accessed by new, advancing roots. The top of the pipe is screened to prevent animal entry and is placed several inches above the level of the soil.

The diameter of the pipe will determine the quantity of water that can be delivered at any one irrigation (Figure 10.137). Given the same pipe lengths, a 2 inch diameter pipe holds 4 times the amount of water as a 1 inch pipe, and a 3 inch diameter pipe holds 8 times the amount of water. Since filling pipes is expensive, determining the proper diameter is important. Oversized pipes will deliver a wetting front that extends beyond where it can be accessed by the root system, and water will be wasted. Pipes that are too small will not fully wet the area around the advancing rooting zone, requiring more frequent irrigations. Pipe size and irrigation frequencies depend on:

Soil Type – Sandy or rocky soils have low water-holding capacities, causing wetting fronts to travel deeper and in a narrower band. Less water but more frequent irrigations are needed in these soils. Pipes must be placed closer to the root plug to ensure the wetting front reaches the root system. Finer textured soils, such as loams and clays, have a higher water-holding capacity and wider wetting fronts. More water can be applied in these soil types and at less frequent intervals than sandy soils.

Stocktype – Large stocktypes have greater root volumes and greater above-ground vegetation to support than smaller stocktypes, and therefore require more irrigation water. However, smaller stocktypes might require more frequent irrigation.

Seedling Quality – Healthy seedlings grow new roots quickly and can access deeper soil moisture. Poor quality seedlings are slow to initiate roots and therefore must be irrigated more frequently.

Competing Vegetation – Where undesirable vegetation is growing near planted seedlings, soil moisture is depleted sooner, requiring more frequent irrigations than if seedlings were free from competing vegetation.

Species – Every species has unique rooting patterns, growth rates, and water needs. Those that grow roots quickly and have a higher rate of water withdrawal require larger, deeper pipes and more frequent irrigations. These species include many of the fast growing riparian species such as cottonwoods, willows, and maples. For more information, contact the nursery manager growing the species of interest. They are very familiar with root growth and water needs by species.

The volume of the pipes and frequency of irrigations will determine the type of water delivery system to use. Sites that need frequent irrigations and high volumes of water per plant might require water delivery through a drip system (See Section 10.4.5.2). For most projects, however, pipes can be economically watered by hand using backpack spray equipment or fire bladder bags. Bladder bags hold approximately 5 gallons of water and can be filled from water trucks or large water containers positioned in pickup beds. Assuming that an irrigator can carry 20 quarts of water at a time (5 gallons) and each plant in the project requires a quart of water, the applicator could irrigate 20 seedlings before returning for more water. If less water is required, more plants could be irrigated before refilling is necessary.

Deep pot irrigation allows for the introduction of soluble fertilizers (See Section 10.1.1) and mycorrhizal fungi inoculum (See Section 10.1.7) if seedlings require these treatments. Since soluble fertilizers are delivered directly to the roots, bypassing the soil surface, weeds are not encouraged to grow. Care must be taken when determining fertilizer rates to avoid increasing soluble salts above levels that are toxic for root growth. Salt levels and pH of the irrigation water must be monitored to assure that salts do not exceed toxicity levels for plant growth (See Section 5.5.5, pH and Salts).

Determining when to irrigate can be based on the moisture stress status of the plant. An accurate method for determining plant moisture stress (PMS) is using a pressure chamber (Inset 10.23). This equipment reads plant stress (in negative bars) at the time of the readings. PMS readings should be made in the early morning, prior to sunrise, when diurnal PMS is at its lowest. Five seedlings should be collected in one area and averaged per site. If pre-dawn PMS readings are less than -15 bars, seedlings are under high moisture stress and must be irrigated soon to keep the seedlings from dying. If the objective of irrigation is for fast seedling growth, then PMS during the plant growth (spring and fall) must be kept above -5 bars. PMS equipment is expensive to purchase. However, many Forest Service district offices use and maintain this equipment.

10.4.5.2 Drip Irrigation

Drip (or low pressure) irrigation is generally a temporary measure to help establish roadside plantings. It is typically used for one or two seasons to establish nursery-grown plants and then removed. Setting up drip irrigation might be considered extravagant. For projects where there is no tolerance for seedling failure, this can be a viable, economical alternative (Bean and others 2004).

Some advantages of using drip systems for roadsides are water efficiency, system flexibility, portability, and ease of application of soluble fertilizers. The main disadvantage is the high maintenance required to keep the system operational. Drip systems are composed of numerous points where failures can occur: storage tanks, burst end clamps, connectors, emitters, hundreds of feet of pipe and drip irrigation tubing. For this reason, the system must be inspected and maintained regularly during the summer to assure that all seedlings are being properly irrigated. This involves inspecting all emitters, pipes, tubing, and tanks. Emitters clog with sediment and insects (Bainbridge 2006c); animals gnaw through tubing when it is above ground; and plastic water tanks make great shooting targets. These damages to the system must be repaired before each irrigation cycle. Another disadvantage is that, on hilly sites, the system must be designed to maintain the correct pressure to each emitter.

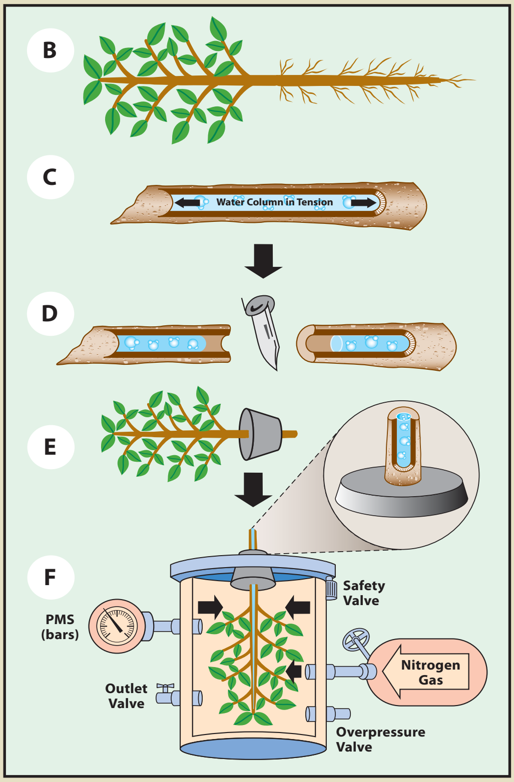
In its simplest form, the drip irrigation system consists of: 1) a water source, 2) mainline and side lateral pipes, and 3) drip pipes and emitters. The system is under pressure during irrigation, which moves water from the water source, through the mainline and side laterals, to the emitters where seedlings are watered. The objective is to deliver equal amounts of water to each seedling. This is not a problem when the system is laid out on flat ground and pressures at any point in the system are equal, but flat terrain is seldom found on highway projects. On projects that have any slope gradients, there will be changes in pressure depending on the elevation of the emitters. The pressure change occurs at a rate of 1 lb/in^2 (PSI) per 2.31 ft elevation drop. This means that an emitter at an elevation that is 46 ft lower than the water source will have a PSI of 20 (46/2.31 = 20), while an emitter at 92 ft lower than the water source will have a PSI of 40 (92/2.31 = 40). Unless pressure-regulating techniques are used to reduce the pressure to the lower elevation emitters, the amount of water delivered to those emitters will be approximately twice that of the upper elevation emitters. Compensating for pressure changes is critical for delivering equal amounts of water to each seedling. Systems that do not compensate will have seedlings that receive too much water, while others will not receive enough during an irrigation cycle.

Water Source – The water source constitutes the beginning point of the drip system. It is typically the most uphill point because it must feed every emitter below. Water is typically trucked to the site and pumped directly into the mainline, or stored in temporary, portable storage tanks (Figure 10.138). Water trucks range in capacity from 1,000 to 2,500 gallons. If there is a location for a portable water storage tank above the planting area, gravity feed can be used

Inset 10.23 – Measuring Plant Moisture Stress
(modified from McDonald 1984)

Measuring plant moisture stress (PMS) is an accurate method to help determine the water needs and status of a plant. When a seedling (A) is under moisture stress, it is pulling water from the soil through the stem. The water in the stem is under tension, much like a rubber band that is being stretched (B). When a small branch is cut, the tension in the stem is released and the water shrinks back from the cut surface (C). The further back the water shrinks, the more moisture stress the plant is under. The cut end of the stem is placed through a small hole in a stopper, with the end protruding from the lid (D). The foliage is placed in the steel chamber and tightened so it is airtight (E). Nitrogen gas is slowly applied into the chamber, exerting pressure through the stomata and pushing water through the stem toward the cut end. When the water just begins to emerge from the cut end, a pressure reading is made. This is the amount of suction or stress that the seedling is under at the time the sample was collected. Since PMS varies throughout a 24-hour period, seedling samples must be taken in the pre-dawn for consistency and comparison purposes.

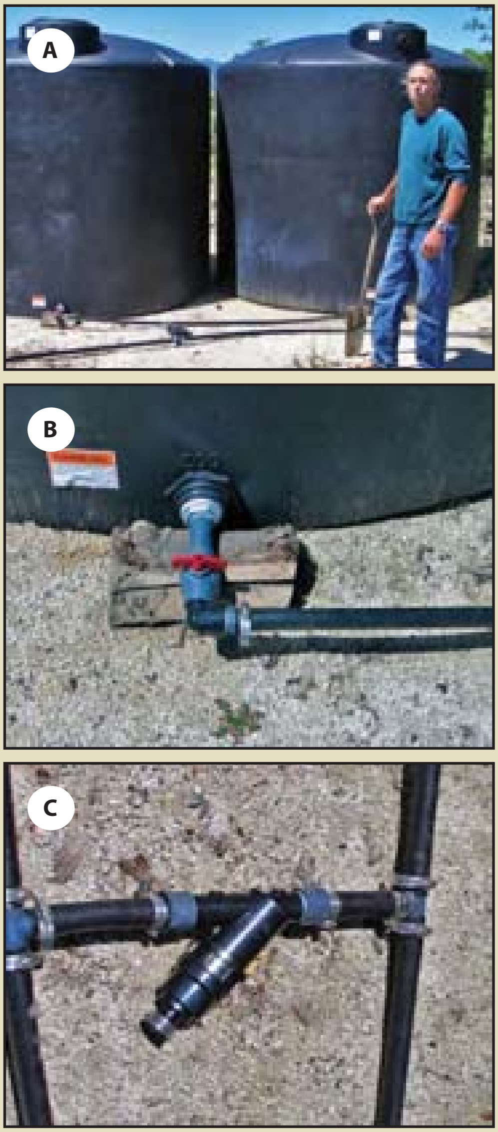
PMS readings can be used to determine when to irrigate seedlings. If pre-dawn PMS readings are greater than -15 bars, seedlings are under high moisture stress and must be irrigated soon to keep the seedlings healthy. If the objective of irrigation is for fast seedling growth, then PMS during the plant growth (spring and fall) must be kept below -5 bars. PMS equipment is expensive to purchase; however, many Forest Service district offices use and maintain this equipment.



to pressurize the system. Operational water pressure for a drip system ranges from 20 to 40 PSI. To achieve a minimum pressure of 20 PSI with a gravity feed system requires a 46 ft elevation drop from the storage tank to the first line of emitters (20 * 2.31 = 46). If this drop does not exist, then a pump will be needed to augment the pressure.

Components of a temporary water tank system include filters, on-off valve, backflow, and a pressure-reducing valve (if the water source pressure is greater than 40 PSI) (Stryker 2001). When planning water storage, ease of access is an important consideration. Sometimes water will need to be pumped a substantial distance to a water storage tank. In other cases, more than one tank will be required to reach all planting areas in complex terrain. Water from unknown sources should be sent to a qualified lab and analyzed for contaminants and impurities (Zoldoske 1998). Chances are that most water sources will have impurities that will clog very small drip emitter openings. Installing a 100 (150 micron) to 150 (100 micron) mesh filter is recommended (Stryker 2001).

Figure 10.138 – *Large holding tanks are used for temporary drip irrigation systems (A). A simple on/off valve controls water to the gravity-feed system (B). Pressure release valves (C) are used to control water pressure on hilly sites.*



Mainline and Laterals – The mainline delivers water from the water source to the lateral pipes. The layout of the mainline and laterals can compensate for pressure changes associated with hilly terrain. A series of parallel lateral lines can be laid out perpendicular to the slope gradient. Since each line is on the contour, there is no pressure difference between emitters within a line. Between lateral lines, however, there is change in pressure based on 1 PSI per 2.31 ft elevation drop. Placing a pressure regulator at the connection between the mainline and each lateral line can compensate for the pressure increase with elevation drop.

The drip tubing diameter determines the volume of water that can be carried in the lateral lines and the rate it will be delivered based on friction losses. A two inch pipe, for instance, carries four times as much water as a one inch pipe, but the costs are correspondingly much higher. For long stretches, increased frictional losses inside narrow diameter pipes can cause inadequate water coverage. Increasing water pressures or increasing pipe diameters can compensate for this.

The carrying capacity is the amount of water that specific tubing can deliver under a specific line pressure. For example, 0.75-inch tubing has a carrying capacity of approximately 160 gallons per hour at a line pressure of 20 PSI, whereas 1-inch pipe has a carrying capacity of 370 gallons per hour at the same pressure. Charts are available that compare various tubing diameters, emitter outputs, and system pressures for determining the length of tubing. These charts must be referenced when designing an efficient drip system.

Emitters – From the laterals, water flows through a smaller diameter pipe to the emitter, which meters out water directly to the base of each plant. Emitters apply water to the soil surface without wasting water on the surrounding area, thus discouraging non-target species. When emitters are placed in a deep pot irrigation system, water efficiency is increased further because water is delivered directly to the roots. There are many types of emitters, but pressure compensating emitters work well on hilly topography because they are designed to discharge water at uniform rates under a range of water pressures. With pressure compensating emitters, a system at 15 PSI would have the same emitter flow rate as a system at 45 PSI (Stryker 2001). These emitters are two to three times more expensive than non-compensating emitters.

Emitters come in a range of flow rates, with the most common rates of 2 liters/hour and 4 liters/hour. Choosing the flow rate for the emitters should be based on soil texture, water requirements of the plants, water delivery capabilities of a system, and budget. Most designers agree that placing two emitters at each plant is better than one emitter with twice the output, because the water distribution area will more closely match the rooting profile of the plant. Two emitters also offer backup should one of the emitters become clogged.

A good grasp of the soil drainage and water storage characteristics is necessary in choosing emitter capacity and duration of irrigations. Well-drained soils (e.g., sandy texture or high coarse fragments) require emitters with higher flow rates, but shorter irrigation time. On the other hand, poorly drained soils (higher in clays, or compacted) require lower output emitters and longer irrigations. Size of planting stock will influence the number of emitters and flow rates; the larger the planting stock, the longer the irrigation cycles and more output emitters are needed.

There are a limited number of emitters that can be installed on any one lateral line. For example, 0.75-inch pipe or tubing delivers approximately 160 gallons per hour, the number of emitters that can be installed on the line will vary by emitter output rates. Installing 0.5 gallon/hour emitters allows approximately 300 emitters (600/2 = 300) on the line. If two emitters were placed by each plant, 150 plants could be watered on a line. If the emitters were rated at 1.0 gallon/hour, then 75 plants could be watered.

Installation – The installation of a drip system involves placing pipe and inserting emitters. Tubing comes in rolls and is easiest to lay out like a wheel to keep kinks from developing in the line. Lateral tubing should be placed upslope from the plant, which will act like a stake should the tubing move downslope. Tubing migrates until it has been used for a while and may require periodic staking. When the main line and laterals are in their general locations, the system is filled with water to flush the pipes clean. The ends are clamped or plugged and then filled again. This will reveal whether there are any leaks or problems to fix before installing the tubing to the emitters. A pressure gauge should be used at this time to take readings across long runs within or between lateral lines to check consistency of pressures. If there are problems, they should be corrected at this time. Puncturing tubing for emitters can be done when the system is charged with water, so that adequate emitter flows and problems are seen immediately. Some designers choose to bury emitters below the soil surface to reduce surface evaporation. Losing visual inspection, however, usually outweighs the benefits of this strategy (Zoldoske 1998).

Operation – Prior to operating the drip system, filters must be cleaned. Check salt levels and pH of the irrigation water using a pH/conductivity meter to assure that salts do not exceed toxicity levels for plant growth (See Section 5.5.5, pH and Salts). Once these measures have been taken, the system can be opened and lines and emitters inspected. If emitters need cleaning, repair, or repositioning, it is done at this time. Tools and spare parts for the system are brought along and used where needed. Determining when to irrigate should be determined through PMS monitoring (Inset 10.23). Determining the duration of the irrigation cycle can be done once or twice during the growing season through a visual inspection soil profiles dug below several emitters. Observing the wetting front should be done several hours after the system has been shut off because the wetting front will have stabilized at that time.

11 MONITORING AND MANAGEMENT

11.1 INTRODUCTION

The goal of roadside revegetation is to establish healthy, functional communities of native plants along roadsides and on road-related disturbances. However, projects to establish native plants on disturbed sites rarely turn out exactly the way they were planned. Therefore, regular visits to the project to evaluate progress, and to intervene if necessary, are essential parts of the revegetation process.

Monitoring is carried out for two reasons: 1) to correct, manage, and maintain the project effectively, and 2) to learn lessons for future projects. Monitoring provides the answers to the following questions:

- Is native vegetation establishing well, or is some corrective action needed?
- Were regulatory standards or revegetation commitments met?
- Were there differences in plant responses between different revegetation treatments?

These questions may be answered simply through general observations during routine field visits, through formal photo point monitoring, or through statistical methods. Monitoring begins during the implementation phase and continues after the project has been installed. A general monitoring protocol that can be applied to all revegetation projects does not exist. Instead, monitoring should be tailored to the objectives of each project and to the uniqueness of the site. It is important to determine in advance whether formal data collection and statistical analysis is necessary for the project. Simple field visits or photo point monitoring may provide sufficient information to determine whether objectives have been met. This chapter discusses general monitoring and management steps. If statistical methods will be necessary, Chapter 12 outlines some statistical monitoring protocols that cover the most common roadside revegetation objectives and conditions.

Information collected during monitoring will guide management and maintenance activities for the current project. This information can also be used to improve revegetation techniques for future projects. Monitoring completes the project cycle by providing feedback regarding the success or failure of a revegetation project. This information is used to adapt and improve other projects that are in the initiation, planning, or even implementation phases of the other project cycles (Figure 11.1).

Monitoring can also play an important role in advancing the knowledge and understanding of establishing native plants on highly disturbed sites. This relatively new field of study lacks basic field-tested techniques. With well-designed monitoring projects, the revegetation specialist can provide valuable information for the use of native plants in revegetating harsh sites.

The monitoring and management phase of the project involves several steps:

- Revisit project objectives and DFCs,
- Develop monitoring strategy and protocol(s),
- Record data and observations,
- Evaluate data and apply any corrective measures,
- Organize and file project results, and
- Share lessons learned.

Monitoring information is utilized to evaluate progress and to inform any management activities needed to correct the results. Long-term road maintenance and management is usually the responsibility of the road-owning agency. However, monitoring information can facilitate long-term results and help inform management even after the revegetation specialist's role is completed.

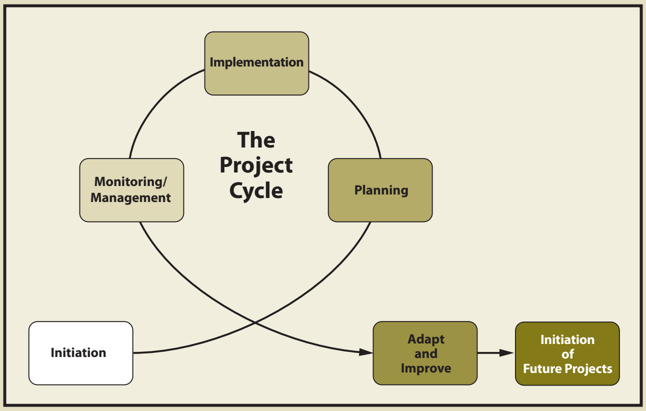


Figure 11.1 – *Monitoring and Management are the final components of the project cycle. Monitoring guides management actions for the current project, and provides valuable information to improve future projects. Management actions can correct shortcomings in results.*

11.2 REVISIT PROJECT OBJECTIVES AND DFCS

A common pitfall in many monitoring projects is the lack of clearly stated objectives or reasoning behind data collection. A good monitoring project is not defined by the amount of data collected, but by whether the data adequately and efficiently determines whether the objectives of the revegetation project were met. This question can only be addressed when the objectives for monitoring are clearly stated. Monitoring efforts must not only link back to the original project objectives, but also to the specific DFCs developed in the planning phase (See Chapter 4). Objectives and DFCs set the standards (sometimes called "performance standards," "thresholds," or "indicators") against which the project is evaluated (Clewell 2004).

DFCs are often stated in quantitative language. For example, the DFC for a cut slope three years after construction is stated in the revegetation plan as "less than 25% bare soil will be exposed" and "vegetative cover will be composed of greater than 70% native species." These DFCs are very specific and can be used as target values, or thresholds, for determining whether or not the project was successful. Monitoring methods, or protocols, are developed specifically around each of these targets or thresholds. When monitoring is approached in this manner, only the information needed to determine whether targets were met is collected. Expensive, superfluous data collection is avoided because the DFCs were clearly defined.

11.3 DEVELOP MONITORING STRATEGY AND PROTOCOL(S)

The DFCs identify what will be monitored and defines the minimum acceptable thresholds. The monitoring strategy defines how those criteria will be measured and evaluated. This involves issues of scope (what level of detail or certainty is needed?), methods (what is the best way to obtain the necessary information?), and location, timing, and frequency (where, when, and how often should monitoring take place?). After the information is collected, the DFC threshold values will be used to evaluate success or failure, in order to determine if results are acceptable or if corrective action is required.

A monitoring protocol is a specific set of directions that outlines, step by step, how the monitoring will actually take place in the field. Sometimes several different protocols will be utilized on one project. The monitoring strategy sums up the monitoring protocols and creates a comprehensive map, schedule, and budget for monitoring activities for the project.

11.3.1 Define Scope

Scope defines the level of monitoring detail. Some portions of the revegetation project might require only a project diary and a series of photographs while other areas within the project will require a statistically designed monitoring protocol. At a minimum, most projects require annual visits and recorded observations or qualitative assessments. Portions of revegetation projects may require statistically-based monitoring to ensure regulatory compliance and accountability. For example, if water quality standards dictate that road sections near a high-value fishery have no greater than 20% bare soil the first year after construction for sediment control, the importance of this project to fisheries and water quality will require high confidence in the accuracy of the data. This might require more intensive data collection and statistical analysis to ensure a higher level of certainty. On the other hand, road sections that do not affect the stream system would have less need to collect data for statistical analysis of this intensity. In such cases, qualitative assessments such as photo point monitoring or fewer sampling points may suffice (Inset 11.1). In general, the scope of monitoring should reflect the importance of the revegetation objective and the ecological sensitivity of the project site and surrounding areas (See Chapter 12).

11.3.2 Determine Location, Timing, and Frequency

Choosing appropriate sampling areas to assess whether project objectives were met is a foundation of a good monitoring strategy. Some revegetation projects can be complex and cover many acres. For these projects, it is important to identify specific monitoring areas. However, not every area needs to be monitored. The revegetation unit is usually the basic unit of sampling. There should be little reason to split out the revegetation units in order to determine whether standards or thresholds were met. Finer delineation of areas within revegetation units for monitoring should only be done if there are specific questions to answer about treatment effectiveness or differences.

Determining the most appropriate time of the year and frequency for monitoring is a key part of developing a monitoring strategy. Some portions of a revegetation project may require only one monitoring visit, which may simply be carried out as part of quality control during the implementation phase (See Chapter 9). For example, if a two-inch application of composted mulch is a stated objective in the revegetation plan, then one visit to the site, preferably during mulch application, will suffice to confirm whether this occurred or not. For other objectives, a series of observations over time will be necessary. For example, a planting contract requires 400 live trees to be established the first year after planting and 300 live trees by the third year. This project would need to be monitored twice, once at the end of the first year and once in the fall of the third year.

It is important to define the season that monitoring will take place because vegetation changes from season to season. This will affect the results of the data being collected. For instance, if the monitoring objective is to determine the species cover after seeding native grasses and forbs, monitoring should take place in the early summer when plants are flowering and species are easily identifiable. Collecting soil cover data, on the other hand, is often done in the fall prior to winter rainstorms, since the revegetation specialist will want to know the amount of ground cover that will be protecting the soil during these events. Monitoring first year seedling survival should be done in fall and not in spring or summer. Taking data in spring or summer will show higher survival; by fall, most of the seedling mortality will have occurred.

11.3.3 Develop Sampling Methods

Sampling methods define what parameters will be measured and how the data will be collected. Parameters may be biotic or abiotic, and are determined by the revegetation objectives. For example, vegetative cover can be measured as basal cover or aerial cover. If the objective is erosion control, then basal area is usually measured. If the revegetation objective is visual aesthetics, then aerial cover would be selected. In another example, if a revegetation objective is to reestablish a working group of species, then measuring for species presence would be conducted. If this is the case, the interest is only in working group species, so only these species need to be monitored. Any other species can be grouped into broader categories, such as grasses and forbs, for measurement. This strategy reduces the need to identify all species present in a sampling unit, and instead focuses data collection on the key species or groups of species that are relevant for meeting project objectives.

11.3.4 Summarize Monitoring Strategy

The monitoring protocol or protocol(s) to be utilized to evaluate the progress should be summarized into an overall monitoring strategy (Table 11.1). The monitoring strategy should have these components (Elzinga and others 1998):

- ***Summary of objectives.*** The purpose for monitoring, the project objectives and DFCs to be met, DFC "threshold values" for success or failure on each revegetation unit.
- ***Monitoring area map.*** The monitoring area map locates and identifies all monitoring areas in the road project area. For example, the monitoring areas identified in Table 11.1 would each be located on a road map.
- ***Summary of monitoring protocols.*** The strategy summarizes the general type of monitoring, including scope, location, timing, frequency, and sampling methods for monitoring each revegetation unit (Table 11.1).
- ***Consolidated timelines.*** A comprehensive timeline should be developed for the entire project, detail the schedule for how each revegetation area will be monitored, and include the due date for the Final Monitoring Report.
- ***Expertise.*** Some monitoring protocols will require specific expertise in botany, soils, or other natural resource disciplines. This should be addressed in the strategy to make sure these resources are available.
- ***Costs.*** A general estimation of costs can be made once the monitoring protocols have been selected. It is important to take stock of the budget at this point since this is the final phase of the revegetation project and there must be enough funding to implement the monitoring.
- ***Monitoring oversight.*** One person must have oversight of all monitoring activities; it is the responsibility of this person to ensure that the protocols are being implemented within the timelines that were developed. This person completes the final monitoring report and summarizes important findings.

Table 11.1 *– Example of a basic monitoring summary. This table, accompanied by a map of the revegetation project, are the basic elements of a monitoring strategy.*

Revegetation Unit	DFCs or Objective	Monitoring Protocol	Year	Expertise Required
1 Steep Cut Slope	-	Photo point	0, 1, 3, 5	-
	70% soil cover	Soil cover	1	-
	90% soil cover	Soil cover	3	-
	60% native vegetation	Species presence	3	Botany
	Nitrogen analysis	Soil samples	2	Soils
2 Obliterated Road	-	Photo point	0, 1, 3, 5	-
	400 live trees per acre	Plant survival	1	-
	300 live trees per acre	Plant survival	3	-
	4 foot average tree height	Plant growth	3	-
3 Wetland	-	Photo point	0, 1, 3, 5	-
	80% survival of plants	Plant survival	1, 3	-
	70% native plant cover	Species cover	3	Botany
	No invasive plants	Invasive plant survey	1, 3	Botany

11.4 RECORD DATA AND OBSERVATIONS

With the monitoring protocols defined and the overall strategy in place, data and observations can be recorded as schedules. Methods of data collection can be qualitative or quantitative, complex or simple. No matter what methods are to be utilized, clear written instructions in the protocols will outline exactly how data is to be collected. Chapter 12 illustrates the most common statistically-based monitoring protocols needed to meet most roadside monitoring objectives. The protocols must still be used in the context of the unique environmental and operational characteristics of the revegetation unit. For example, accessibility to a cut slope for monitoring soil cover might be limited due to very steep slope gradients. Although the soil cover monitoring protocol would be selected, modifications would be necessary to assure personnel safety. The modified protocol would not be the same as one developed for areas where slope gradients are gentle. Keep good records of the information that is collected. A field monitoring form (such as the example provided in Table 11.2) is a useful tool to keep information organized and consistent as measurements are taken over time.

11.5 EVALUATE DATA AND APPLY ANY CORRECTIVE MEASURES

There is no purpose in monitoring if the information will not be appropriately analyzed. The primary reasons monitoring data is not analyzed may include: 1) the monitoring plan was too complicated (massive amounts of data were generated); 2) insufficient thought was given to analytic methods; 3) monitoring was not designed in a meaningful or statistical manner; or 4) the monitoring objectives were poorly stated. Chapter 12 addresses these issues and presents strategies to streamline monitoring so that only essential information is collected and data can be quickly and easily analyzed.

Analysis of the monitoring data provides the feedback needed to identify and correct problems as they arise (Figure 11.1). There are many reasons corrective actions may be necessary as the project develops. This may include unanticipated events, such as unforeseen invasion/infestation of weeds or other pests, theft or human impacts, or unforeseen weather events, such as drought or early frost. In addition, there may have been some erroneous assumptions during the planning phase about either the appropriate future conditions for the site, or about the appropriate method to achieve the desired conditions. The sooner issues can be identified through data collection and analysis, the sooner (and more economically) they can be corrected. This is the basis of good management.

***Table 11.2** – Example Field Monitoring Form (adapted from Elzinga and others 1998).*

Project name:
Dates of data collection:
Personnel:
Location of monitoring (attach map and GPS coordinates):
Revegetation unit:
Revegetation treatments:
Desired future conditions (DFCs):
Sampling objectives:
Monitoring protocol (soil cover, species presence, species cover, etc.):
Sampling design (size and shape of sampling unit):
Number of transects or quadrats:
Type of data analysis:
Description of codes (on map or in notes):
Notes and location of accompanying map and data files:

Inset 11.1 Photo Point Monitoring
(Adapted from Hall 2002a, 2002b)

Photo point monitoring is a method of displaying landscape changes in vegetation over time. If a picture is worth a thousand words, photo point monitoring is often a useful way to show the success or failure of a revegetation project. Landscape images from photo point monitoring, in conjunction with data collected from other monitoring methods, can be very effective in describing the results of revegetation efforts. Hall's *Photo Point Monitoring Handbook* (2002a, 2002b) provide more thorough coverage of the subject.

Locating photo points. The first step in photo point monitoring is to establish where the photo will be taken. The locations of the photo point should be based on the objectives of the revegetation project. These should include the important aspects of revegetation to document over time. For example, if the objectives for revegetation are visual enhancement, photo points should be located in the best places for showing these changes over time. The effects that vegetative growth will have on the line-of-site as vegetation matures should also be considered. Small shrub and tree seedlings planted along roadsides will, with time, fill in the entire picture frame, obscuring any long-distance views. To avoid this, the location and direction of the camera should place the road corridor in the foreground, since the road corridor will always be free of vegetation.

Photo point locations should be described in detail to be easily located years later by personnel other than the person who took the original photograph. Permanent structures that can be easily described and located by others make good reference points for photo locations. These include culvert inlets and outlets, guardrail posts, mile post markers, road signs, road intersections, telephone poles, and other types of permanent utility structures. Since these features are not always permanent, it is important to locate more than one structure in the field.

The photograph is either taken from the permanent structure or from a measured distance. For example, a photographer might decide to take a picture on the fog line directly above a culvert outlet. This spot would be easily described and locatable in the field by another person several years later. A photographer might also locate a site at a permanent sign post or by counting the number of posts in a guardrail back from a known spot. An azimuth reading and measured distance from the structure should be recorded in the notes.

A common method for locating a photo point is to drive a stake (rebar) at the spot. This method works but has some drawbacks: the stake must be set back far enough so that it does not interfere with maintenance activities or traffic safety; the stake must be driven several feet into the soil, which is limiting on most cut slopes and some fill slopes; and the stake must be identified with a tag that is readable over time. One problem associated with poorly placed stakes is that they are often displaced through active soil movement, animal traffic, vandalism, or road maintenance activities. Utilizing a permanent feature of the roadside, such as a guardrail or signpost, is generally a better alternative. GPS points can also help locate photo points.

The camera. Digital and film cameras are both acceptable for photo point monitoring. For digital cameras, a dpi setting of 2280 by 1800 (4.1-megapixel or higher) should be used to obtain adequate resolution. For film cameras, a ISO rating of 100 should be used. Using cameras with good lens quality is also essential for optimum photographs. Avoid using the zoom lens because this feature can pose problems in reproducing the original photograph (Hall 2002b).

Taking the first picture. The camera is set on a tripod over the identified photo point location and image is previewed on the LCD screen or through the lens. With a compass aligned to the side of the camera, an azimuth reading is taken. (Be sure that the declination of the compass is defined in the notes.) Using a clinometer on the top of the camera, the degrees from horizontal are recorded.

Keep a log or electronic document that includes the following information about the photograph being taken:

- Photograph name;
- Project name;
- Date;
- Time;
- Photographer;
- Location on plan map;
- Location description;
- Azimuth of camera;
- Angle of camera;
- Manufacturer and model of camera;
- Focal length;
- Brand, type of film, and ISO rating (for film cameras); and
- Large imported jpeg image of photograph.

Photo data bases, where this information is tied directly to the image, are great storage systems for electronic photographs. Digital images can also be filed with the hard copies.

Taking subsequent photographs. At later dates, the photo point is relocated using the map, photo, GPS point, and/or and location description. The camera azimuth and vertical angle is set, and the image is viewed through the LCD screen or lens and compared to the print of the original photograph. If the original spot cannot be located, then relocating the photo point can be attempted using the procedures outlined in Figure 11.2.

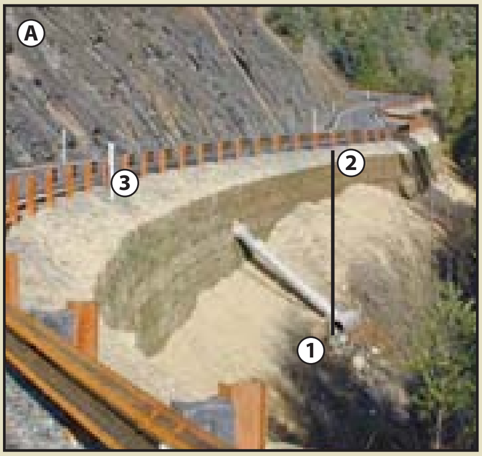


Figure 11.2 – *If no records exist for the original photo locations, then a close approximation can be determined (after Hall 2002a). If the photographs were taken along a roadside, it is often possible to relocate the approximate point the photograph was taken by locating permanent structures (such as guardrails and culverts).*

To relocate the photo point in the historic photograph (A), a large print was made and taken to the general location in the field. Since the original photograph was obviously taken from the paved road surface on the inside of the guardrail, there was little doubt that the elevation of the second photograph (B) would be approximately the same.

Locating the original photo point along the guardrail was accomplished by establishing a relatively vertical centerline connecting two identifiable points on both the original photograph (A) and the photograph to be taken (B). In this example, the centerline is drawn from the left side of the culvert (1) to the 12th post of the guardrail (2) from the reflector stake (3). Picture B is a close approximation to the photo point location of photo A, but notice that the centerline is not quite in the same direction as in photo A. To find the more exact location, the photographer should move to the right along the inside of the guardrail until the centerline lines up in the same direction as in photograph A.

11.6 ORGANIZE, FILE AND REPORT PROJECT RESULTS

Monitoring is a long-term effort that can span many years. It is important to document, organize, and file monitoring information in a manner that will be understandable to others years later. The cover sheet illustrated in Table 11.2 is useful to attach to the front of a monitoring data set when filing. It details the date, location, and methods of monitoring.

Be sure that the project records include:

- The diary or log kept during the project,
- Copies of all maps and plans,
- Copies of all budgets and task orders,
- Photos and data, and
- Reports and evaluations.

Depending on the complexity of the project and the agencies involved, some reporting of monitoring results will be necessary. Reports are an excellent opportunity to summarize the information collected and describe any management actions taken to correct shortcomings.

Timing varies, but typically, a Final Monitoring Report is submitted after the third monitoring season. This report summarizes whether the revegetation project met standards and commitments made during the planning stages. It is important to review the original revegetation plan to address whether the desired future condition was fulfilled as stated. The report should address this in the context of successes or failures in each revegetation unit.

11.7 SHARE LESSONS LEARNED

Revegetating highly disturbed sites with native plants is a relatively new field of study. Well-designed and analyzed monitoring projects can provide good information to a wider audience of practitioners and scientists working in this field. By taking the time to share monitoring results, the science and practice of revegetating highly disturbed sites can be advanced.

Conferences, societies, newsletters, internet sites, and trade publications are some venues to share knowledge. The small-scale trials that were carried out to test, for example, different rates of fertilizer, tackifier, seeds, or hydromulch should also be of great interest. Case histories or trials can be shared on websites, in journals, or in posters and presentations at conferences (SER 2005). Evaluations of the overall approach taken and the lessons learned will be an important contribution to future projects.

11.8 ROADSIDE MAINTENANCE AND MANAGEMENT

Following road construction, maintenance of roadside revegetation is usually administered by local agencies. Once the final revegetation report is submitted and the reimbursable agreement is closed, maintenance and monitoring of vegetation is no longer the responsibility of the revegetation specialist. However, coordination with the road maintenance agency is vital to ensure the long-term success of the project. Monitoring information can help guide effective decision-making for the life of the project site. While specific maintenance strategies are beyond the scope of this manual, many resources exist to protect and enhance native vegetation on roadsides and to reduce the spread of invasive species. For example, on a national level, guidelines have been developed for Integrated Roadside Vegetation Management (IRVM) to maintain healthy populations of native plant communities to exclude invasive species (Berger 2005). Many road-owning agencies have their own protocols for monitoring and managing roadsides. Readers are encouraged to explore these resources in order to support the goal of healthy native plant communities on roadsides.

11.9 CONCLUSION

Roadside revegetation is an integrative process that involves careful planning, implementation, and monitoring. It is important to select monitoring strategies that generate useful information targeted to project objectives and DFCs. Analyzing and sharing results is a key practice to guide effective management of the project, as well as to improve results on future projects.

12 MONITORING PROTOCOLS

12.1 INTRODUCTION

This chapter describes statistical sampling design, data collection techniques, and analysis methods for quantifiable parameters to determine success of roadside revegetation projects. It is written specifically for field personnel as a quick guide to monitoring roadsides. It is not intended to teach statistics or explain the statistical basis behind the procedures addressed in this section. If the reader wishes to explore the statistics used in this chapter, a supplemental report (Kern 2007) details the statistical basis for each procedure. There are many approaches to statistically monitoring roadside vegetation. This report takes the approach that if monitoring is not simple, inexpensive, and objective-based, it will not be done well, or done at all.

The reader will be directed to those sections necessary to prepare and implement a monitoring plan. Three questions must be to answered before monitoring begins:

1) What are you monitoring?
2) What is the shape of the sampling area?
3) What is the objective behind monitoring?

The answers to these questions will lead the reader to different parts of the chapter (Figure 12.1). This chapter presents methods to record, summarize, and analyze data using the Excel® spreadsheet program. You can create your own spreadsheet, or obtain a monitoring Excel® workbook which contains the spreadsheets shown in the chapter by contacting the authors of the report. Before using the spreadsheets, the reader is advised to see whether the Analysis ToolPak is installed. If it is not, many of the spreadsheets will not function properly. To do this, go to the toolbar and select Tools, Add-Ins, then make sure that the box next to Analysis ToolPak is checked.

What are you monitoring? There are many revegetation parameters that can be monitored. In this chapter, parameters are grouped into 5 categories based on the following revegetation objectives:

- ***Soil cover*** – to determine whether treatments increased soil cover for erosion control.
- ***Species cover*** – to determine whether treatments increased native grass and forb cover.
- ***Species presence*** – to determine whether there was an increase in the number of seeded native grass and forb species.
- ***Plant density*** – to determine how many seedlings or cuttings became established after planting to assess whether stocking is adequate or the site needs replanting. Plant survival can also be determined from this protocol.
- ***Plant attributes*** – to determine how fast planted shrubs and trees are growing.

The procedures for monitoring each of these parameters are described in Sections 12.2 through 12.6. Each protocol discusses how

Figure 12.1 *– Quick Guide to Monitoring Chapter.*

What are you monitoring?	Read
Soil Cover	12.2
Species Cover	12.3
Species Presence	12.4
Plant Density	12.5
Plant Attributes	12.6
What is the shape of the sampling area?	
Linear	12.7.1
Rectilinear	12.7.2
Dispersed	12.7.3
What is the objective for monitoring?	
Compliance	12.9.1
Treatment Differences	12.9.2
Trends	12.9.3

Note: This chapter uses abbreviated scientific names, or plant symbols, from the PLANTS Database (http://www.plants.usda.gov) to conserve space in spreadsheets. The PLANTS Database includes scientific names, plant symbols, common names, distributional data, images, and species characteristics for vascular plants of the United States.

transects and quadrats (or plots) are located, methods for collecting data at each plot, and how data is summarized for statistical analysis.

What is the shape of the sampling area? Revegetation projects associated with road construction can be classified into three broad sampling design categories based on the spatial features of the sampling unit:

- ***Linear areas*** – associated with cut slopes, fill slopes, and abandoned roads
- ***Rectilinear areas*** – associated with staging areas and material stock piles
- ***Dispersed areas*** – associated with planting islands, planting pockets, clump plantings

Each of these sampling designs has a set of procedures defining how transects and quadrats will be laid out. Section 12.8 guides the reader through methods for determining how many transects and quadrats to establish.

What is the objective behind monitoring? There are three basic reasons for statistical monitoring:

- ***Compliance*** – were regulatory standards or project objectives met?
- ***Treatment differences*** – are there differences between revegetation treatments?
- ***Trends*** – what degree of change is occurring over time?

Monitoring for most projects will be conducted to determine whether standards were met (compliance) since this will be of most interest to the reviewing officials. There will be occasions however, when you might want to know if different revegetation treatments applied to the same area resulting in a different vegetative response. There might also be times when it will be important to know to what degree things have changed over time. It is important to discern which of these three objectives meet the intent of your monitoring.

As you move through this chapter to the appropriate sections, you will develop, by the end, a set of instructions that establish:

- Quadrat locations (See Section 12.7)
- Quantity of quadrats to take (See Section 12.8)
- Type of data collection at each quadrat (See Sections 12.2 through 12.6)
- Type of data analysis to perform (See Section 12.9)

These instructions should be developed prior to any monitoring work and organized in a manner that is easy to reference in the field.

12.2 SOIL COVER PROTOCOL

Reestablishing grasses and forbs on disturbed sites is essential for erosion control. In general, erosion and sediment transport is a function of live or dead cover in contact with the soil surface. Soil cover protocol can be selected to determine the amount and type of cover existing on the surface after construction.

The quadrat is the unit of area that is monitored for soil cover. Exact measurements are based on recording the surface soil attributes at 20 data points within each quadrat. In this assessment, a grid of 20 data points is placed on the surface of the soil; where each point hits the surface is where the soil cover attribute is recorded. For instance, the data recorded at the first quadrat shows that 5 points were rock, 10 points were live plant cover, and 5 points were soil. The results for that quadrat would be 25% rock, 50% live plant cover, and 25% bare soil.

Quadrats are read in the field using a fixed frame (See Section 12.2.1), or read later in the office from digital pictures of quadrats. A system for taking digital photographs of the surface, where the photograph itself becomes the quadrat, is described in Section 12.2.2.

The sampling design for laying out transects and quadrats depends on the shape of the sampling unit (See Section 12.7). The number of transects and quadrats depends on the variability of the parameter of interest (See Section 12.8). How the data will be analyzed will be based on the objectives for monitoring (See Section 12.9). These sections should be reviewed before this protocol is used.

Figure 12.2 – A fixed frame for measuring soil cover is placed at predetermined distances on a transect.

Figure 12.3 – A fixed frame can be adapted to allow for the positioning of a laser pointer at 20 points in the frame. Soil cover or plant cover attributes are recorded at each laser point. The frame in this example is 8 in by 20 in, with 2 in spacing within rows and 4 in spacing between rows. The laser is a Class IIIa red laser diode module that produces a 1mm dot.

12.2.1 Sampling by Fixed Frame

Soil cover is quantified at each quadrat based on readings from a 20 point fixed frame. There are several types of frames that have been developed. The most appropriate frames are 1) light weight and portable, 2) stable, and 3) easy to assess data points on the ground surface. One frame that meets these criteria uses a laser pointer to identify data points. The frame shown in Figure 12.3 has 20 slots to position a laser pointer. During monitoring, the laser pointer is moved to each of the 20 slots. Soil cover attributes are recorded where the laser hits the ground surface. Contact the authors of this report for more information on this frame.

The fixed frame must be located along the tape in a consistent manner throughout the sampling of a unit (Figure 12.2). For instance, the frame might be placed on the right side of the tape with the lower corner of the frame at the predetermined distance on the tape. This procedure would be applied across the entire sampling area. The legs of the frame are positioned so that the surface of the frame is on the same plane as the ground surface (Elliot personal correspondence 2007).

Each data point is characterized from a set of predetermined label descriptors which include, but are not limited to:

- Soil
- Gravel (2mm to 3 inches)
- Rock (> 3 inches)
- Applied mulch
- Live vegetation (grasses, forbs, lichens, mosses)
- Dead vegetation

Ideally, one would quantify only cover in contact with the soil surface. However, differentiating between plant leaves and stems that are in direct contact with the soil as opposed to simply in close proximity to the soil surface can be difficult and not always feasible. In this protocol, the assumption is that if live or dead vegetation is within one inch of the soil surface, it will be recorded as soil cover.

Different levels of vegetative cover will block the view of the soil surface. To circumvent this problem, the quadrat will be clipped of standing vegetation (dead or alive) at a one inch height

Figure 12.4 – *A data collection and summary form can be developed similar to the first 7 columns in this spreadsheet. The field recorder fills in the transect and quadrat number at each plot (columns A and B). The names of the attributes being sampled are written in cells C3 through G3. The columns below each attribute (columns C through G) are filled in with the number of points out of 20 that fall into each category. These points are converted into percent of total points by copying the equations from columns H through M. Filling in the equations can be done simply and accurately by filling out the first row (cells H4 through M4) exactly as it is shown in the figure, then highlighting the first row of cells, and moving the cursor to the lower right hand corner of the last cell. When the cursor turns into a small cross, click and drag the cells down. The equations will fill in as you drag the curser down the page. Note: Rectilinear study areas will not use the transect column.*

A2 fx Transect

	A	B	C	D	E	F	G	H	I	J	K	L	M
1	Sampling Area:												
2			Number of Points						% of Points				
3	Transect	Quadrat	Soil	Gravel	Mulch	Live Veg	Dead Veg	Total Points	Soil	Gravel	Mulch	Live Veg	Dead Veg
4	1	1	3	5	6	3	3	20	15	25	30	15	15
5	1	2	4	7	8	1	0	20	20	35	40	5	0
6	1	3	0	1	12	3	4	20	0	5	60	15	20
7	1	4	1	2	8	3	6	20	5	10	40	15	30
8	2	1	3	5	12	0	0	20	15	25	60	0	0
9	2	2	0	1	10	6	3	20	0	5	50	30	15

H	I	J	K	L	M
	% of Points				
Total Points	=C3	=D3	=E3	=F3	=G3
=SUM (C4:G4)	=C4/20*100	=D4/20*100	=E4/20*100	=F4/20*100	=G4/20*100
=SUM (C5:G5)	=C5/20*100	=D5/20*100	=E5/20*100	=F5/20*100	=G5/20*100

above the ground surface prior to taking the readings. The clipped vegetation is removed from the plot before the reading is made. This method errs on the side of lower ground cover readings because the standing vegetative material that is clipped and removed would have eventually become ground cover.

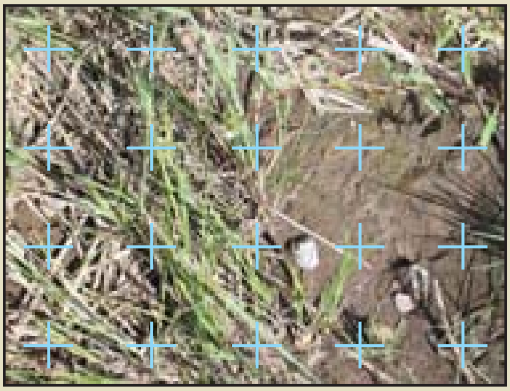
Data can be recorded on a field-going computer or on paper. Recording data on paper bypasses the need for electronic equipment in the field. However, it requires that data be entered into a computer at a later time. The development of a paper form should consider how data will be entered and statistically analyzed. Figure 12.4 shows a spreadsheet for collecting data which also will summarize the data by % of surface in a cover attribute.

12.2.2 Sampling by Digital Camera

Digital cameras are being used more and more frequently for monitoring plants and animal life. This technology allows the data collector to spend most of the field time laying out transects and taking pictures of quadrats, reducing field time significantly. With recent developments in photo-imaging software, photos can be assessed quickly back in the office. Because these are permanently stored records, digital photographs have several advantages: 1) photographs can be reviewed during the "off" season or "down time," 2) they are historical records that can be referenced years later, and 3) they can be reviewed by supervisors for quality control. In addition, taking digital photographs of ground cover can be accomplished by one person, not two as is often required of fixed frame monitoring. On steeper slopes, using a digital camera to record quadrats is much quicker and simpler than reading attributes from a fixed frame which is often very difficult (Figure 12.6).

Sampling by camera requires the same statistical design and plot layout as the fixed frame method. The difference is that a picture is taken at the quadrat location instead of on-site measurements. In the office, digital photographs are catalogued electronically and a 20-point

Figure 12.5 – *For the soil cover protocol, a 20 point grid is randomly positioned on a digital photograph of the plot. Soil cover attributes are identified where the point hits. In this example, there are 8 "soil" points (40%), 3 "grass" (15%), 7 "dead vegetation" (35%), and 2 "straw mulch" (10%).*



overlay is placed on the image that identifies the data points to be described (Figure 12.5). The data points are described in the same manner as the fixed frame method.

Prior to photo monitoring, the resolution of the images must be determined. Setting the camera at the highest resolution is fine provided the camera has the memory capacity to store large images. It is possible that over a hundred digital images will be recorded for each sampling area. When memory is limiting, it is important to select the minimum resolution that will allow fine surface details to be observed. Resolution should be determined for each camera by taking photos of a soil surface at several camera settings (see the camera manual) and viewing them on a computer screen to determine whether photos are detailed enough for accurate measurement of the soil cover attributes. It is important to have enough memory to store the number of pictures required. Carrying extra memory (as well as an extra battery) is always a good idea.

The camera should be secured to a tripod at a fixed height between 3 to 5 feet above the ground surface. The camera height should be adjusted so it is comfortable for the person sampling while still capable of capturing the image within a photo frame. A photo frame defines the area within which the photograph will be taken. The frame can be easily made from PVC pipe joined together with pipe connectors. There is not a standard frame size however, an 11 in by 14 in frame seems to work well. Prior to each photograph, the transect/quadrat must be recorded within each frame so that each image can be accurately identified later. This can be done with by writing the number on small tags or paper and included in a corner of the frame. Quadrat identifiers are abbreviation of the transect and quadrat numbers (e.g., "4-2" represents the fourth transect/second quadrat).

Figure 12.6 – *Road cuts are often too steep for sampling without the aid of ladders or ropes. A hazard analysis must be conducted prior to implementing such measures. For the monitoring shown in this picture, a camera was used for the soil cover protocol which cut down the amount of time spent on the ladder (Photo by Greg Carey).*

When the photo frame is in place and the quadrat has been identified, vegetation greater than one inch from the surface of the soil is cut to a height of one inch and removed. The tripod is positioned over the photo frame so the camera is approximately on the same plane as the ground surface. The camera lens should be adjusted so the photo image in the view screen is just inside the quadrat frame. The picture should be taken so shadows from the tripod or the photographer are not in the frame. Cloudy days are often ideal due to the lack of shadows. Clear days, especially when the plots are in direct sunlight, can be difficult because of the extreme shadows. The camera flash can be used under these conditions to reduce the contrasts within the images.

The FHWA and USDA Forest Service have developed a method for evaluating digital photographs by adapting a software program for monitoring underwater coral cover. The program is called "Monitoring soil cover using CPCe digital photo assessment method" and it automates the configuration of a large group of digital photographs so that they are easy to evaluate and record. The program navigates the user to the 20 points on each digitally photographed quadrat at the click of a mouse. At each point the user records the observed soil cover attribute. The data is summarized and can be taken directly into spreadsheets for statistical analysis.

12.3 SPECIES COVER PROTOCOL

The species cover protocol is used to assess the aerial dominance of seeded species. This protocol is used when revegetation standards require that a certain percentage of vegetative cover be composed of native species. For example, revegetation objectives that were agreed upon during the planning phase state that over 50% of the vegetative cover existing on the site two years after construction will be composed of native species that were seeded. Monitoring the vegetative cover through this protocol will assess whether this was accomplished. Since grass and forb cover changes during the season, the timing of species cover monitoring is important. The best time to monitor is during flowering, typically from mid-May through July, because the species are identifiable during this period.

Use of a digital camera is not usually applicable to species cover monitoring because identifying species is not always possible in digital photographs. Sampling is therefore accomplished

***Figure 12.7** – This spreadsheet can be used to summarize species cover data and is similar to Figure 12.4. Fill in the names of the seeded species in cells C3 through G3. Beneath each species, report the number of points that were encountered for each species. The corresponding percent cover for each species will show up in the formula cells. Insert additional rows and columns if more are needed. Note: Rectilinear study areas will not have the transect column filled in.*

P4 fx

	A	B	C	D	E	F	G	H	I	J	K	L	M	N
1														
2			Number of Points						% of Points					
3	Transect / Dispersed Unit	Quadrat	ELGL	BRCA5	FECA	ERLA	ERUM	Total Points	ELGL	BRCA5	FECA	ERLA	ERUM	% Cover by Seeded Species
4	1	1	3	5	2	3	3	20	15	25	10	15	15	80
5	1	2	4	7	4	1	0	20	20	35	20	5	0	80
6	1	3	0	1	6	3	4	20	0	5	30	15	20	70
7	1	4	1	2	4	3	2	20	5	10	20	15	10	60
8	2	1	3	5	5	0	0	20	15	25	25	0	0	65
9	2	2	0	1	3	6	3	20	0	5	15	30	15	65

I	J	K	L	M	N
% of Points					% Cover by Seeded Species
=C3	=D3	=E3	=F3	=G3	
=C4/20*100	=D4/20*100	=E4/20*100	=F4/20*100	=G4/20*100	=SUM(C4:G4)/H4*100
=C5/20*100	=D5/20*100	=E5/20*100	=F5/20*100	=G5/20*100	=SUM(C5:G5)/H5*100

with a fixed frame. This sampling protocol typically requires a botanist to identify species and another person to help lay out the plots and record data.

Species cover is quantified at each quadrat based on readings from a 20-point fixed frame (See Section 12.2.1). At each point, the species is recorded on a spreadsheet similar to Figure 12.7. More columns can be inserted on the spreadsheet to account for a larger number of species. The tendency can be to record all species encountered in a sampling area; however, this is not recommended. Instead, we recommend grouping species into such categories as "non-native grasses," or "non-seeded native forbs," which can be useful for later analysis and reporting.

As with all protocols, the sampling design for laying out transects and quadrats depends on the shape of the sampling unit (See Section 12.7), and the number of quadrats to sample depends on the variability of the parameter of interest (See Section 12.8). How the data will be analyzed will be based on the objectives for monitoring (See Section 12.9). These sections should be reviewed before this protocol is used.

12.4 SPECIES PRESENCE PROTOCOL

Determining species cover, as outlined in the previous section, can be time-consuming and expensive. The species presence protocol is an alternative method of determining whether or not species that were seeded are present on the site. While this method still requires a botanist in the field, it takes far less time per plot because only presence or absence of a species is recorded.

Figure 12.8 – *Species of interest (seeded species) are placed as headings in this spreadsheet (cells C3 through G3). In the columns below each species, the presence or absence of the species is recorded as a "1" for present or "0" for absent. Fill in cells H4 and I4 with equations shown in inset. Copy the remainder of the cells with equations by highlighting cells H4 and I4, then, while they are highlighted move the curser to the lower right hand corner of cell I4. When the curser turns into a cross, left click the mouse and drag the equations down the page. After the spreadsheet is completed, do a test run with the data shown in columns A through G to see if the equations in column H and I are correct. Note: Rectilinear study areas will not have the transect column filled in.*

I17 | fx SUM(C17:G17)/H17*100

	A	B	C	D	E	F	G	H	I
1									
2			Presence of Plants (1=presence, 0=not present)						
3	Transect / Dispersed Unit	Quadrat	ELGL	BRCA5	FECA	ERLA	ERUM	Total Number Species Sown	% Seeded Species Present in Plot
4	1	1	1	0	0	1	1	5	60
5	1	2	1	1	0	0	0	5	40
6	1	3	0	1	1	1	1	5	80
7	1	4	1	0	1	1	1	5	80
8	2	1	0	1	1	0	0	5	40
9	2	2	0	1	1	1	1	5	80

H	I
Total Number Species Sown	**Percent Seeded Species Present in Plot**
=COUNT(C4:G4)	=SUM(C4:G4)/H4*100
=COUNT(C5:G5)	=SUM(C5:G5)/H5*100

In this method, a fixed frame is placed on the surface of the soil at each quadrat. The size of the fixed frame should be based on what is considered a measurement of success. For instance, for shrub or tree species, having one plant established every 10 ft^2 (equivalent to 4,356 plants/acre) would be very successful. However one grass plant every 10 ft^2 might not be considered successful. For monitoring most species, we recommend a frame size of 4 ft^2 (2 ft on each side) using a PVC pipe with connectors. This size frame is easy to carry and read. Whatever size is used, we recommend that the frame dimension stay the same throughout the monitoring project. Prior to sampling, the species of interest (typically just the seeded species) are identified and recorded on the data form (Figure 12.8). These will be the only species recorded at each quadrat. At each quadrat, the species of interest are evaluated for presence or absence. If the species is present, it is given a "1," and if it is not present, it is given a "0." The data is summarized by the percentage of the species present on the quadrat out of the total number of seeded species.

As with all protocols, the sampling design for laying out transects and quadrats depends on the shape of the sampling unit (See Section 12.7), and the number of quadrats to sample depends on the variability of the parameter of interest (See Section 12.8). How the data will be analyzed will be based on the objectives for monitoring (See Section 12.9). These sections should be reviewed before this protocol is used.

12.5 PLANT DENSITY PROTOCOL

Trees and shrubs are typically established from plants (See Section 10.2.6, Nursery Plant Production and Section 10.2.3, Collecting Wild Plants) or cuttings (See Section 10.2.2, Collecting Wild Cuttings and Section 10.2.5, Nursery Cutting Production). Many constructed wetlands are also planted from nursery grown or wild collected seedlings. Monitoring the density of live plants following the first and third year after they are planted is important in order to determine if they have survived and whether the site will need to be replanted. In the case of constructed wetlands, plant density monitoring is conducted to determine whether regulatory requirements were met.

The quadrat in this protocol is a circular plot with a specified radius. We recommend using a 1/100 acre plot, which has an 11.7 ft radius and covers 436 ft^2. A staff is placed at plot center and a tape or rope is stretched 11.7 ft. While one person holds the staff, the other walks the

Figure 12.9 *– Prior to monitoring, a list of planted species are identified in cells C3 through G3. At each plot, the number of plants of each species is recorded in columns C through G. The size of the quadrat is recorded in Column H (a 1/100 acre plot is 436 ft^2). Using the equations shown in the inset for Columns I through N, the number of plants per species per acre is calculated. Column N sums the total number of plants per acre as represented in each plot. Fill in cells I4 through N4 with the equations, then copy to the remaining cells. Note: There is only one quadrat per transect.*

H20 | fx

	A	B	C	D	E	F	G	H	I	J	K	L	M	N
1														
2			Number of Plants per Quadrat						Plants per Acre					
3	Transect / Dispersed Unit	Quadrat	PIPO	PSME	LIDE	ARME	ARPA	Size of Quadrat (sq ft)	PIPO	PSME	LIDE	ARME	ARPA	Total Plants per Acre
4	1	1	3	1	0	1	0	436	300	100	0	100	0	500
5	2	2	4	3	2	0	1	436	400	300	200	0	100	999
6	3	3	4	1	1	3	4	436	400	100	100	300	400	1,299
7	4	4	1	2	0	3	2	436	100	200	0	300	200	799
8	5	5	3	1	0	0	2	436	300	100	0	0	200	599
9	6	6	0	1	1	2	1	436	0	100	100	200	100	500

I	J	K	L	M	N
Plants per Acre					Total Plants per Acre
=C3	=D3	=E3	=F3	=G3	
=C4*43560/H4	=D4*43560/H4	=E4*43560/H4	=F4*43560/H4	=G4*43560/H4	=SUM(I4:M4)
=C5*43560/H5	=D5*43560/H5	=E5*43560/H5	=F5*43560/H5	=G5*43560/H5	=SUM(I5:M5)

circumference of the plot and counts the number of plants within the quadrat. This information is recorded on a spreadsheet similar to Figure 12.9. This spreadsheet reports the number of plants per acre by species. It also summarizes total plants per acre.

From this spreadsheet plant density can be estimated and an approximate survival rate can be determined by dividing the estimated density (average of column N) by the original planting density (per acre basis from planting records). Plant density monitoring used to determine survival rates are called survival surveys and these are usually conducted in the fall or winter. If the site is planted in the fall or spring and monitoring occurs the following fall, the results are referred to as the "first year survival." Plant density monitoring thereafter, is referred to as the years after planting (e.g., third year sampling is "third year survival").

The sampling design for laying out transects and quadrats depends on the shape of the sampling unit (See Section 12.7), and the number of quadrats to collect from depends on the variability of the parameter of interest as discussed in Section 12.8. (Note that for linear sampling designs, there is only one randomly placed quadrat per transect.) How the data will be analyzed will be based on the objectives for monitoring (See Section 12.9). These sections should be reviewed before this protocol is used.

12.6 PLANT ATTRIBUTES PROTOCOL

The plant attributes protocol is used to measure plant growth. This protocol can be used to assess growth responses between revegetation treatments or revegetation units, and to determine whether standards pertaining to growth requirements were met. Typically only sensitive areas, such as visual corridors or wetlands, have stated growth requirements that must be monitored. This protocol might have limited applicability to most revegetation projects.

Any part of a plant can be measured, and the selection of an attribute is dependent on the species being sampled. Common attributes include:

- Total height – trees and most shrubs
- Last season's leader length – most trees
- Stem diameter – shrubs and trees
- Crown cover – shrubs, forbs, and grasses
- Weight – grasses and forbs

Total height is typically measured from the ground surface to the top of the bud. If the plant has several leaders (or tops), the most dominant leader is used for measurement. Last season's leader growth can be observed in most tree species. For conifers, leader growth is measured

***Figure 12.10** – A spreadsheet is shown here for recording one species and one attribute. This spreadsheet can be developed to record several attributes or several species.*

K4 fx

	A	B	C	D	E	F	G
1	Species: PIPO						
2		Attribute: Plant Height (in)					
3	Quadrat	Plant 1	Plant 2	Plant 3	Plant 4	Plant 5	Average
4	1	32	41	34	33	27	33
5	2	36	29	25	32	25	29
6	3	35	33	33	36	31	34
7	4	30	34	32	39	39	35
8	5	27	25	33	41	25	30

G
Average
=AVERAGE(B4:F4)
=AVERAGE(B5:F5)

from the last whirl of branches to the base of the bud. Comparing leader growth from year to year can indicate whether plants are healthy and actively growing. Stem diameter can be used to measure most trees and shrubs; in this method, the basal portion of the plant is measured with calipers at the ground surface. Crown cover is more conducive to spreading plants, such as shrubs, grasses, and forbs. This measurement requires the use of a large frame with grids or points that can be placed over the plant to obtain an aerial coverage. Weight of the plant is typically used for grasses and forbs. Foliage is clipped at the base and weighed immediately for fresh weight, or dry weight after the sample has been oven-dried.

Sampling plant attributes should be narrowed to a species of interest. It is probably not necessary to measure all species on a site. Those species that are easy to measure and will dominate the site are the best to sample (typically trees and shrubs). It is not necessary to sample all plants in a quadrat. We suggest a minimum sample of 5 plants from each species. An unbiased way to select which plants of each species to monitor is to sample those plants closest to plot center. If there are not enough plants in the quadrat to sample, then the nearest plants outside of the quadrat should be sampled.

The measurement for each plant is recorded in a data sheet similar to Figure 12.10. The species and the attribute being measured must be identified on each sheet (cell B2). The number of quadrats to establish depends on the variability of the plant attribute which is discussed in Section 12.8. How the data will be analyzed is based on the objectives for monitoring (See Section 12.9). These sections should be reviewed before this protocol is used.

12.7 SAMPLING AREA DESIGN

Three basic sampling designs are used to monitor revegetation units depending on the shape or geometry of the sampling areas. The primary objective of these designs is to provide even spatial coverage of sampling locations within revegetation units that results in unbiased data collection. The three types of designs that will be covered are:

Linear (See Section 12.7.1). Long and narrow sampling areas, such as road cut and fill slopes, are sampled using a systematic series of transects, oriented perpendicular to the road, along which are located a set of quadrats. Each transect is treated as the primary experimental unit for statistical analysis.

Rectilinear (See Section 12.7.2). For more rectilinear sampling areas, a systematic grid (that is, a checkerboard) of quadrats is sampled, and each quadrat is treated as the primary experimental unit for statistical analysis.

Dispersed (See Section 12.7.3). When a series of discrete areas (e.g., planting pockets, planting islands) are encountered, a systematic or grid sample design of dispersed areas is identified for sampling. Depending on the geometry and size of these areas, either complete enumeration (measuring all plants) or subsampling using transects or grids is employed within selected areas.

12.7.1 Linear Sampling Areas

Linear areas, such as cut and fill slopes and abandoned roads, are sampled using a systematic series of equally spaced transects. Each transect has varying numbers of quadrats (plots), depending on the length of the transect. When the revegetation unit is fairly uniform in width, each transect will have approximately an equal number of quadrats; when the width of the revegetation unit is highly variable, there will be unequal numbers of quadrats per transect. In either case, each transect is treated as the primary experimental unit.

Figure 12.11 shows a typical sampling design for a linear area. In this example, the sampling area included only those portions of the cut slope that were seeded; it did not include road shoulders or ditch line. For statistical analysis, the number of transects (n) to collect was estimated to be 20 based on pre-monitoring data (See Section 12.8). Spacing the 20 transects equally along the sampling area was calculated by dividing the total length of the sampling area by the number of transects to obtain the distance between transects (3,100/20 = 155 ft). Locating the first transect was done in an unbiased way by generating a random number between 1 and 155 using the random number spreadsheet function shown in Figure 12.12.

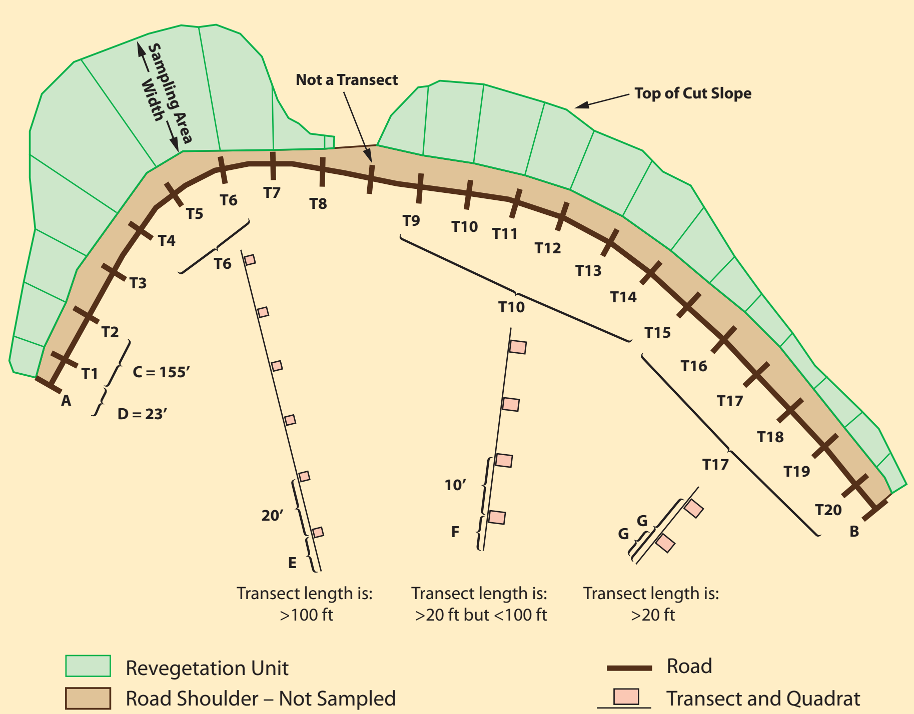
Transects are laid out by establishing a line perpendicular to the edge of the road. The transect begins at the edge of where seeding or other treatments were completed, which is typically beyond the road shoulder and ditch. Each transect contains a group of evenly spaced quadrats.

The spacing between quadrats vary by the length of the transect:

- ***<20 ft transect lengths.*** For sampling areas where transect lengths are less than 20 feet, 2 quadrats are installed. Two random numbers (G) are generated between the numbers 1 and 19. These numbers indicate the location of each transect.
- ***>20 and <100 ft transect lengths.*** For sampling areas where transect lengths are between 20 and 100 feet, quadrats are placed at 10 foot intervals. The distance to the first quadrat will be based on a random number between 1 and 10 feet.
- ***>100 ft transect lengths.*** These long transects have 20 feet between quadrats. The distance to the first quadrat will be based on a random number between 1 and 20 feet.

For the Plant Density and Plant Attribute protocols, only one quadrat is randomly located within each transect. The location is determined by assigning the RANDBETWEEN random number function to the length of each transect (Figure 12.12).

Figure 12.11 – *Linear sampling areas are typically long units with varying widths. Road cuts, fills and abandoned roads typically fit this sampling design. The design of linear sampling areas uses a series of transects with uniformly spaced quadrats within each transect. The distance between quadrats varies by the length of the transect. Transects longer than 100 feet have 20 feet of spacing between quadrats (T4 through T6), transects between 20 and 100 feet have 10 feet between quadrats (T9 through T14), and transects less than 20 feet long have two randomly placed quadrats (T15 through T20).*



A = Starting point
B = Ending point
A to B = Length (L) of sampling area (3,100 ft)
n = Number of transects (20) calculated from pre-monitoring data (Section 12.8)
C = Distance between transects = length (L) / number (n) of transects = 3,100/20 = 155 ft
D = Distance to first transect = random number within the distance between transects (between 1 and 155 ft)
E = For >100 ft transect, a random number between 1 and 20
F = For >20 ft but <100 ft transect, a random number between 1 and 10
G = for <20 ft transect, two random numbers between 1 and 19

Figure 12.12 – *The locations for the first quadrat for each transect are based on randomly assigned numbers that can be obtained prior to going to the field using the RANDBETWEEN function. This tool provides uniformly distributed random numbers within a specified range. For example, if the distance between quadrats has been calculated to be 52 ft, then random numbers between 0 and 52 feet can be calculated by providing the following equation for each transect: "=RANDBETWEEN(0,52)." The number given for each transect is the distance from the edge of the revegetation unit to the first quadrat.*

SUM fx

	A	B	C	D
1	**Transect ID**	**Random Start**		
2	**T1**	=RANDBETWEEN (0,52)		
3	**T2**	32		
4	**T3**	43		
5	**T4**	24		
6	**T5**	28		
7	**T6**	17		
8	**T7**	2		
9	**T8**	38		
10	**T9**	40		
11	**T10**	44		
12	**T11**	18		
13				
14				
15				

Sheet 1

12.7.2 Rectilinear Sampling Areas

When sampling areas are more elliptical or rectangular in shape, or composed of several large irregular polygons, the sampling design will be based on a rectangular grid of quadrats systematically located with a random starting point. Figure 12.13 shows an example of such a sampling design. Notice that this design is different from the linear sampling design in that there are no transects. The quadrat in this sampling design is the primary experimental unit, not the transect.

To determine the grid spacing (E) for the quadrat locations, the area of the sampling unit must be obtained from maps, and the number of quadrats to be sampled (n) must be determined from pre-monitoring data (See Section 12.8.2). The following equation gives the length of each side of a square grid (E):

$$E = \sqrt{\frac{\text{Area}}{n}}$$

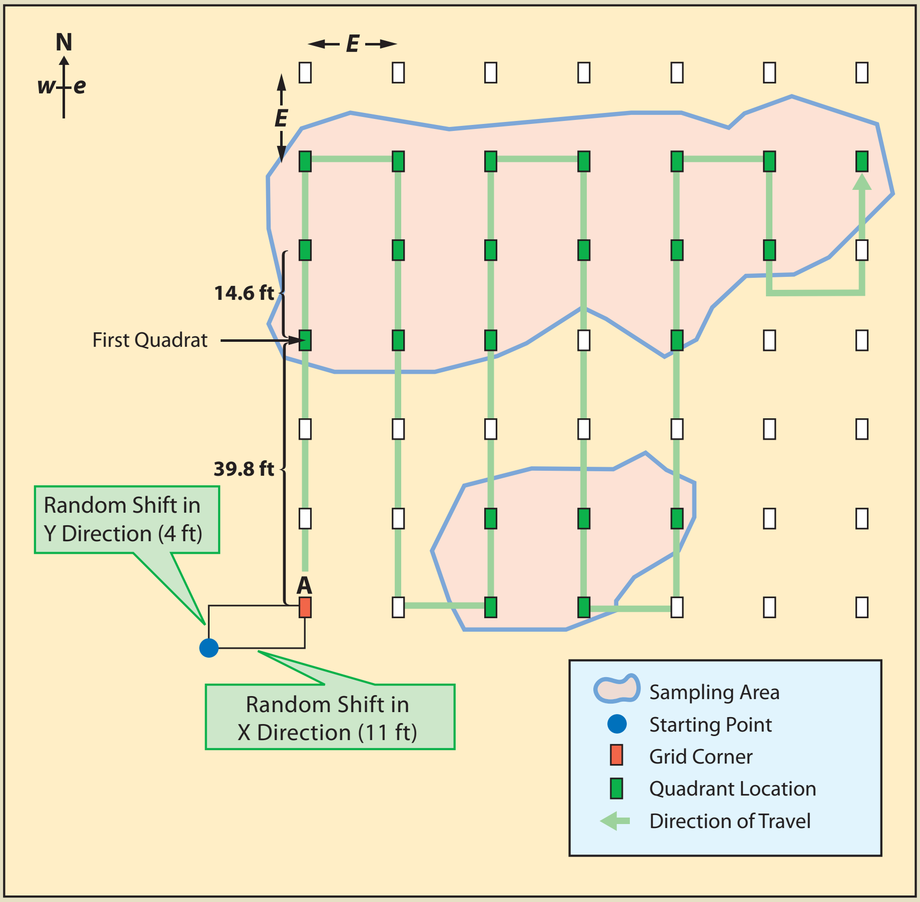
For example, the sampling area in Figure 12.13 covers 4,262 ft^2 and it has been determined from pre-monitoring data that approximately 20 quadrats are necessary to attain the statistical sampling requirements for this sampling area. The formula indicates that each side (E) of the grid should be 14.6 ft:

$$E = \sqrt{4{,}262 / 20} = 14.6 \text{ ft}$$

A starting point of the grid is arbitrarily located in any corner of the study area. To avoid biasing the placement of the quadrats, the corner of the grid must be shifted by assigning random numbers to the x and the y coordinates as shown in Figure 12.13. This is called a systematic design with a random start. It provides equal likelihood that any point in the study area is included in the sample unless there are obvious systematic patterns in the site such as planting rows. In this case, the random number shifts were 11 ft in the horizontal direction and 4 ft in the vertical direction.

In this example, the monitoring team would locate the starting point in the field. Taking a true north bearing, the team would measure 39.8 ft (10.6+14.6+14.6 = 39.8) to take the first plot. They would measure 14.6 ft on that bearing to locate the next quadrat. After they collected data from the last quadrat in that line, they would take a due east bearing and walk 14.6 ft to locate the next plot. This system of sampling would continue until the entire area has been sampled.

Figure 12.13 *– For rectangular or elliptical sampling areas, a grid composed of quadrats is used. The length of the grid cells (E) is calculated , which becomes the standard distance between quadrats for this sampling area. To avoid bias, the x and y axis of the grid is randomly offset. The monitoring team follows compass bearings and uses a measuring tape in a systematic manner to locate all quadrats.*



12.7.3 Dispersed Area Sampling

When sampling areas occur as small, distinct areas, a two-stage sampling design is recommended. The first stage is to determine which dispersed areas to sample and the second stage is determining how to sample within each selected area. For the first sampling stage we suggest that a minimum of 20 dispersed areas be monitored within each revegetation unit. If there are 20 dispersed areas or fewer, then all dispersed areas would be sampled. If there are more areas than 20, then they must be sampled using one of two sampling designs. For dispersed areas that range in sizes from small to large and are mapped, the systematic sampling design is used (See Section 12.7.3.1). If the dispersed areas are small or are not mapped, then a grid sampling design is used (See Section 12.7.3.2). In most cases, the grid sampling method is recommended.

12.7.3.1 Systematic Sampling of Dispersed Areas

First Stage – The systematic sampling method of dispersed areas assumes that the dispersed areas have been mapped and identified. The dispersed area in this method is the experimental unit. In this approach, the dispersed areas are numbered sequentially by progressing from one dispersed area to the next closest dispersed area. Determining how to calculate the number (n) of dispersed areas to sample is presented in 12.8.3. Odd- or even-numbered dispersed areas are selected based on a random number using the RANDBETWEEN function. For example, if there were 40 dispersed areas (N) but only 20 dispersed areas needed to be sampled (n), then 50% of the dispersed areas would be sampled (n/N). A random number using RANDBETWEEN(1,2) is used. If the function returns a "1" the odd numbered dispersed areas are selected; if 2, then even numbered areas are selected. Figure 12.14 provides a schematic depiction of such a design.

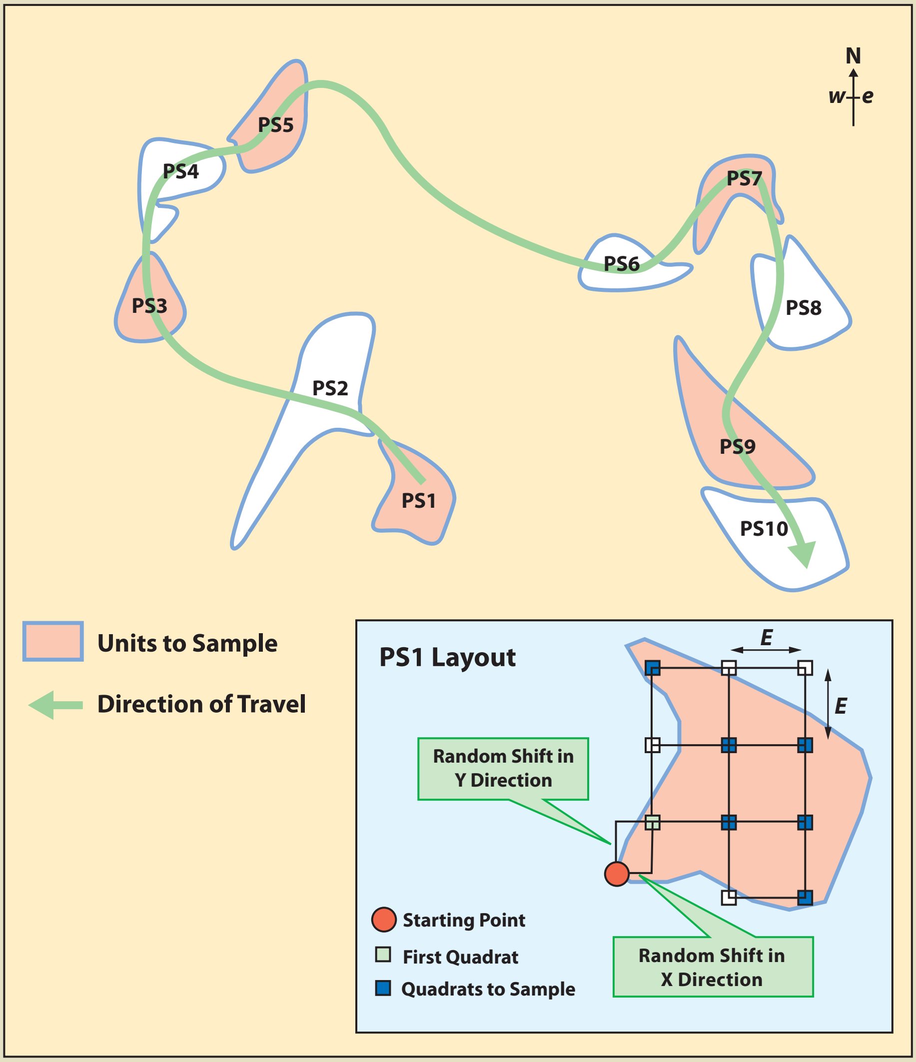
Second Stage – Once the dispersed areas have been selected, the layout of quadrats within each dispersed area is determined. A grid-based sampling design, as described in Section 12.7.2, can be used. To determine the grid spacing (E) for the quadrat locations, determine whether the size of the dispersed area is >1,600 ft² or <1,600 ft² (1,600 ft² is a 40 by 40 ft area). Depending on the sample size, the number of quadrats will be:

- Less than 1,600 ft – 4 quadrats
- Greater than 1,600 ft – 8 quadrats

Using the following equation, the grid sides (E) are determined where n = 4 or 8 depending on the size of the dispersed area and Area is the estimated dispersed area size.

$$E = \sqrt{\frac{\text{Area}}{n}}$$

Figure 12.14 – *A systematic sample of dispersed areas, shown in this example, is based on 50% sampling (the pink areas). Alternating dispersed areas were sampled. Quadrats were located in each sampling area by first locating a starting point and then measuring off random x and y offset coordinates to locate the first quadrat of the sampling grid.*



This calculation will be made for each dispersed area. To avoid biasing the placement of quadrats, a predetermined starting point is decided upon (e.g., the northwest corner of each dispersed area). Random x and y coordinates are generated for each dispersed area that are within the predetermined length of the square grid (E). The corner of the grid is placed at this point and oriented north. The location of the first quadrat is x and y coordinates from the starting point as shown in Figure 12.14.

For the plant density and plant attribute protocols, only one quadrat is randomly located within each dispersed sampling area. The location is determined by assigning the RANDBETWEEN random number function to the number of quadrats determined for the dispersed area. The random number that is generated is the quadrat selected for sampling.

12.7.3.2 Grid Sampling of Dispersed Areas

First Stage – A grid sampling design is used on projects where dispersed areas have not been mapped and there are more than 30 areas. This sampling design is typically used on projects where dispersed areas are numerous and the sizes of the areas are small. In this sampling design a grid is placed over the revegetation unit as shown in Figure 12.15 and the dispersed area nearest to the grid center is selected for monitoring. One quadrat is randomly placed in each dispersed area and this becomes the experimental unit.

Determining the grid cell dimensions (E) is accomplished by using the following equation:

$$E = \sqrt{\frac{\text{Area}}{n}}$$

where the area is the total area of the revegetation unit and n is the number of quadrats to locate (See Section 12.8.3 for determining number of quadrats to sample).

The grid is laid out unbiasedly by locating a starting point just outside the revegetation unit and assigning random numbers to the x and the y coordinates. The corner of the grid is placed at the x and y offset point and oriented north. In the field the grid centers are located using a compass and measuring tape. At each grid center, the closest dispersed area is selected for monitoring. If there are no dispersed areas found within half the distance between grid centers (E/2), then the monitoring team moves on to the next grid center. For revegetation units that have dispersed areas somewhat clustered, grid centers will sometimes be located where there will be no dispersed areas to sample. For this reason, when calculating the grid cell dimension (E) from the equation above, the number of quadrats (n) should be increased 10 to 20% to compensate for grid centers where dispersed areas are not in close proximity.

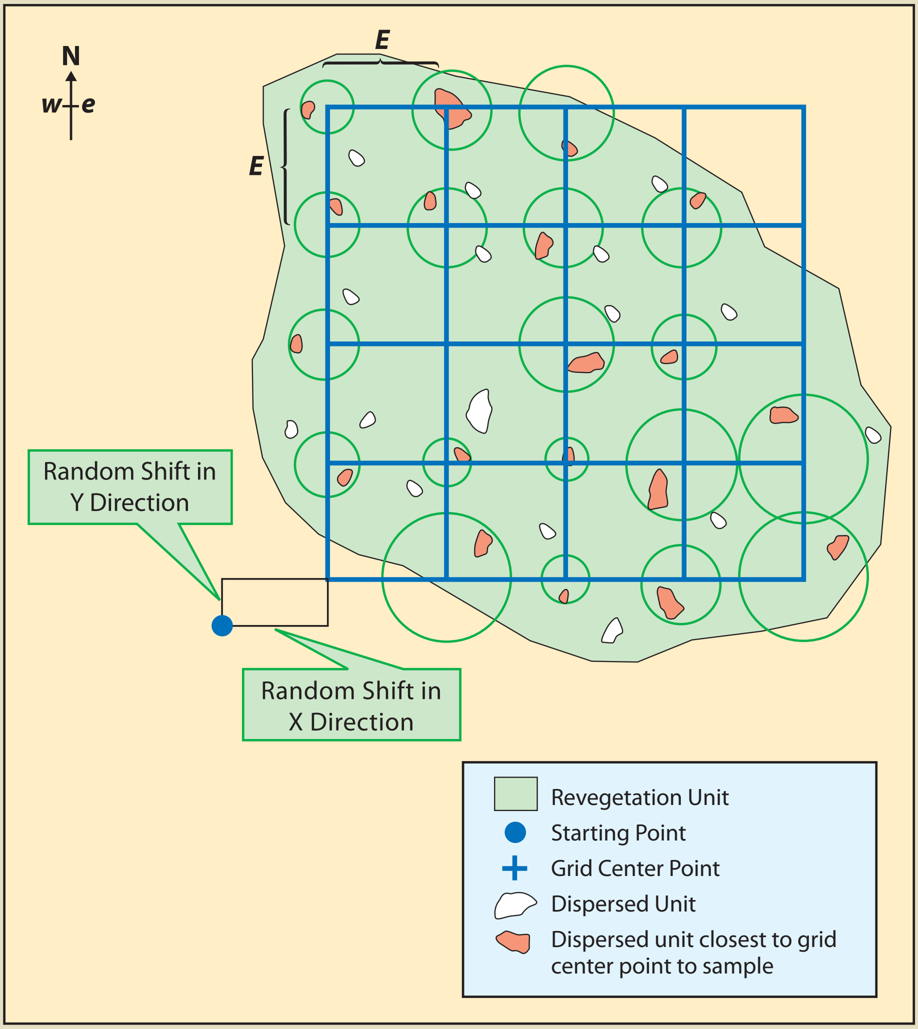
Second Stage – For seedling density and seedling attribute protocols, dispersed units that are selected for sampling may be small enough that plant measurements can be exhaustive (e.g., all plants are measured). These situations usually arise when seedlings are planted in planting islands, benches, or pockets. When this is not possible, or other protocols, such as soil cover, species cover, or species presence protocols are being used, one quadrat is located randomly by facing away from the dispersed area and throwing a rock, hammer, or something heavy and selecting the quadrat location where it lands.

12.8 SAMPLE SIZE DETERMINATION

The number of experimental units needed to statistically sample a revegetation area is based on the variability of the attributes being sampled. By pre-sampling representative areas prior to monitoring, an approximate number of quadrats and transects can be determined. Using pre-monitoring data, however, does not always guarantee enough samples will be taken. There will be projects where pre-monitoring data will not predict the variability, and more samples will be needed. This is usually discovered after reviewing the data back at the office. At that time, the monitoring leader has to decide whether to return to the site and collect more data. To avoid this expensive scenario, we recommend that each revegetation unit be composed of at least 20 primary experimental units (20 transects for linear sampling design, 20 quadrats for rectilinear, or 20 dispersed areas for dispersed area sampling design).

Taking a minimum of 20 samples should help prevent the possibility of having to return to the site to collect more data. The cost of collecting a small amount of extra data from quadrats or transects during initial monitoring is typically low relative to the cost of personnel, equipment, and travel to and from the project area. Taking a minimum of 20 samples is considered a prudent

***Figure 12.15** – Small dispersed areas can be randomly sampled using a grid that is offset in the x and y axis. The grid dimensions (E) are calculated based on number of grid centers (n) needed and the size of the revegetation unit. Once grid centers are located, the nearest dispersed unit is found (closest dispersed unit is shown in circle). If there are no dispersed units within half the distance between grid centers (E/2), then the monitoring team moves to the next grid center.*



precaution. While 20 samples should be enough for most projects, sample size calculations should nevertheless be conducted to determine whether additional primary experimental units may be needed to achieve the precision requirements of the monitoring plan.

Sample size determination methods must be tailored to the monitoring objectives and sampling area design. For compliance objectives for linear area sampling design see Section 12.8.1, rectilinear sampling area design see Section 12.8.2, and dispersed areas see Section 12.8.3. For determining sample size for comparing treatments areas see Section 12.8.4

12.8.1 Comparing Means with Standards – Linear Sample Size Determination

To calculate the minimum sample size for linear sampling areas (See Section 12.7.1), it is necessary to approximate the expected sample mean and the range in values. A visual estimate of the mean and the range of values may be adequate. However, for more precise estimates, 4 transects can be sampled to establish estimates of the mean and range of values.

The following is a quick method of determining the number of transects to sample based on pre-monitoring data collection:

1) Drive the entire revegetation unit and note the different extremes of revegetation success.
2) Find 4 areas that represent the extremes and lay out a transect in each area.
3) Randomly place 2 quadrats within each transect to collect data on the attribute of interest (e.g., % ground cover).
4) For each transect, average the quadrat values (4 averages).
5) Calculate the average of the 4 transect averages and calculate the range (difference between highest and lowest values of the 4 averages).
6) Apply the range and the average to the following equation to obtain the minimum number of transects needed to monitor the revegetation unit (equation based on a sample size of 20% of the true population value with 90% confidence).

$$n = (0.838 * \text{Range})^2 / (0.2 * \bar{x})^2$$

The number of transects (n) obtained from this quick assessment is used to determine the layout of the monitoring design as discussed in Section 12.7.

Example: Suppose that monitoring is to be conducted along a road cut to determine the percentage of soil cover. The monitoring objective is to estimate mean percent cover to within 20% of the true population value with 90% confidence. Four transects that represent a range in conditions are laid out within the revegetation unit. These transects do not need to be located randomly, but rather should be sited to capture the range of values observed in the sampling area. It is better to over-estimate the range of values, as this will tend to result in a conservative estimate of the sample size. The data set and equation is shown in Figure 12.16.

Using the equation presented above, an estimated 13 transects were calculated for a minimum sample size. Although the minimum sample size is estimated at 13, it is still recommended that at least 20 transects be sampled because the cost of additional transects (should the actual monitoring data be more variable than the pre-monitoring data) is minor relative to the expense of returning to the site and collecting more data.

12.8.2 Comparing Means with Standards –Rectilinear Sample Size Determination

When a grid of quadrats is to be implemented (See Section 12.7.2), the sample size calculations use quadrat measurements as opposed to the transect averages that were used in linear sampling areas. The steps involved in calculating the number (n) of quadrats are:

1) Visit the entire revegetation unit and notice the different extremes of revegetation success.
2) Find 4 areas that represent these extremes and lay out a transect in each area.
3) Randomly place 2 to 3 quadrats within each transect to collect data on the variable of interest (e.g., % ground cover).
4) Average the quadrat values (8 quadrat values to average)
5) Calculate the range of all 8 samples (difference between highest and lowest values).

Figure 12.16 *– Example of how to calculate the number of transects needed to be established from pre-monitoring data set.*

	Quadrat		
Transect	**Q1**	**Q2**	**Averages**
T1	10	15	12.5
T2	12	22	17
T3	18	6	12
T4	32	21	26.5

Estimated Mean = **17**
Range (26.5 - 12.5) = **14.5**

$n = (0.838 * \mathbf{14.5})^2 / (0.2 * \mathbf{17.0})^2 =$ **12.8** transects

6) Apply the range and the average to the following equation to obtain the minimum number (n) of transects needed to monitor the revegetation unit.

$$n = (0.838 * Range)^2 / (0.2 * \bar{x})^2$$

Using the data from the previous example (Figure 12.16), the 8 quadrats would be averaged. While the mean in this example would still remain at 17, the range has spread to 26 (maximum 32 minus the minimum 6) The number of quadrats to sample would be 41:

$$n = (0.838 * 26)^2 / (0.2 * 17.0)^2 = 41.1$$

12.8.3 Comparing Means with Standards – Dispersed Area Sample Size Determination

Systematic Sampling Method: The systematic sampling method is used when the dispersed areas are mapped. The experimental unit in this design is the dispersed area.

1) Find 4 dispersed areas that represent the extremes of the attribute of interest and lay out.
2) Randomly place 2 quadrats within each dispersed area to collect data on the attribute of interest (e.g., % ground cover).
3) For each dispersed area, calculate the average of the 4 dispersed areas' averages and the range.
4) Apply the range and the average to the following equation to obtain the minimum number of dispersed areas needed to monitor in a revegetation unit (equation based on a sample size of 20% of the true population value with 90% confidence).

$$n = (0.838 * Range)^2 / (0.2 * \bar{x})^2$$

Grid Sampling Method: The grid sampling method is used for revegetation units that have small dispersed areas that have not been mapped (See Section 12.7.3.2). Since only one quadrat is located in a dispersed area, the quadrat becomes the experimental unit. The number of quadrats to sample is estimated by following these steps:

1) Visit a range of dispersed areas and select 4 dispersed areas that represent these extremes of site conditions.
2) Randomly place 1 quadrat in each of the 4 dispersed areas and collect data on the parameter of interest (e.g., % ground cover).
3) Calculate the average and range in values.
4) Apply the range and the average to the following equation to obtain the minimum number (n) of dispersed areas to sample.

$$n = (0.838 * Range)^2 / (0.2 * \bar{x})^2$$

12.8.4 Sample Size for Comparing Means Among Treatment Groups

When determining the sample size for comparing treatment differences (See Section 12.9.2), it is not necessary to differentiate between linear, rectilinear, or dispersed sampling designs. Sample size determinations can be made by following these steps:

1) Review each treatment area to be compared. These can be different revegetation units or different types of revegetation treatments.
2) From each treatment area, collect data from 2 transects composed of 2 quadrats. These should represent a range of extremes for a total of 4 transects.
3) Determine the range.
4) Determine delta. Delta defines the level of significance that is needed for monitoring, or the meaningful difference in measurement output. For example, calculating bare soil at 1% differences in means would be unimportant, that is, the difference between 8% and 9% bare soil is too fine a distinction to make. A 5% difference might be important if the amount of data that is needed to be collected was not great. More than likely, a 10% difference (e.g., the difference between 10% and 20% bare soil) would be an

acceptable delta value for bare soil cover. It is important to note, the smaller the delta value, the more samples need to be collected.

The number of transects (n) can be calculated using a simplified equation:

$$n = 15.68 / (\Delta * 2.059 / Range)^2$$

The number of transects determined from these calculations are applied equally to the two (or more) areas being compared. This equation assumes that tests will be conducted at the delta level of significance and that there will be a difference detected at or greater than an 80% probability. Readers who prefer to apply different assumptions are encouraged to read the backup document to this guide (Kern 2007).

Example: Suppose you are interested in finding out whether a commercial product actually increases plant cover by at least 10% after the first year as advertised. You have set up similar areas, one where the product was applied and one where it was not. A year later, you want to determine whether there is a difference in the percentage of vegetative ground cover. To determine the number of transects to install in each area, you set out 4 transects, 2 in each area. From this information, you find a range in % vegetative ground cover values of 22. You assume that tests will be conducted at the delta level of significance of 10% (important to be able to detect a difference in 10% cover with at least 80% probability). Using the simplified equation stated above, the following number of transects are required for each treatment area:

$$n = 15.68 / (10 * 2.059 / 22)^2 = 17.9 \text{ transects}$$

In general, using the simple equation provided here, and possibly adding 10% to 20% additional samples as a level of conservatism, is a reasonable approach.

12.9 STATISTICAL ANALYSIS USING CONFIDENCE INTERVALS

This section provides statistical methods for analyzing data collected for all monitoring protocols covered in this chapter. There are three types of analysis based on these monitoring objectives:

- Compliance – determine whether standards were met (See Section 12.9.1).
- Treatment differences – determine whether there is a difference between treatments or changes between years (See Section 12.9.2).
- Trends – determine the degree of vegetation or soil cover change over time (See Section 12.9.3).

The analysis for these objectives uses the concept of confidence intervals for determining the statistical significance of the monitoring data set.

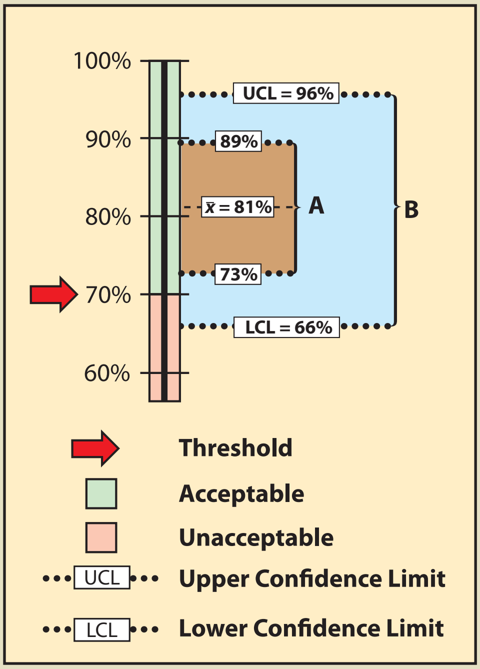
12.9.1 Determine Standards Compliance

The objective behind most monitoring is to answer the following questions: were regulatory standards met? Did we actually do what we stated we were going to do in our reports and commitments to the community in terms of protecting soil and reestablishing native vegetation?

To answer these questions requires comparing the means of the attribute data collected (e.g., bare soil, species presence) with the set standard or stated threshold. For example, a project has a standard of at least 70% soil cover on a road cut near a live stream one year after road construction. Using the soil cover protocol, data is collected on 20 transects and a mean of 81% soil cover is determined by averaging the quadrat means. At this point, the reader might conclude that the standards were met. From a statistician's point of view however, the data displayed in this context is inconclusive because we do not know, or cannot account for, the variability of the soil cover in the sampling area. In other words, how do we know how good the number is? Is it really depicting what is happening on the site? If another person were to use the soil cover protocol in the same sampling area, but at a different spot, would the soil cover be exactly 81%? This is highly unlikely because of the high variability of soil cover.

Confidence intervals give us the means of predicting, at a chosen level of certainty, that the soil cover value collected anywhere in the sampling area will be within a stated range. Confidence intervals are an alternative to saying, "We think the soil cover at any point in the sampling area

***Figure 12.17** – Data set A has an upper confidence limit of 89% and a lower confidence limit of 73%. Since the lower confidence limit is above the standard of 70%, it can be stated with 90% confidence that the standards were met. Data set B has a wider confidence interval and a lower confidence limit of 66%, which is below the standard. In this case, there is uncertainty at the 90% confidence limit that the standards were met.*



will be around 81%." Using confidence intervals we can say instead that, "we are 90% confident that if the study were repeated at this site 10 times, 9 out of 10 times the average soil cover estimate would be within our confidence limits." If you want to feel more confident than that about your predictions (most scientists working in the health fields want to be very certain) you might decide you want to have confidence intervals based on 95% or even 99% certainty. If this is the case, the confidence interval would be much wider.

The data sets from very different revegetation units are shown in Figure 12.17 to convey the concept of confidence intervals. While both data sets have the same mean of 81% soil cover, the confidence intervals are very different. Data set A was taken at a site with very uniform soil cover, while data set B had much more variability. For both data sets, we want to define the confidence intervals at a 90% confidence. Notice that the confidence interval for data set B is much wider than data set A since it has greater variability.

With confidence intervals, we can say with greater certainty whether the standard of 70% soil cover was met or not. We can state with 90% confidence that data set A met the standards because the lower confidence limit (73%) is above the stated standard of 70%. Data set B, on the other hand, poses some problems. We cannot say with 90% confidence that the unit average is above the standard of 70%. The lower confidence limit of data set B is 66%, or 4% below the standard. The reader might argue that, because the mean is above the standard, the standards were met ("hey, it's close enough!"). To statisticians, however, the fact that the lower confidence interval is below the stated standards indicates a fair amount of uncertainty. They would tell you that you cannot make that statement without getting more data or changing how confident you are with the prediction.

One of the main purposes for monitoring roadside vegetation is to document successful project completion. Statistically based sampling designs and analysis provides an objective way to describe revegetation performance. An understanding of confidence limits and their interpretation is critical to documenting that standards have been met. The following section outlines how confidence intervals are calculated and compared with standards. It is organized by sampling design: linear, rectilinear, and dispersed.

***Figure 12.18** – Confidence intervals for linear sampling designs can be easily obtained by copying equations and format of this spreadsheet.*

	A	B	C	D	E	F	G	H	I	J	K
1											
2	**Transect ID**	**Transect Length**	**Parameter:**						**Calculations**		
3			**Q1**	**Q2**	**Q3**	**Q4**	**Q5**	**Q6**	**Average**	**$L_1 \times \bar{x}_1$**	**L_1^2**
4	**T1**								= AVERAGE(C4:H4)	= B4*14	= B4^2
5	**T2**								= AVERAGE(C5:H5)	= B5*15	= B5^2
6	**T3**								= AVERAGE(C6:H6)	= B6*16	= B6^2
7	**T4**								= AVERAGE(C7:H7)	= B7*17	= B7^2
8	**T5**								= AVERAGE(C8:H8)	= B8*18	= B8^2
9	**T6**								= AVERAGE(C9:H9)	= B9*19	= B9^2
10	**T7**								= AVERAGE(C10:H10)	= B10*110	= B10^2
11	**T8**								= AVERAGE(C11:H11)	= B11*111	= B11^2
12	**T9**								= AVERAGE(C12:H12)	= B12*112	= B12^2
13	**T10**								= AVERAGE(C13:H13)	= B13*113	= B13^2
14	**T11**								= AVERAGE(C14:H14)	= B14*114	= B14^2
15	**T12**								= AVERAGE(C15:H15)	= B15*115	= B15^2
16	**T13**								= AVERAGE(C16:H16)	= B16*116	= B16^2
17	**T14**								= AVERAGE(C17:H17)	= B17*117	= B17^2
18	**T15**								= AVERAGE(C18:H18)	= B18*118	= B18^2
19	**T16**								= AVERAGE(C19:H19)	= B19*119	= B19^2
20	**T17**								= AVERAGE(C20:H20)	= B20*120	= B20^2
21	**T18**								= AVERAGE(C21:H21)	= B21*121	= B21^2
22	**T19**								= AVERAGE(C22:H22)	= B22*122	= B22^2
23	**T20**								= AVERAGE(C23:H23)	= B23*123	= B23^2
24										**= Sum (J4:J23)**	**= Sum (K4:K23)**
25											
26					**Equations**						
27					= SUM(B4:B23)						
28				**Mean**	= J24/E27						
29				**Between Transect Variance**	= VAR(I4:I23)						
30				**Variance of Mean**	= K24/E27/E27*VAR(I4:I23)						
31				**Standard Error**	= SQRT(E30)						
32				**Degrees of Freedom**	= COUNT(I4:I23)-1						
33				**T**	= TINV(0.1,E32)						
34											
35				**90% Lower Confidence Limit:**	= E28-E33*E31						
36				**90% Upper Confidence Limit:**	= E28+E33*E31						
37											
38											

Field Data

12.9.1.1 Calculating Confidence Intervals for Linear Sampling Design

Figures 12.18 and 12.19 give examples of how to calculate confidence intervals from a data set for a linear sampling area (See Section 12.7.1). Figure 12.18 shows how to set up the spreadsheet and Figure 12.19 shows what a typical data set might look like. Once you have set the spreadsheet up exactly as it is shown in Figure 12.18, it needs to be tested by entering the data shown in Figure 12.19. If the confidence intervals in your spreadsheet do not match those of Figure 12.19, then you will need to review the spreadsheet for errors in copying. Make sure that the equations are in the same cells as shown in Figure 12.18. To obtain a number for "T" (cell E31) the Excel ToolPak must be installed. To do this, go to the toolbar and select Tools, Add-Ins, and check the box next to Analysis ToolPak.

The essential data needed to complete the spreadsheet in Figure 12.18 is:

Transect Length (Column B) **–** This is the total length of the transect recorded in the field at the time the transect is laid out.

Parameters (Cell C2) **–** There may be several parameters collected at each quadrat. The parameter (or attribute) to be evaluated should be stated at the top of the quadrat columns. For instance, in Figure 12.19, the attribute to be analyzed is "% bare soil," which was obtained using the Soil Cover Protocol spreadsheet (Figure 12.4). Only one attribute can be measured on a spreadsheet. Gravel, rock, live and dead vegetation, for instance, are often collected in the soil cover protocol. If a statistical analysis of these attributes is needed, a spreadsheet must be developed for each attribute. While not all attributes need to be statistically analyzed, it is important to analyze those attributes that have been identified for measurements of success (e.g., % bare soil or % soil cover).

***Figure 12.19** – The spreadsheet developed from Figure 12.18 can be checked for accuracy by entering the data in this spreadsheet.*

P10 fx

	A	B	C	D	E	F	G	H	I	J	K
1											
2	Transect	Transect	Parameter: % bare soil						Calculations		
3	ID	Length	Q1	Q2	Q3	Q4	Q5	Q6	Average	$L_1 \times \bar{x}_1$	L_1^2
4	T1	38	25.0						25.0	950.00	1444
5	T2	98	30.0	40.0					35.0	3430.00	9604
6	T3	261	20.0	10.0	40.0	50.0	20.0		28.0	7308.00	68121
7	T4	100	30.0	20.0					25.0	2500.00	10000
8	T5	207	10.0	30.0	10.0	15.0			16.3	3363.75	42849
9	T6	207	50.0	22.0	40.0	35.0			36.8	7607.25	42849
10	T7	150	21.0	54.0	11.0				28.7	4300.00	22500
11	T8	154	40.0	30.0	10.0				26.7	4106.67	23716
12	T9	131	10.0	30.0					20.0	2620.00	17161
13	T10	131	20.0	40.0					30.0	3930.00	17161
14	T11	84	30.0						30.0	2520.00	7056
15	T12										0
16	T13										0
17	T14										0
18	T15										0
19	T16										0
20	T17										0
21	T18										0
22	T19										0
23	T20										0
24										42635.67	262461
25					Equations						
26					= 1561						
27				Mean	= 27.31						
28				Between Transect Variance	= 35.18068182						
29				Variance of Mean	= 3.7893						
30				Standard Error	= 1.9466						
31				Degrees of Freedom	= 10						
32				T	= 1.8125						
33											
34				90% Lower Confidence Limit	= 23.8						
35				90% Upper Confidence Limit	= 30.8						
36											
37											
38											

Erase these formulas if transects were not taken

Field Data (Columns C Through H) **–** The data collected at each transect and quadrat for the parameter of interest is typed into these cells. This information comes from the spreadsheets developed for each protocol (Soil Cover Protocol – Figure 12.4, Species Cover Protocol – Figure 12.7, Species Presence Protocol – Figure 12.8, Plant Density Protocol – Figure 12.9, and Plant Attributes Protocol – Figure 12.20) and it is entered and summarized by transect.

Columns I and J **–** If fewer than 20 transects were taken, the equations in the cells of column I and J that do not have data must be cleared for the spreadsheet to work (see highlighted cells in Figure 12.19).

12.9.1.2 Calculating Confidence Intervals for Rectilinear Sampling Designs

Figure 12.20 shows how to calculate confidence intervals for rectilinear sampling areas (See Section 12.7.2). Copy the equations exactly as they are shown in Figure 12.20 into your spreadsheet. Once you have created the spreadsheet, check the confidence limits in your spreadsheet. They should match those shown Figure 12.20. If they do not, then review your spreadsheet for errors. To obtain a number for "T" (cell C28) the Excel ToolPak must be installed. To do this, go to the toolbar and select Tools, Add-Ins, and check the box next to Analysis ToolPak.

The essential data needed to complete the spreadsheet is:

Parameters (Cell C2) **–** The parameter to be evaluated should be stated at the top of the quadrat columns. In this example, total cover for "seeded" native species was obtained from Figure 12.7, but any number of site attributes can be analyzed. Copying column C and pasting it in the columns to the right allows for multiple attributes to be analyzed in one spreadsheet.

***Figure 12.20 –** This figure shows how confidence intervals are obtained from a spreadsheet developed for rectilinear sampling designs.*

B34 fx

	A	B	C
1			
2		Quadrat	Parameter:
3			
4			
5			
6			
7			
8			
9			
10			
11			
12			
13			
14			
15			
16			
17			
18			
19			
20			
21			
22			
23			
24		Mean	= AVERAGE (C3:C22)
25		Variance	= VAR(C3:C22)
26		Standard Error	= SQRT(C25/COUNT(C3:C22))
27		Degrees of Freedom	= COUNT(C3:C22)-1
28		T	= TINV(0.1,C27)
29		90% Lower Confidence Limit:	= C24-C28*C26
30		90% Upper Confidence Limit:	= C24+C26*N28
31			

Field Data

F16 fx

	A	B	C
1			
2		Quadrat	Parameter: Native Species Cover
3		T1	80
4		T2	90
5		T3	75
6		T4	60
7		T5	45
8		T6	32
9		T7	67
10		T8	50
11		T9	80
12		T10	50
13		T11	30
14		T12	50
15		T13	70
16		T14	90
17		T15	100
18		T16	80
19		T17	70
20		T18	65
21		T19	75
22		T20	25
23			
24		Mean	= 64.2
25		Variance	= 442.4
26		Standard Error	= 4.7
27		Degrees of Freedom	= 19
28		T	= 1.7
29		90% Lower Confidence Limit:	= 56.1
30		90% Upper Confidence Limit:	= 64.2
31			

Field Data (Columns C Through H) – The data collected at each quadrat for the parameter of interest is typed into these cells. This information comes from the spreadsheets developed for each protocol (Soil Cover Protocol – Figure 12.4, Species Cover Protocol – Figure 12.7, Species Presence Protocol – Figure 12.8, Plant Density Protocol – Figure 12.9, and Plant Attributes Protocol – Figure 12.10).

12.9.1.3 Calculating Confidence Intervals for Dispersed Sampling Design

There are two methods for determining confidence intervals for dispersed sampling design – the systematic sampling design (See Section 12.7.3.1) and the grid sampling design (See Section 12.7.3.2). Confidence intervals for the grid sampling design are obtained by using the spreadsheet shown in Figure 12.20. For the systematic sampling design, Figure 12.21 is used. The essential data needed to complete the spreadsheet is:

Dispersed Area ID – For some projects, not all dispersed areas will be sampled. Identify in Column A which areas were sampled.

Number of Quadrats (Column B) – Specify the number of quadrats that were sampled for each dispersed area.

Parameters (Cell C2) – There may be several parameters collected at each quadrat. The parameter to be evaluated should be stated at the top of the quadrat columns. Only one attribute can be analyzed on a spreadsheet. Gravel, rock, live and dead vegetation, for instance, are often collected in the soil cover protocol. If a statistical analysis of these attributes is needed, a spreadsheet must be developed for each attribute. While not all attributes need to be statistically analyzed, it is important to analyze those attributes that have been identified for measurements of success (e.g., % bare soil or % soil cover).

Field Data (Columns C Through H) – The data collected at quadrats for each dispersed area for the parameter of interest is typed into these cells. This information comes from the spreadsheets developed for each protocol (Soil Cover Protocol – Figure 12.4, Species Cover Protocol – Figure 12.7, Species Presence Protocol – Figure 12.8, Plant Density Protocol – Figure 12.9, and Plant Attributes Protocol – Figure 12.10) and it is entered and summarized by dispersed area.

Figure 12.21 – *Confidence intervals for dispersed areas using the systematic sampling design can be obtained by using the equations shown in this spreadsheet.*

N36 fx

	A	B	C	D	E	F	G	H	I	J	K
1											
2	Transect	Transect	Parameter:						Calculations		
3	ID	Length	Q1	Q2	Q3	Q4	Q5	Q6	Average	L_1 x $\bar{x}_1$	L_1^2
4	D1								= AVERAGE(C4:H4)	= B4*14	= B4^2
5	D2								= AVERAGE(C5:H5)	= B5*15	= B5^2
6	D3								= AVERAGE(C6:H6)	= B6*16	= B6^2
7	D4								= AVERAGE(C7:H7)	= B7*17	= B7^2
8	D5								= AVERAGE(C8:H8)	= B8*18	= B8^2
9	D6								= AVERAGE(C9:H9)	= B9*19	= B9^2
10	D7								= AVERAGE(C10:H10)	= B10*110	= B10^2
11	D8								= AVERAGE(C11:H11)	= B11*111	= B11^2
12	D9								= AVERAGE(C12:H12)	= B12*112	= B12^2
13	D10								= AVERAGE(C13:H13)	= B13*113	= B13^2
14	D11								= AVERAGE(C14:H14)	= B14*114	= B14^2
15	D12								= AVERAGE(C15:H15)	= B15*115	= B15^2
16	D13								= AVERAGE(C16:H16)	= B16*116	= B16^2
17	D14								= AVERAGE(C17:H17)	= B17*117	= B17^2
18	D15								= AVERAGE(C18:H18)	= B18*118	= B18^2
19	D16								= AVERAGE(C19:H19)	= B19*119	= B19^2
20	D17								= AVERAGE(C20:H20)	= B20*120	= B20^2
21	D18								= AVERAGE(C21:H21)	= B21*121	= B21^2
22	D19								= AVERAGE(C22:H22)	= B22*122	= B22^2
23	D20								= AVERAGE(C23:H23)	= B23*123	= B23^2
24										**= Sum (J4:J23)**	**= Sum (K4:K23)**
25											
26					**Equations**						
27					= SUM(B4:B23)						
28				$\bar{x}_w$	= J24/E27						
29				$s^2(\bar{x}_i)$	= VAR(I4:I23)						
30				$s^2(\bar{x}_w)$	= K24/E27/E27*VAR(I4:I23)						
31				$SE(\bar{x}_w)$	= SQRT(E30)						
32				Degrees of Freedom (n-1)	= COUNT(C4:C23)-1						
33				$T_{n-1, 0.95}$	= TINV(0.1,E32)						
34											
35				90% Lower Confidence Limit	= E28-E33*E31						
36				90% Upper Confidence Limit	= E28+E33*E31						
37											
38											

Field Data

Columns I and J – If fewer than 20 dispersed areas were taken, the equations in the cells of column I and J that do not have data must be cleared for the spreadsheet to work (see highlighted cells in Figure 12.19).

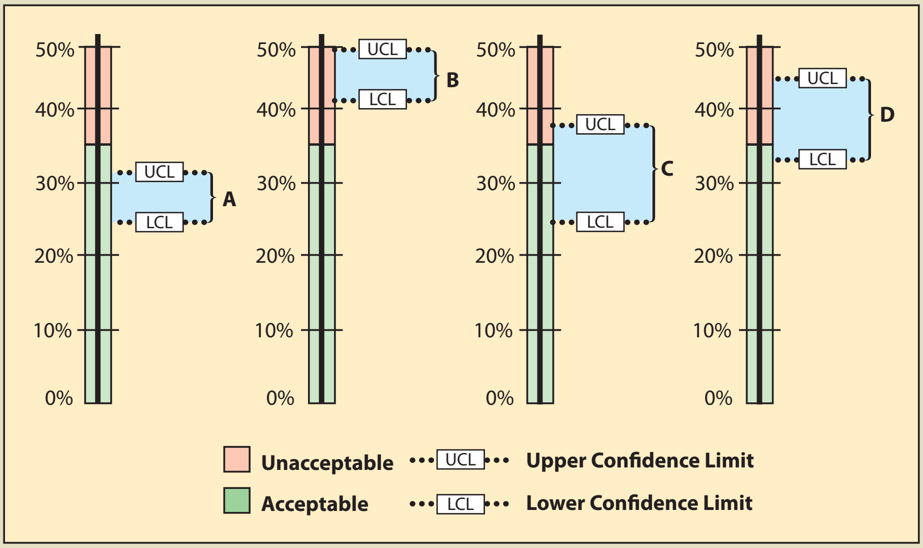
12.9.1.4 Interpreting Confidence Intervals for Compliance

Confidence intervals, as stated previously, are used to evaluate the success of a revegetation project relative to specified standards or stated goals. Suppose that one of the objectives of the revegetation plan was to establish at least 65% total cover over the soil to protect against surface erosion. Or stated another way, the objective is no more than 35% bare soil exposed one year after revegetation treatments were applied. In the example shown in Figure 12.19 (cells E34 and E35), the confidence interval was below 35%. We can say with 90% level of confidence that the objectives were met. But what if the confidence interval was either above the standard or straddled the standard?

Figure 12.22 shows four possible scenarios for confidence intervals that the revegetation specialist may encounter. Scenario A is a case where the data supports the conclusion at 90% confidence that the project met the standard. Scenario B did not meet the standard because the lower confidence limit was above 35% bare soil.

Scenario C is a case where the mean meets the standard, but the upper confidence limit is above the standard. It cannot be said with 90% confidence that the standards were met. At this point you might ask how important it is to know whether the standards were met or not. If the site directly influences a live stream, it might be very important to know. However, if streams are miles away, it might suffice to report that the there was some uncertainty whether the

***Figure 12.22 –** Four possible scenarios that can be encountered when comparing standards to confidence intervals. Confidence interval A is clearly acceptable, whereas confidence interval B is clearly unacceptable. Uncertainty arises when the lower confidence limit is acceptable but the upper confidence limit is unacceptable. This is shown in cases where the mean is in the acceptable range (C) and in the unacceptable range (D).*



standards were met. If you determine that you need to be more certain about the results, more data will need to be collected.

Scenario D is a case where the mean does not meet the standard, but the lower confidence limit is below the standard of 35% bare soil. One might state that this project did not meet the standards, but this still could not be stated with 90% confidence. In this scenario, more transects could be taken to narrow the confidence interval and hope that the results do not straddle the standard. Another option might be to take measures that would decrease the amount of bare soil to meet the standards. This could include more seeding or mulch application. A resampling of the site later would reveal whether the standards were met.

12.9.2 Determine Treatment Differences

There will be opportunities to compare the effects of different revegetation products or methods on plant establishment and growth using monitoring data. Some of these opportunities will be planned (e.g., trying a new product), and some will be mistakes (e.g., inadvertently doubling the rate of mulch). Planned or unplanned, when different revegetation activities have occurred within a revegetation unit, monitoring can be designed to assess whether there is a different vegetative response between those activities or treatments. Note: The monitoring design outlined in this section will not replace a well-designed study or experiment; we suggest that if more conclusive results of treatment differences are required, a study should be designed with statistical oversight.

The confidence interval concept is applied in this section to determine differences between new revegetation treatments (new treatments) and routine revegetation methods (standard treatments). Three possible outcomes are possible when new treatments are compared to standard methods: 1) the new treatment results in a favorable increase in the measured parameters over the standard treatment (positive difference), 2) the new treatment results in a decrease (negative difference), or 3) there is no positive or negative difference (no difference). Using confidence intervals, it is possible to determine which of these outcomes is statistically supported for any monitoring data set. In this method, the means and variance of means are calculated for both the new treatment and standard treatment and a confidence interval is calculated for the certainty of the treatment differences.

Figure 12.23 *– Treatment differences can be determined using the following spreadsheet. Copy each equation exactly as presented. Fill in cell B2 with the parameters being compared. In this example, vegetative ground cover (cell B2) and native species cover (cell C2) are being compared. From the two data sets that were summarized from spreadsheets in Figure 12.18, 12.20, or 12.21, the number of transects, means, and variance of the mean from each can be obtained. From this information the spreadsheet calculates the lower and upper confidence limits for each attribute at 90% confidence.*

B27 fx

	A	B	C	B
1		**Parameter**		**Parameter**
2		**Veg Ground Cover**	**Native Species Cover**	
3	**Treatment: 2X Additional Fertilizer**			
4	Number of Transects:	10	10	From Spreadsheets 12.18, 12.20, or 12.21
5	Mean:	62	45	From Spreadsheets 12.18, 12.20, or 12.21
6	Variance of the Mean:	47	23	From Spreadsheets 12.18, 12.20, or 12.21
7				
8	**Treatment: Standard Fertilizer Rates**			
9	Number of Transects:	10	10	From Spreadsheets 12.18, 12.20, or 12.21
10	Mean:	33	90	From Spreadsheets 12.18, 12.20, or 12.21
11	Variance of the Mean:	10	40	From Spreadsheets 12.18, 12.20, or 12.21
12				
13	**Two Sample T-Test**			
14	Degrees of Freedom (df):	12.000000	17.000000	=ROUND((B6/B4+B11/B9)^2/(B6^2/B4^3+B11^2/B9^3)-2,0)
15	T Statistic:	3.907370	-5.669467	=(B5-B10)/SQRT(B6+B11)
16	Statistical Significance:	0.002082	0.000028	=TDIST(B15,B14,2)
17				
18	**Confidence Interval for Difference in Means**			
19	Difference:	29.5000	-45.0000	=B5-B10
20	Variance of Difference:	57.0000	63.0000	=B6+B11
21	Standard Error of Difference:	7.5498	7.9373	=SQRT (B20)
22	Degrees of Freedom (df):	12	17	=ROUND((B6/B4+B11/B9)^2/(B6^2/B4^3+B11^2/B9^3)-2,0)
23	T Statistic (90% Critical Value):	1.7823	1.7396	=TINV(0.1,B22)
24	Lower 90% Confidence Limit:	16.0440	-58.8077	=B19-B23*B21
25	Upper 90% Confidence Limit:	42.9560	-31.1923	=B19+B23*B21

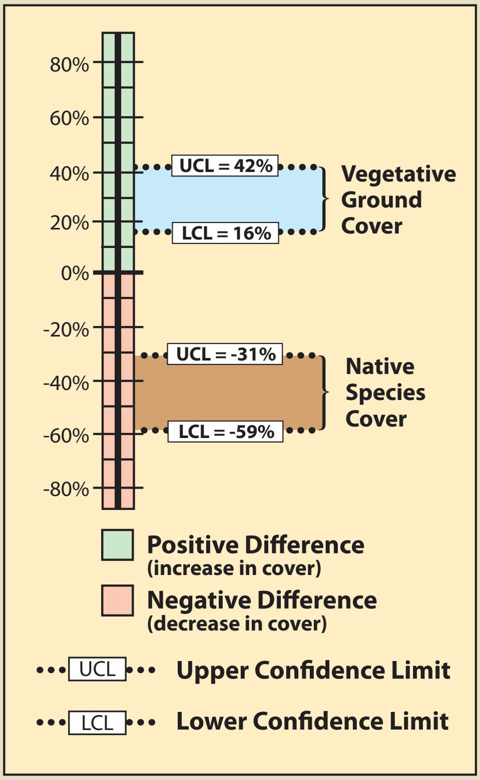
The following example demonstrates how a confidence interval is determined and how it can be used to interpret two data sets. During a hydroseeding operation, someone discovers that the rate of fertilizer application was mistakenly applied at twice the normal rate in one area. This area was staked in the field and visited by the project team a year later. Some on the team believed that there was more vegetative ground cover where fertilizer was doubled; others felt that there was actually less. One or two on the team did not believe they could make either call. Since monitoring was going to take place a few weeks later, they decided to design a monitoring protocol to answer the question, "Was there a positive, negative, or no response of vegetative ground cover to the application of additional fertilizer?"

Within the framework of monitoring that was already scheduled for this revegetation unit, a monitoring strategy was developed. The soil cover protocol was used (See Section 12.2) along with the linear sampling design since this was a road cut (See Section 12.7.1). Each treatment area was considered a separate sampling unit, and monitoring took place independently of each other. The data from each treatment area was summarized from Figure 12.4 into % vegetative ground cover and entered into Figure 12.18 to obtain means and variance of means. Number of transects, means, and variance of means for each treatment were then entered into Figure 12.23 (cells B4–B6 for the new treatment and B9-B11 for the standard treatment), producing a confidence interval (cells B24 and B25) for comparison.

The results of this analysis showed that the standard rates of fertilizer had an average vegetative ground cover of 33% (cell B10) as compared to 62% (B5) for double the fertilizer rate. While this looks like an obvious difference, how certain could the team be? A confidence interval was derived to answer that question. In this example, the confidence interval (at 90% confidence) showed that additional fertilizer significantly increased vegetative ground cover. This can be shown graphically in Figure 12.24. The 2X fertilizer treatment increased ground cover a minimum of 16% over the standard treatment (lower confidence limit) to as high as 42% ground cover (upper confidence limit).

The team accepted these results and commented that they should increase fertilizer rates for future projects. One member posed the question, "We might have achieved better cover on

Figure 12.24 – In the example presented in the text and Figure 12.23, confidence intervals are used to answer: 1) how vegetative ground cover responds to 2X the fertilizer rate, and 2) how native species cover responds to 2X fertilizer rates. The confidence interval collected for the first question was found to be positive, indicating that vegetative ground cover responds positively to twice the fertilizer. The confidence interval for the data set collected for the second question was negative, indicating that native species cover responded negatively to more fertilizer.



this site during the first year, but is it the vegetative cover we really want?" Since the monitoring team was still on the project site, they resampled the two areas using the species cover protocol (See Section 12.3). In this protocol, native and non-native annuals and perennials were recorded at each quadrat. Confidence intervals were determined for each treatment for native perennial cover (Figure 12.23, cells C24 and C25). They learned, in this case, that additional fertilizer had a negative effect on the establishment of native perennial cover (Figure 12.24). But what if the upper confidence interval in this example had been positive and the lower confidence interval had been negative? In this case, it would have to be concluded that there was no difference between treatments at 90% confidence.

12.9.3 Determine Trends

The last of the three objectives for roadside monitoring is assessing trend, or the degree of vegetative or soil cover over time. The reason to perform this type of monitoring is usually based on the need to understand how growth patterns of certain species or soil cover changes over the years. Many monitoring protocols employ permanent monitoring plots or transects that can be repeatedly and accurately revisited for sampling. We take the approach that collecting data in the same location over time is not feasible for roadside monitoring because of the hazards to road maintenance personnel and to the public of placing permanent stakes in road corridors. In addition, permanent markers are often hard to relocate years later or can move due to the instability of steep cut and fill slopes. In this section we offer a statistical analysis that does not require locating and resurveying of exact quadrats.

The confidence interval concept is applied in this section to determine if there are differences in attributes from one sampling date to another. Three outcomes are possible when comparing data from one sampling date to the next: 1) plant or soil cover attributes have increased since the last sampling period (positive difference); 2)) plant or soil cover attributes have decreased since the last sampling period (negative difference); or 3) either there was no change in plant or soil cover attributes or the number of samples was inadequate to detect the amount of change that occurred. Using confidence intervals it is possible to make statistically valid statements regarding the observed outcomes.

The following example demonstrates how a confidence interval is determined and how it is used to interpret data taken at different sampling dates. Members of the revegetation team believed that California brome (*Bromus carinatus*) was a short lived species; that it established well after seeding but by the fifth year it had very little presence on most sites. They also believed that Idaho fescue started out slowly but gained dominance over time. The team felt that by understanding these trends they might develop a better seed mix for sites similar to the ones they were monitoring. The question they posed was: "is there a positive, negative, or no difference in the cover of California brome and Idaho fescue from the first year to the fifth year after seeding?"

This question required the use of the species cover protocol (See Section 12.3) since dominance was being expressed as % crown cover for each species. Linear Sampling Design was used for both monitoring dates because the sampling area was a long cut slope. The data from each sampling date was summarized into % cover for California brome (BRCA5) and entered into Figure 12.18 to obtain means and variance of means. Number of transects, means, and variance of means for each treatment were then entered into Figure 12.25 (cells B9–B11 for earliest sampling date and B4 through B6 for latest sampling date), producing a confidence interval (cells B24 and B25) for comparison. Data entry was also done in the same manner for Idaho fescue (FEID).

The results of this analysis showed that California brome had an average crown cover of 35% (B10) in 2001 but decreased to 27% (B5) in 2006, five years later. Was this a statistically significantly difference? Using confidence intervals, they found that the means were not statistically different at 90% confidence. This can be shown graphically in Figure 12.26. The BRCA5 in 2006 had a maximum of 3% crown cover increase over 2001 and a minimum of -19% ground cover over 2001. Because the upper confidence limit (UCL) was positive and the lower

Figure 12.25 – *Changes in attributes over time can be determined using the following spreadsheet. The equations shown in the right column (B14 through B25) correspond to the cells located in column B (left side spreadsheet). Copy each equation exactly as they appear. Fill in cell B2 with the attribute of interest. In this example, the attribute of interest is the crown cover of California brome and Idaho fescue (cell C4). From the data sets (see Figures 12.18, 12.20, and 12.21) obtained on the two sampling dates (2001 and 2006), the number of transects, means, and variance of the mean are obtained and copied into rows 4, 5 and 6 for the latest sampling date and in rows 9, 10, and 11 for the earlier date. From this information the spreadsheet calculates the lower and upper confidence limit at 90% confidence.*

G10 fx

	A	B	C	B
1		**Parameter: % Crown Cover**		**Parameter**
2		**BRCA5**	**FEID**	
3	**Sampling Year: 2006**			
4	Number of Transects:	20	20	From Spreadsheets 12.18, 12.20, or 12.21
5	Mean:	27	33	From Spreadsheets 12.18, 12.20, or 12.21
6	Variance of the Mean:	19	15	From Spreadsheets 12.18, 12.20, or 12.21
7				
8	**Sampling Year: 2001**			
9	Number of Transects:	20	20	From Spreadsheets 12.18, 12.20, or 12.21
10	Mean:	35	5	From Spreadsheets 12.18, 12.20, or 12.21
11	Variance of the Mean:	22	10	From Spreadsheets 12.18, 12.20, or 12.21
12				
13	**Two Sample T-Test**			
14	Degrees of Freedom (df):	38.000000	36.000000	=ROUND((B6/B4+B11/B9)^2/(B6^2/B4^3+B11^2/B9^3)-2,0)
15	T Statistic:	-1.249390	5.600000	=(B5-B10)/SQRT(B6+B11)
16	Statistical Significance:	0.219164	0.000002	=TDIST(B15,B14,2)
17				
18	**Difference in Means**			
19	Difference:	-8.0000	28.0000	=B5-B10
20	Variance of Difference:	41.0000	25.0000	=B6+B11
21	Standard Error of Difference:	6.4031	5.0000	=SQRT (B20)
22	Degrees of Freedom (df):	38	36	=ROUND((B6/B4+B11/B9)^2/(B6^2/B4^3+B11^2/B9^3)-2,0)
23	T Statistic (90% Critical Value):	1.6860	1.6883	=TINV(0.1,B22)
24	Lower 90% Confidence Limit:	-18.7954	19.5585	=B19-B23*B21
25	Upper 90% Confidence Limit:	2.7954	36.4415	=B19+B23*B21

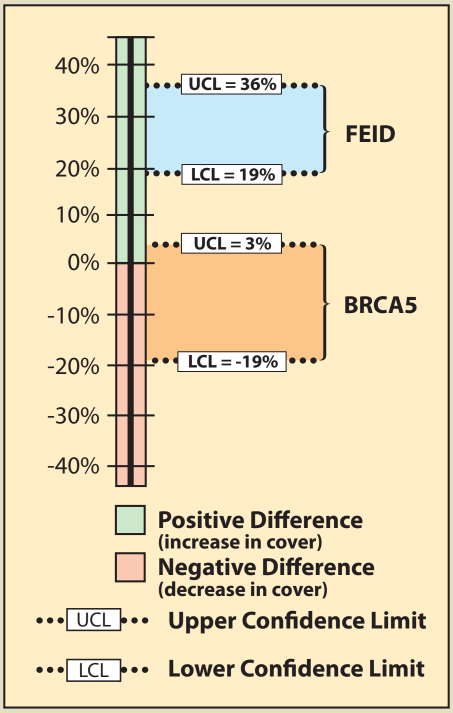


Figure 12.26 *– In the example presented in the text and Figure 12.25, confidence intervals are used to answer whether California brome and Idaho fescue increased, decreased, or stayed the same from 2001 to 2006. The % cover of California brome was found not to have changed in this time period because the lower confidence limit was negative and the upper confidence limit was positive. The confidence interval for the Idaho fescue showed a positive difference between 2001 and 2006 (cells C24 and C25). Since the upper and lower confidence limits were positive, the differences in the means between sampling dates was significant at 90% confidence.*

confidence limit (LCL) was negative, the observed data was not adequate to demonstrate a change in % crown cover of California brome with 90% level of confidence.

Idaho fescue, on the other hand, did show an increase in mean cover from 2001 to 2006, from 5% (cell B10)to 33% (cell B5) respectively. The team could be 90% confident that the true percent crown cover did indeed increase from 5% in 2001 to 33% in 2006 because the upper confidence limit (UCL) and the lower confidence limit (LCL) were positive (Figure 12.26).

12.10 SUMMARY

This chapter guided the revegetation specialist through a series of steps for collecting field data, developing a sampling design, and statistically analyzing data needed to monitor vegetation on roadsides. Monitoring completes the project cycle by answering the question: Did we accomplish what we proposed in the revegetation plan?

13 SUMMARY

Within the transportation community, the challenge is to move beyond regulation-driven mitigation approaches and into proactive environmental stewardship. Native plants are a foundation of ecological health and function. Roadside revegetation with native plants has become a key practice for managing environmental impacts and improving conditions for healthy ecosystems. This report synthesizes an integrated approach that can be used to effectively revegetate roadsides and other disturbance areas associated with road construction, modification, or obliteration. The report will be of interest to public and private sector practitioners, as well as to transportation and planning professionals, land managers, policy makers, and owners and operators of roads. The report can be consulted during any phase of a revegetation project. It is also intended to serve as a foundation for future trainings.

After introducing the challenges of roadside revegetation, the report provides a systematic, interdisciplinary guide through the process in four stages. The Initiation section helps the user bridge terminology and technical expertise between non-engineers and engineers, create key relationships, and navigate the decision process in order to initiate a project. Essential steps to coordinate revegetation efforts with road planning and construction are detailed, including budgetary and scheduling issues.

Next, the Planning section guides the reader through the process of defining project objectives, assessing the site, overcoming limitations, strategizing revegetation procedures, and integrating the revegetation activities with the road project.

The Implementation section provides information on how to make the project unfold in the field, from coordinating contracts and creating budgets and timelines to caring for the plants as they mature. Implementation Guides are filled with practical how-to information for many cost-effective site treatments and revegetation tactics that are used to revegetate roadsides.

Finally, the Monitoring and Management section describes how to assess the effectiveness of the revegetation project to correct any shortcomings, improve practice, and add to future knowledge. Example monitoring protocols are included to guide readers in selecting appropriate monitoring methods for the project's goals.

When planned well, the successful establishment of desirable vegetation supports transportation goals for safety and efficiency, stabilizing slopes, reinforcing infrastructure, and improving the road user's experience by creating natural beauty and diversity along the roadside. Healthy native plant communities are often the best long-term defense against invasive and noxious weeds. Maintenance costs for managing problematic vegetation are reduced, as is the controversy that sometimes results when weeds from roadsides invade neighboring lands, or where pollution from herbicide use is a concern.

Revegetation success is a key factor in determining whether the over 12 million acres that make up the transportation corridor of the United States will be hospitable environments to plants and other forms of life – or a wasteland. It is hoped that continuing improvements in interagency cooperation, enlightened policies, better science and technology, and the dedication and innovation of field-based practitioners will continue to build a foundation for a more sustainable future.

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