part two
TOOLKIT

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INTRODUCTION TO THE TOOLKIT

The Sediment Source Control Toolkit describes specific techniques that can be used individually or together to implement effective sediment source control projects and to measure the effectiveness of those projects.

The California Alpine Resort Environmental Cooperative (CAREC) was formed in 2003 to develop a process for planning and implementing erosion control projects and to experiment, through field tests, with various approaches to keep sediment on site and thus reduce erosion. As part of the *Sediment Source Control Handbook,* the group wanted a "toolkit" that would provide detailed explanations for land managers to select appropriate treatments. This Toolkit is comprised of a series of Tools that provide more in-depth and technical information to complement the Guiding Principles. This Toolkit expands on the 2005 preliminary edition of the *Technical Notes,* incorporating five years of test plot monitoring and input from the CAREC Technical Advisory Committee, with an aim to make the Tools as useful as possible to ski area land managers. It is our intention and experience that these tools are highly transferable and can also be utilized by land managers working outside of ski areas.

We have incorporated a great deal of data on erosion control and sustainable plant-soil systems that are capable of controlling erosion and sustaining robust plant communities. Many of the BMPs or "Best Management Practices" in use today have either not been adequately tested and researched or are not correctly implemented (improper installation or lack of site specificity). This situation poses both a challenge and set of opportunities to land managers and regulatory agencies alike. The Tools found in this Toolkit describe key treatment approaches as a starting point towards developing better practices, procedures, materials, and monitoring protocols.

The Tools in this section generally follow a consistent format. Each Tool begins with a definition and purpose, but, due to the differences in scope and subject matter, subsequent content is not always consistent from one tool to another.

For references cited please see the Reference List in the Literature Review (Handbook Part Three).

NOTES

A Conceptual Framework for Soil and Vegetation Treatments

In order to get the most out of the specific tools described in the Sediment Source Control Toolkit, it is important to first understand a few key factors that provide a conceptual framework for designing and constructing sustainable erosion control and restoration projects. Of particular interest is the relationship between *plants, soil,* and *soil water content.* After reviewing this conceptual framework, the remainder of the Toolkit will provide the tools necessary to plan, implement, monitor, and evaluate a project.

When designing and monitoring a project, practitioners often find themselves considering whether the soil or the plant functions are more important to erosion control, disturbed site restoration, and long-term site stability. A simple answer is that it generally takes thoughtful consideration of both to make a project successful. In order to provide a general understanding of the issue, it is important to consider it in relation to soil water content. *Soil water content* is the amount of water that is in the soil at any given time. Water can fill the pores within the soil, and once filled, no additional water can be accommodated. At this point, any additional water must run over the surface of the soil, thus becoming runoff. In the process of runoff, any exposed soil can be picked up and moved off site, thus resulting in erosion and sedimentation. Soil-water relationships are at the core of erosion and water quality.

Foundational Concepts

Pore Space

Soil is essential to most life on earth. It is a relatively thin crust where an even smaller portion contains the majority of the biological activity. Soil consists of three different phases: solid, liquid, and gas. In the solid phase, soil contains mainly minerals of varying sizes and organic compounds, and the rest is *pore space,* which contains the liquid and gas phases of the soil components. These pores are essential to the dynamics of the soil profile. Pore space allows for the transmission and exchange of water, gas and nutrients within soil. This pore space acts like a sponge and plays a critical role in how much water can be contained within that soil. A highly compacted soil may have as little as 5% pore space, while the same soil in native or undisturbed condition may have as much as 40% pore space. Thus, pore space represents the capacity the soil has to soak up water.

Soil Density and Infiltration Rate

A low-density soil will nearly always be able to hold a significantly higher amount of water, as much as ten times more by volume, than a high-density soil. A high-density soil will also usually exhibit a lower infiltration rate and therefore will tend to generate surface runoff more quickly during high-intensity rainfall events. For example, if the infiltration rate is 0.5 inches per hour and the rainfall rate is 1.0 inches per hour, 0.5 inches per hour of rain must run off since the soil can only infiltrate the first 0.5 inches of rain.

Soil Moisture Continuum and Project Design

It can be difficult to design for a broad range of soil moisture conditions, especially when those conditions change on a seasonal basis. Soil moisture exists along a continuum that ranges from dry to moist to saturated. Each moisture condition carries with it a unique set of requirements that must be accommodated if a site is to be successful through all of those conditions. Soil moisture content exerts a major influence on project performance, and since soil moisture content changes seasonally and with each rainfall event, a range of treatment elements (described in the Toolkit) must be integrated to create conditions that resist erosion across a range of soil moisture conditions.

Site Stability and Soil Moisture Conditions

In order to understand the influence of plants and soil on site stability, we must discuss this influence in the context of soil moisture conditions.

Dry Soil

"Dry" soil is a bit of a misnomer, because even *dry* soils still contain a small amount of residual water. It is when soils are dry that they are typically able to absorb the highest amount of water. An exception to this rule exists when a soil is hydrophobic, causing water to collect on the surface rather than infiltrate into the ground. So, during normal dry conditions, soil density will play a key role in erosion resistance. Low-density soils can absorb a large amount of water, perhaps up to 40% of their total volume.

Dry Soil Stability Influences

When soil is dry, *infiltration* is a key element of erosion control and site stability. High rates of infiltration allow more water to soak in the soil before run off begins. As water infiltrates, it becomes available to plants and microbes. Low *soil density* is a key influence on infiltration and therefore on erosion control. However, when rain falls on dry, bare soil, soil particles can become detached and move downward into the pores, clogging those pores and reducing infiltration rates. Therefore, *mulch* and other surface protection measures also play an important role in reducing soil erosion during dry periods since mulch can dissipate and absorb raindrop impact, thus preventing soil pores from becoming clogged.

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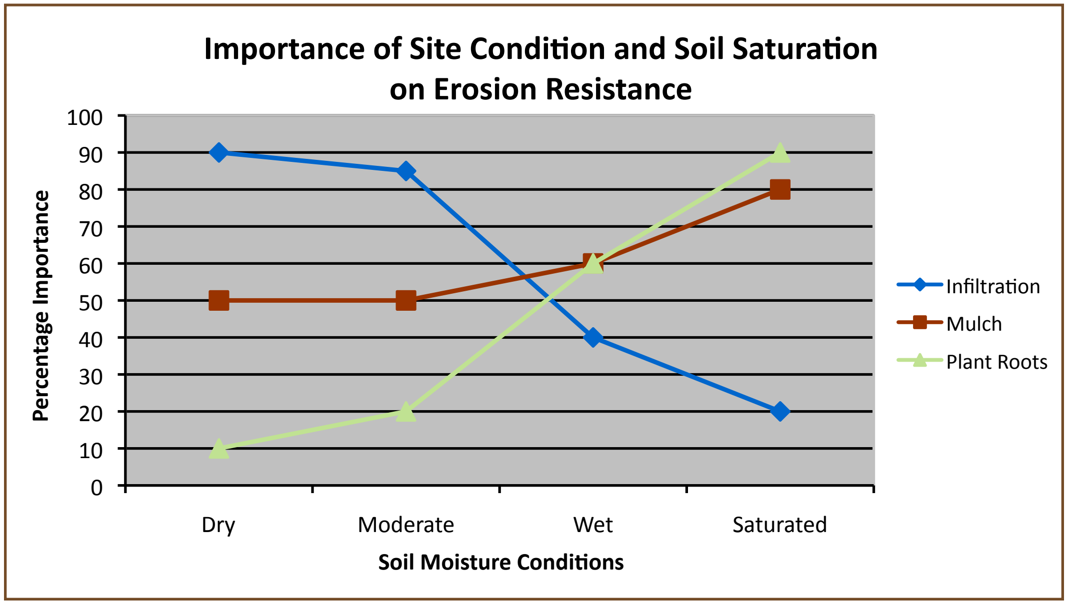

Figure 1: A graphical model of soil moisture levels: The influence of specific site conditions on erosion over a range of soil moisture conditions by approximate percentage of importance. For instance, when soil is dry, infiltration is the dominant process that minimizes erosion. However, when the soil is saturated and infiltration is no longer possible, plant roots, which hold the soil together, and mulch, which lowers surface shear forces, exert a much more important influence over a site's ability to resist erosion. This is a critical point. Soil moisture levels also exert a critical influence on erosion potential but are often overlooked with regard to their influence on the so-called storm return period. For instance, if a 20-year, 1-hour storm took place in dry soil conditions with high infiltration, most or all of that rainfall would be infiltrated, producing no runoff. However, if that same storm took place in saturated soil conditions, virtually all of the water would run off, producing very different surface flow patterns. Thus, projects must be designed with both dry and saturated conditions in mind.

Saturated Soil

When soil is completely saturated, it can accept no more water. When this occurs, water runs over the soil surface, carrying soil particles with it. As surface flow increases in velocity, it can detach and move larger and larger particles. Additionally, when soils are saturated, they can exhibit *positive pore pressure*, which can result in mass failures (landslides).

Saturated Soil Stability Influences

When soil is saturated, plant roots play a critical role in soil stability. Plant roots provide shear and tensile strength to the soil, much as reinforcing steel bars (rebar) provide strength to concrete. *Soil aggregation* is also a critical stabilizing influence on soil stability in saturated conditions. Aggregated soil forms largely as a result of microbial activity. Robust microbial activity is generally dependent upon an adequate amount of soil organic matter. Thus, *soil organic matter* plays numerous roles in long-term site stability. *Mulch* can also play an important role in saturated soil stability. When water flows over the soil surface due to saturated soil conditions, mulch can significantly slow overland flow, thus reducing the shear force of the moving water over the surface. Mulch can also capture moving sediment, thus reducing the overall amount of sediment transported off site. The influence of mulch is largely dependent upon mulch type, thickness, and direct soil contact. Organic *netting* or *fabric,* such as coconut or jute fabric, can also slow or reduce surface erosion during saturated conditions, and, as is the case for mulch, its effectiveness will depend on type and especially on maintaining surface contact. You will learn how to incorporate mulch and many other treatment tools into your projects throughout this Toolkit.

Positive Pore Pressure — The "Balloon Effect"

When soil reaches full saturation, aside from runoff, one additional physical result occurs: positive pore pressure. *Positive pore pressure* is the pressure exerted in an outward direction from within a pore. This phenomenon is caused by water trying to enter the pore without any more water leaving the pore. This process is analogous to a balloon being blown up within a space that is smaller than the balloon. If the strength of the space is strong, the balloon cannot be blown up any larger. If the strength of the space is weak, the containing space itself may rupture, allowing more room for the balloon expansion. In much the same way, positive pore pressure tries to expand the pore size. If soil cohesion is strong, the soil will not move. However, if the soil is non-cohesive or unconsolidated, the soil pores will tend to expand and the soil will tend to move. The most well known examples of this are water-caused landslides or *mass failures.* Once pores expand, they also become a lubricant, allowing soil to slide against itself.

Designing for Sustainability

Treatments should be designed with sustainability as the goal. *Sustainability* can be defined as the ability of a site to persist in a state of dynamic equilibrium (change within limits) and to withstand normal perturbations from climate and other non-anthropogenic (non-man-made) inputs. Sustainability is difficult to design for, especially since we do not know all of the variables required to provide that long-term process. However, a healthy, robust, and self-sustaining site will consist of at least these general elements:

- Sufficiently low or optimal soil density that allows for oxygen exchange, water infiltration, water storage, and root penetration
- Adequate amount and type of soil organic matter to provide nutrients and energy to the soil microbial community so that

nutrients are provided to plants, soil aggregation takes place, and carbon is sequestered through extracellular exudates

- Adequate and appropriate plant community capable of physically strengthening the soil and being supported by the climate and soil conditions of the site
- Adequate mulch cover capable of long-term persistence until the plant community can produce its own protective mulch cover

Keep these concepts in mind as you explore the Toolkit and consider how different treatment tools can be integrated to achieve long-term site stability and sustainable sediment source control across a range of soil moisture conditions in your next erosion control and restoration project.

"THE ECONOMY IS A WHOLLY OWNED SUBSIDIARY OF THE ENVIRONMENT..." – ROBERT F. KENNEDY JR.

Tool 1 - SETTING GOALS

Definition

A number of definitions have been put forth for the term "goal." The simplest and perhaps most elegant definition of the term "goal" is *the result or achievement toward which effort is directed.*

The terms *goals* and *objectives* are often used interchangeably but in fact each serves a different purpose. This Tool will not go into great depth on these differences (see Guiding Principle 2), except to say that the term *objective* carries the root "object" and therefore can be thought of as a physical manifestation of a goal. For instance, in football the *goal* is the end zone. The *objective* is to get the ball into the end zone by running or throwing. Thus, the *objective* is the method or process that will be used to achieve the *goal.*

Purpose

Setting goals and objectives forces all parties to clearly define both general and specific desired project outcomes and the methods that will be used to get there. Once the need for action is identified, carefully developing goals and objectives is the first step to a successful project.

Setting Goals and Objectives

This tool supports Guiding Principle 2, *State Project Goals and Objectives.* This separate tool on setting goals has been included because setting goals is the foundation of any successful sediment source control or restoration project, and users may benefit from additional clarification and examples. Without clearly articulated goals, it is not possible to determine whether a project has been successful, because project success is directly measured against the goals that have been set.

Setting goals consists of determining what you intend the final product or condition to be. This can be difficult and often requires drilling down into the seemingly obvious goals. For instance, the goal of an erosion control project is often stated as the "revegetation" of a disturbed site. However, one may argue that this is actually an objective, since a true *goal* might be to "reduce erosion." In this case, revegetation may be a method to achieve this goal. While this difference may be subtle, it is critical. Many project managers attempt to achieve the goal of revegetation on ski slopes or road cuts by applying fertilizer and large amounts of irrigation to a seeded area. These two practices have been shown to have negative effects on water quality by creating runoff and erosion issues. However, managers frequently continue to apply these practices because regulatory and other land management agencies (as well as the managers themselves) have confused *revegetation* (an objective) with *controlling sediment at the source* (a goal). If the goal is stated as "revegetation," then the practitioner might not take the measurements that would show that their newly revegetated slope is actually still contributing sediment and nutrients to a nearby water body.

Setting goals is a critical first step toward quantitatively defining and determining success (see Tool 4, Success Criteria). Specific goals for a sediment source control or site restoration project may include:

- To reduce sediment yield
- To eliminate sediment yield during a normal (< 2 in/hr) storm
- To infiltrate all rainfall during a normal (< 2 in/hr) storm
- To develop a diverse, self-sustaining, grass-dominated vegetation community that will anchor the site and enable a shrub-dominated plant community to become established
- To create habitat for the Yellow Warbler
- To reduce in-stream water temperature by providing vegetative (willow) shade cover
- To develop a trail system through a project area that does not increase erosion
- To sink carbon in a ski run soil during run construction
- To reduce the presence of roads within the project area boundary
- To minimize the impacts of roads on watershed processes within the property boundary

The list above contains some goal statements that may begin to meet the criteria of an objective. For instance, the second to last, "to reduce the presence of roads within the project area boundary," may be an objective that is also linked to the goal of "to minimize the impacts of roads on watershed processes within the property boundary." These examples are included to demonstrate that it is more important to define outcomes than to be overly concerned with whether a statement meets the criteria of a goal or an objective. Some goals may be mutually exclusive, some will require modification of specific plans, and others may actually create synergy within a project. For instance, goals such as "increase infiltration" and "maintain equipment access" may be in conflict with one another, whereas "reduce presence of roads" may support the creation of Yellow Warbler habitat or additional trails.

The exercise of developing clearly articulated goals and objectives will anchor a project from both a planning and a permitting perspective. The road removal example, for instance, can be further refined through the development of objectives such as: 1) to remove 100,000 square feet of dirt road surface (8% of all roads within the property boundaries) within three years and 2) to demonstrate a complete restoration of surface hydrology on the restored road areas by establishing infiltration rates that are equal to or greater than the surrounding native (reference) conditions. These two objectives, then, become the foundation of success criteria, which may also be useful as permit conditions. See Table 1.1 for examples of goals, objectives, and success criteria.

Success criteria are included in this Tool in order to demonstrate how they relate to goals and objectives. Refer to Tool 4, Success Criteria, for further guidance on developing success criteria that are linked to goals and objectives. The adaptive management process is partly founded on the concept that what can be measured can be improved (and vice versa). However, measurements that are not linked to the achievement of explicitly stated project goals are meaningless.

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Table 1.1: Examples of goals, objectives, and success criteria.

Goal	Objective	Success Criteria
To minimize erosion from the road cut on Upper Elbow Road.	Stabilize the Upper Elbow road cut using full soil restoration treatment such that erosion is reduced by at least 50% within 1 year.	Sediment yield from the Upper Elbow road cut is reduced by 50% compared to background rates as measured with simulated rainfall.
To increase summer habitat value for Loomis' Ground Squirrel on the Mongolian Plains ski run.	Establish a robust community of Mann's Groundcherry and Knudsen's Squirrelbrush on the Mongolian Plains ski run.	• A density of Mann's Groundcherry of at least 0.5 plants per square yard. • A total vegetative cover of Knudsen's Squirrelbrush of at least 15% over the run surface (80% confidence level).
To enhance the aesthetic appeal of road cut and fill slopes in the Fallback development area.	Increase plant cover and color on the road cut and fill slopes throughout the Fallback development area.	• Plant cover of at least 50% on Fallback roadcuts. • Plant mix shall consist of plants with at least three different leaf colors such as olive, medium, and dark green. 25% of the plant palette may consist of leaves that change color through the season rather than distinctly different base leaf color.

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"Restoration of a disturbed ecosystem is an acid test of our understanding of that ecosystem." – A.D. Bradshaw

Tool 2 - WATERSHED FLOW ASSESSMENT

Definition

Watershed flow assessment (for the purposes of this document) is the process of identifying and mapping surface water flow patterns and erosion problem areas ("hot spots") within a defined drainage area (i.e. catchment, sub-watershed, watershed).

Purpose

A watershed flow assessment is conducted in order to develop a complete understanding of existing and potential (seasonal) water flow paths that will influence the design, implementation, and eventual success or failure of a project. Information and data collected through watershed flow assessment should be used by the project team to ensure that existing and seasonal water flow is both accounted for and accommodated in project planning, design, and implementation. This tool can be used in planning a single project or in assessing an entire watershed or drainage area.

Overview

Watershed flow assessment is an important but often overlooked element of project planning, implementation, and monitoring. Most watersheds have undergone some level of hydrologic manipulation. Constructed features such as roads, drainages, and buildings change hydrologic patterns in a watershed and can create erosion problems. Common erosion "hot spots" include stream crossings (roads or trails), roads built along creeks or other flow areas, unprotected slopes that receive flows during runoff periods, and of course roads in general (see photo). These areas are considered "hot spots" because of the immediate interaction between water flow and unprotected soil surfaces.

Water flow assessments integrate many processes within an entire watershed. It is this understanding that encourages practitioners to map water flows and integrate them into project planning, thereby avoiding the common problem of fixing a problem site while ignoring the "plumbing" of the watershed. A useful adage is "Disregard at your own risk." Many project sites have been destroyed by inadequate consideration and accommodation of surface flows. A complete assessment of the network of interconnected erosion issues throughout a watershed will produce an "erosion master plan" that will provide the context for all other activities in the watershed.

Steps in Conducting a Watershed Flow Assessment

The following steps describe a logical process for planning, conducting, and using a watershed flow assessment:

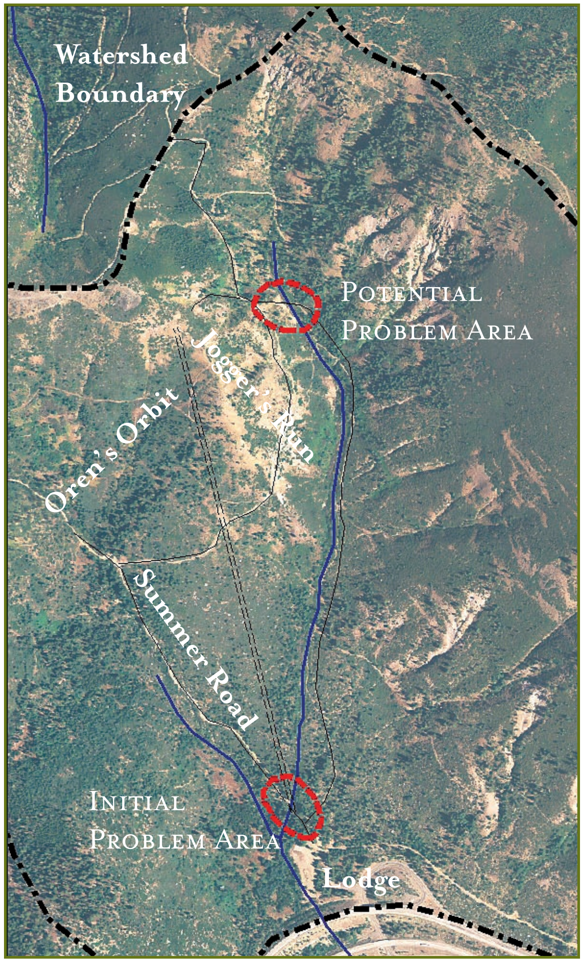

Figure 2.1, Map 1: Example base map with key water flow features, known and potential problem areas.

Step 1. Prepare a map showing key watershed features (see Map 1)

The map should include, at a minimum, roads (active and abandoned), streams, ski runs, drainage infrastructure, and known water flow areas. Ideally, this base map is developed using a Geographic Information System (GIS). GIS allows for clear and accurate representation of a wide range of features and efficient incorporation and presentation of new features that have been located and mapped with a Global Positioning System (GPS) unit. Various base maps are available free of charge from online mapping web sites such as Google Earth or Topozone. Some of these online applications also allow users to import GPS data.

Step 2. Identify known and potential erosion problem areas (see Map 1)

Review the map and identify known and potential erosion problem areas. Areas where roads or ski runs intersect with streams or water flow paths are generally noted as "hot spot" locations. Many land managers are aware of areas that have been observed as sources of erosion—all of these areas should be marked on the map. Identification of problem areas provides the basis for a targeted field assessment starting with the "hot spots" that have been identified on the map to determine whether erosion is actually occurring in those areas. Where problems are identified, those problems should be traced upslope to their source. Finding sources of drainages and erosion areas is also referred to as *erosion forensics* and is a critical step in addressing erosion issues. Without identifying the source of a problem or drainage, it is often impossible to develop a comprehensive and effective solution. This step also requires an erosion specialist who has worked in the field of erosion forensics. A GPS unit can also be used to locate problem areas and intermittent watercourses that are not obvious on most maps. During this field process, an

Mountain bikes can be an efficient method of conducting watershed flow assessments.

Erosion on dirt road.

overall assessment of additional flow patterns and problem areas should be done for the entire watershed. All problem areas should be documented with photos, field observations, notes, and GPS locations.

Step 4. Identify actual problem areas and interconnections (see Map 2)

After updating the map with new problem areas and features, identify the interconnections between the problem areas and the root problems that need to be addressed. Draw lines on the map showing the connections between problem areas and root causes. Take notes describing the interactions between problem areas. This information is the basis for framing the problem(s) and defining projects.

Step 5. Prioritize and select problem areas to be treated (see Map 3)

Once the project team has a good understanding of what erosion problems exist and how interconnected they are, prioritize problem areas for treatment. Whenever possible, treatments should begin at the top of the watershed or the upslope origin of the erosion issue. Where this is not possible or practical, treatment area(s) must be protected from on-site flows. The watershed flow assessment can be used to prioritize treatment areas or projects in a number of ways. For instance, if the goal is to systematically address erosion areas in terms of their sediment contribution, begin with those areas that are closest to a year-round stream. By addressing those areas and their root cause(s), the most problematic areas get addressed first. Or, if planning an expansion project, identify whether there are any areas that will contribute either surface flow or sediment to the site and repair those areas prior to, or as part of, the project.

Step 6. Conduct Site Condition Assessment at selected project sites (see Tool 3, Site Condition Assessment)

Once problem areas have been prioritized and specific project sites have been selected for near-term treatment, conduct a site condition assessment at each site to develop an understanding of general site characteristics and specific functional characteristics. This

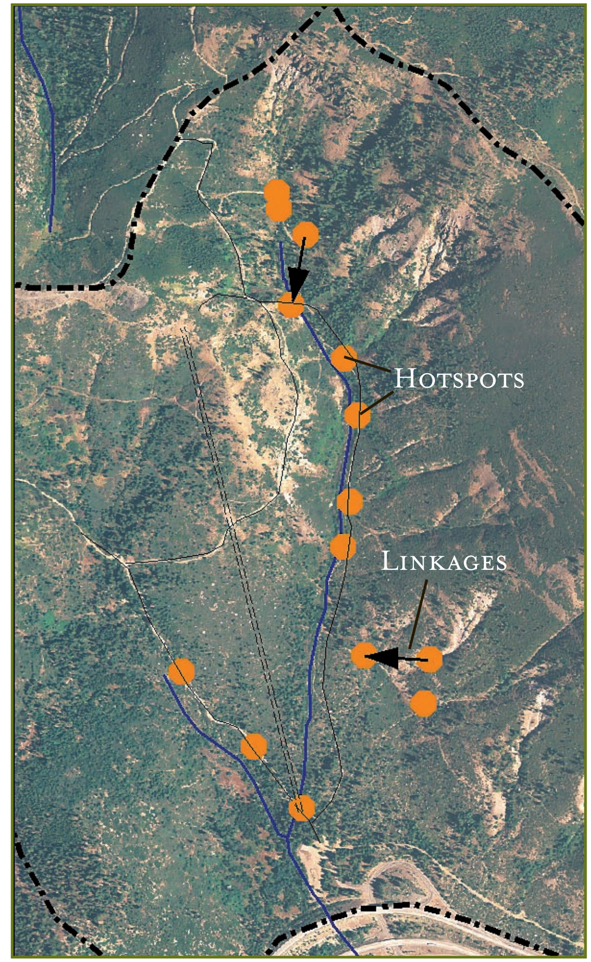

Figure 2.2, Map 2: Example map of problem areas (hot spots) and interconnections.

step is critical to project success, as it allows the project team to understand enough about a site to develop a complete and effective implementation plan.

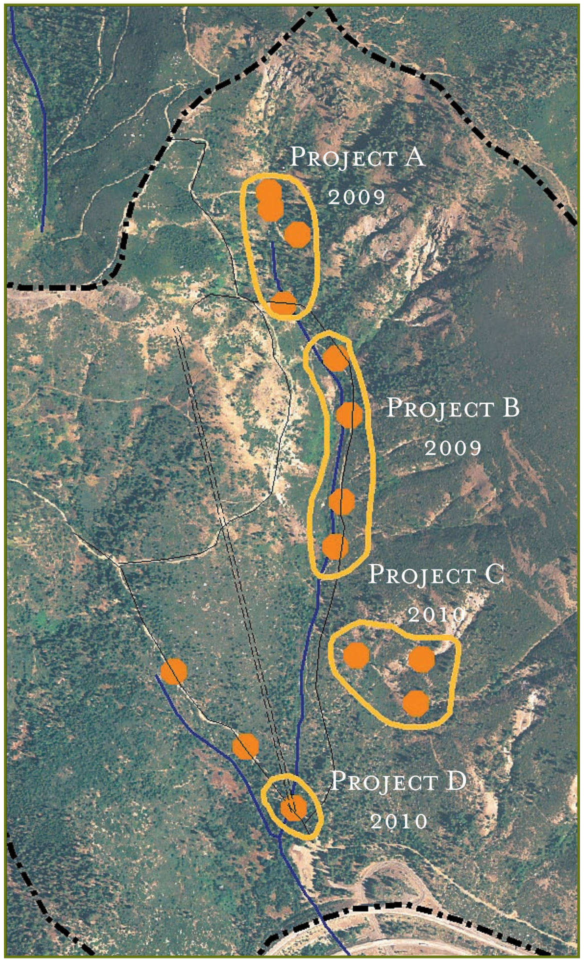

Figure 2.3, Map 3: Example map of problem areas prioritized for treatment.

Step 7. Incorporate the previous information into project plans

All the information gathered previously should be used to develop project plans. For instance, if a seasonal drainage flows through the project site, that flow should be accommodated by installing a rock-lined conveyance channel or by diverting the flow around the site. (See Tool 18, Accomodating Water Flow.) In addition, flow created from the site itself can be "plumbed" into an existing watercourse if that water is clean. Many culverts and other outflows are not adequately armored with rock or other protection. For instance, a culvert may have a 10-foot rock dissipation structure. However, during saturated soil/high flow conditions, flow will move beyond that rock apron and begin down-cutting into native soil, thus creating an erosion problem. All flows must ultimately be connected, both entering and exiting a project site, and that connection should be presented in project plans.

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Tool 3 - SITE CONDITION ASSESSMENT

Definition

Site condition assessment is the process of collecting site-specific information and data in order to develop a complete understanding of the pre-treatment condition and restoration potential of a particular project site. Site condition assessment includes *baseline monitoring* of a number of parameters and documentation of site-specific characteristics that will guide the implementation plan and outcome of the project. There are two general categories of information to be collected:

1) **General site characteristics** such as slope, aspect, elevation, soil type, solar exposure, etc.

2) **Specific functional characteristics** of the project area, such as soil density and soil nutrient content, which will help define specific treatments.

Purpose

Site condition assessment is conducted to provide project planners and implementers with enough site-specific information to develop an effective treatment plan.

Overview

Projects are often planned and implemented without an adequate understanding of treatment site conditions, limitations and off-site influences. Planners and implementers often rush to apply "standard" erosion control treatments that do not take into consideration unique site conditions. In order to plan and implement a successful project that efficiently meets project goals and long-term expectations, the planner and implementer need to understand as much as possible about the existing (baseline) condition of the site. While it is not possible to understand everything about a site, certain site-specific conditions must be well understood, even on small projects. These conditions include soil conditions, where water enters and exits the site, the use patterns of the site, and the current condition of the vegetation community. If the treatment area has been previously disturbed, it is also important to collect information at a nearby reference site in order to determine reasonable targets and site-specific success criteria for the treatment site. Baseline data provide the foundation for assessing and understanding project performance over time in order to improve future projects. Ultimately, site condition assessment helps the planner and implementer understand and define the context of the project, the influence of the surrounding landscape, and the root cause(s) of an erosion problem.

Elements of a Robust Site Condition Assessment

The more robust and complete the site condition assessment is, the higher the probability of a successful project outcome. While collecting baseline site information requires time, the amount of time required to re-treat a failed project area or conduct ongoing site maintenance is usually much greater. The key elements of a robust site condition assessment are listed and described below. For information about specific monitoring tools and techniques, refer to Tool 16, Monitoring.

General Site Characteristics

Surveying and documenting the physical and geographic characteristics of a site is an important first step in developing an appropriate and effective treatment plan. Assessment of general site characteristics should help to identify the limitations of the site. This understanding should influence treatment planning. Site characteristics that should be documented include slope, aspect, elevation, soil type, solar exposure, landscape position, treatment area size, and water flow paths, among others. **A site assessment information sheet** is provided at the end of this Tool for documenting general site characteristics and preliminary project information.

Tools for surveying and documenting general site characteristics include:

- Global Positioning System (GPS) unit
- Topographical map
- Soil survey map
- Inclinometer
- Compass
- Measuring wheel
- Camera (digital)
- Solar input measurement device (such as a Solar Pathfinder)
- Site assessment information sheet (found at the end of this Tool)

A Note About Watersheds

All projects are implemented within a watershed. The watershed will influence the project and the project will influence the watershed. A basic understanding of the watershed as project context is critical if the designer and implementer are to realize a successful project outcome. See Tool 2, Watershed Flow Assessment, for more information on assessing and understanding watersheds.

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Hydrologic Condition

Hydrologic condition includes soil physical parameters such as water infiltration, water flow paths, soil water content, and water storage capacity. In other words, assessment of soil hydrologic conditions provides information about how the water that enters a site is infiltrated, transmitted, and stored. Hydrologic condition assessment assumes that a larger-scale watershed flow assessment has already been conducted (see Tool 2, Watershed Flow Assessment) and that the planner and implementer already have a thorough understanding of how water enters and exits the site during different storm events and flow regimes. Many projects have been destroyed by inadequate consideration of surface flows.

Soil Condition

Soil condition is perhaps the most critical variable that influences project outcome and refers to a wide range of parameters such as soil nutrient and organic matter content, soil texture, biological (microbial) activity, and soil density/compaction. Hydrologic and vegetation conditions are interdependent and are intimately tied to soil conditions. *Soil organic matter* is the most critical variable that influences soil condition, as it is the primary source of energy and food for soil microbes, drives soil aggregation, increases the soil's capacity to store water, and provides a long-term source of nutrients for plants. *Soil nutrient content* limits how well a vegetation community can develop and sustain itself. Inadequate types and amounts of soil nutrients will severely limit plant growth.

NOTES

Table 3.1: Methods for assessing hydrologic condition.

Method	What It Measures	Cost	Time	Skill
Cone Penetrometer	Soil resistance to force; can be used as a surrogate for soil density	+	+	++
Soil Moisture Meter	Volumetric soil water content	+	+	+
Rainfall or Runoff Simulator	Infiltration, sediment yield, and nutrient content of runoff from rainfall or sheet flow	+++	+++	+++
Mini Disk Infiltrometer	Soil hydraulic conductivity	+	++	++
		+(low)	++(moderate)	+++(high)

Table 3.2: Methods for assessing soil condition.

Method	What It Measures	Cost	Time	Skill
Soil Sampling and Nutrient/Organic Matter Analysis	Specific nutrient and physical parameters	++	++	++
Cone Penetrometer	Soil resistance to force; can be used as a surrogate for soil density	+	+	++
Soil Pits	Creates soil cross-section that allows for targeted soil sampling, identification of root-restricting layers, etc.	+	++	+++
		+(low)	++(moderate)	+++(high)

Vegetation Condition

Vegetation condition refers to the types and amounts of vegetation present on a site. The composition of the vegetation community can provide an indication of soil conditions at the site and may inform specific treatments. For instance, if weeds are dominant at the site, full vegetation removal and a weed management plan may need to be included as part of the treatment plan. If native vegetation is already present, the treatment plan may be designed to minimize disturbance of existing vegetation. If the site is highly disturbed, surveying a nearby reference site will help determine the appropriate types, species, and amount of vegetation that is possible at the treatment site.

Table 3.3: Methods for assessing vegetation condition.

Method	What It Measures	Cost	Time	Skill
Surface Cover Monitoring (Cover Point Method)	Soil cover by different elements such as vegetation, mulch, etc. *Quantitative method*	++	++	+++
Surface Cover Monitoring (Ocular Method)	Soil cover by different elements such as vegetation, mulch, etc. *Subjective method*	+	+	+++
Plant Density Monitoring (Plant Census)	Plant survival, plant density	+	++	++
Plant Type Survey	Presence and diversity of different plant types (e.g. native, invasive, annual, perennial, etc.)	+	+	+++
Species Composition Survey	Vegetation composition by species	++	++	+++
Biomass Measurement	Plant biomass can include above-ground and/or below-ground	+	+++	+
		+(low)	++(moderate)	+++(high)

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Reference Site Condition

A *reference site* is a site that represents the ideal used for comparison. A reference site should also be a site that is self-sustaining and therefore defines at least a minimum adequate site condition. Typically, a reference site is a well-functioning area (native or restored) that is located near the treatment site. The conditions of the reference site are monitored and defined to help identify specific potential future condition for the treatment site. Reference sites are used when the treatment or problem site is highly disturbed. Appropriate amendment additions and physical treatments can be developed based upon the difference between the reference site conditions and the problem site conditions. For instance, if the reference site consists of soil that contains 7% organic matter and has a low soil density, whereas the treatment site has 2.5% organic matter and a much higher density soil, 4.5 to 7% organic matter addition and full soil tilling treatment would be required to restore impaired functions at the treatment site. Reference site conditions can also be compared with measured project site conditions following treatment to determine treatment success (see Tool 4, Success Criteria). For instance, soil nutrient levels can be compared to determine if the amount of soil amendments added during treatment achieved target nutrient levels (as measured at the reference site).

Methods for assessing reference site condition include some or all of the methods listed above under *hydrologic condition, soil condition,* and *vegetation condition*. Typically, all parameters that are measured at the project site should also be measured at the reference site.

Soil Moisture Considerations

Properly treated or undisturbed soils have been shown to infiltrate large amounts of water (upwards of 5 inches of rainfall per hour) until that soil is saturated. Once soil becomes fully saturated, runoff occurs. Runoff will occur much sooner on a compacted soil because of a reduction in void space and soil water storage capacity (also referred to as water holding capacity). However, all soils will become saturated at some point. Once saturated, the soil cannot hold any additional water and surface flow occurs. Surface flow can also occur when the precipitation rate exceeds infiltration rate, such as during an intense rainstorm. When surface flow occurs, vegetation and mulch become critical elements of sediment reduction.

Case Study: A Tale of Two Road Cuts

Currently, most projects that are implemented do not go through an assessment process that allows adequate understanding of the limiting factors of the site. For example, many roadside erosion control projects use a mixture of seed and fertilizer that is applied by a hydroseeding machine. If planners were to compare nutrient content in a bare road cut soil to a nearby native or other self-sustaining site, they would usually find that elements, especially those used in great quantities by plants (such as nitrogen), are as much as an order of magnitude ten times lower than those at a native site. However, nutrient additions (fertilizers, amendments) are seldom matched to what is specifically needed to sustain vegetation at a site. Thus, adequate site assessment and careful planning can lead to significantly enhanced project outcomes.

At a development in Martis Valley near Truckee, California, two contiguous road cut slopes were treated using different techniques. In 1999, with no pre-construction site assessment, the slope in the left photo was treated using hydroseeding (no soil treatment). The slope in the right photo was thoroughly assessed prior to construction, and appropriate treatments were developed. The assessment indicated a severe lack of soil organic matter, low levels of nitrogen, and extremely dense soil. In 2001, the slope on the right was treated using compost, tilling, and hand application of fertilizer, seed, and mulch (full soil treatment). In 2006, the slope with full soil treatment exhibited the following characteristics when compared to the hydroseeded slope:

- Infiltration rate was 1.4 times higher
- Sediment yield was 32 times lower
- Penetrometer depths to refusal (surrogate for soil density) were 2.5 times deeper
- Plant cover was 2 times higher
- Mulch cover was 5 times greater and 3.5 times deeper

Contiguous slopes at Northstar Unit 7 in 2006 — hydroseeding treatment (left); full soil treatment (right).

TOOLKIT

Site Assessment Information Sheet

This form is provided as a standard, basic format for consistent collection of site information. Additional information may be relevant on some projects, and this form should be adapted to fit the needs of each project and user. The fields below are considered to be the minimum amount of site information needed to develop an effective implementation plan. This form should take less than one hour to complete, with additional data collection, such as soil sampling and vegetation cover assessment, taking longer to complete.

Project Name		Project ID *(unique for each project)*	
Observers		Date	
Location Description *(include driving directions)*			
Problem Description *(describe type and level of disturbance, source of erosion problems, etc.)*			
Use Pattern Description *(any trails, roads, ongoing access requirements?)*			
Photo Point ID and File Names *(important to record in field)*			
GPS Coordinates *(Lat, Lon)*			
Landscape Position *(upland, meadow/flat, riparian, wetland)*		Landscape Shape *(concave, convex, undulating)*	
Slope Angle *(degrees)*		Aspect *(degrees and direction)*	
Elevation *(feet)*		Soil Parent Material	
Project/Treatment Area *(dimensions and total square feet)*		Monitoring Plot Area *(dimensions and total square feet)*	
Project Area Map Completed?		Evidence of Rodent Activity?	
Solar Input *(% direct sunlight in August)*		Tree Canopy Cover (%)	
Hydrologic Condition Assessment Complete?		Soil Condition Assessment Complete?	
Vegetation Condition Assessment Complete?		Reference Site Condition Assessment Complete?	

Site Assessment Map Template

Project Name

Project Map Checklist

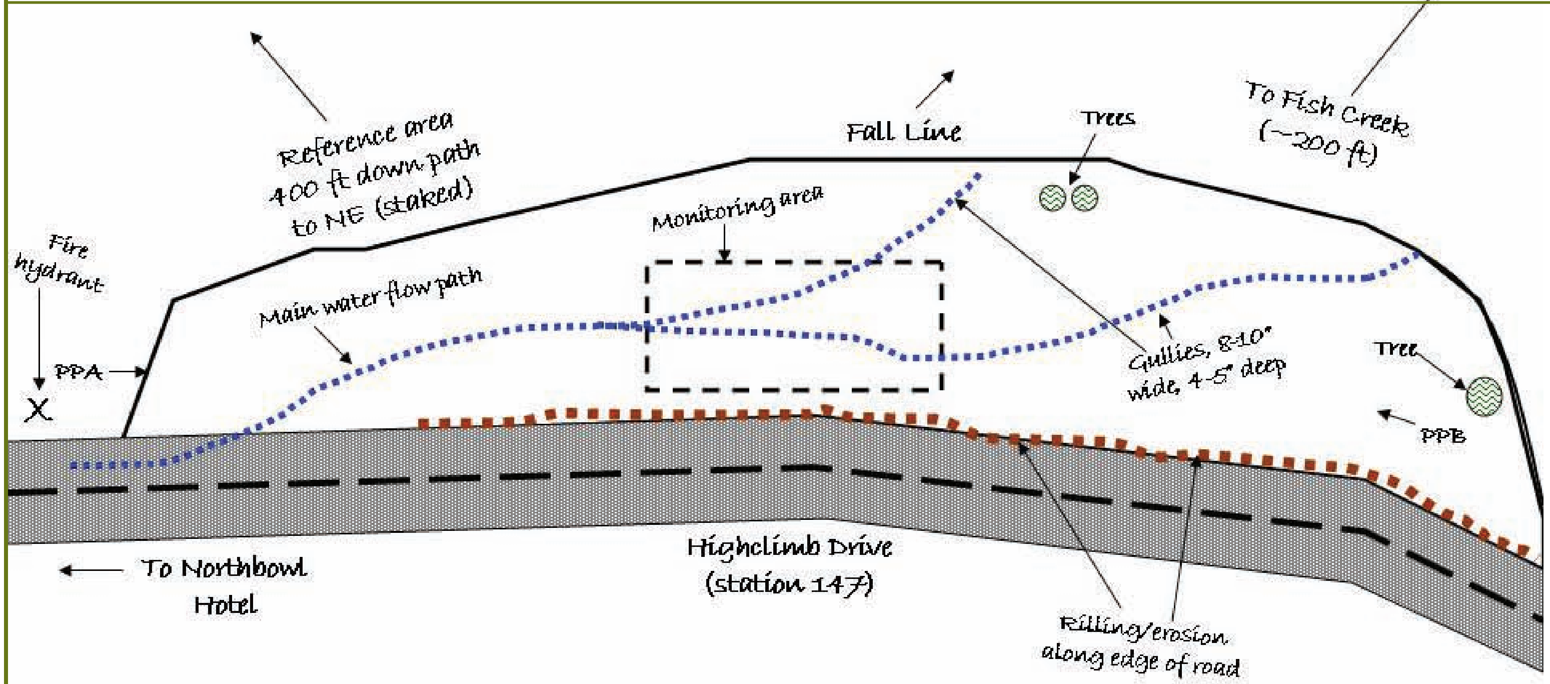
- ✓ North Arrow
- ✓ Project/Treatment Area Dimensions
- ✓ Monitoring Plot Locations (including Reference Site)
- ✓ Photo Point Locations
- ✓ Soil Sample Locations
- ✓ Water Flow Areas
- ✓ Trails, Roads
- ✓ Snowmaking, Other Utilities
- ✓ Landmarks (e.g. Signs)

Site Assessment Information Sheet (EXAMPLE)

This form is provided as a standard, basic format for consistent collection of site information. Additional information may be relevant on some projects, and this form should be adapted to fit the needs of each project and user. The fields below are considered to be the minimum amount of site information needed to develop an effective implementation plan. This form should take less than one hour to complete, with additional data collection, such as soil sampling and vegetation cover assessment, taking longer to complete.

PROJECT NAME	Highclimb Drive, Station 147	PROJECT ID *(unique for each project)*	HCD 147
OBSERVERS	Lorenzo Mulchman, Dave Wattle, Jeremy Lovestoseed	DATE	6/1/08
LOCATION DESCRIPTION *(include driving directions)*	Road shoulder at Station 147 on the west side of Highclimb Drive at North Bowl Ski Resort (1.4 miles from Highway 267)		
PROBLEM DESCRIPTION *(describe type and level of disturbance, source of erosion problems, etc.)*	Bare road shoulder was heavily compacted during road construction. The area receives runoff from road and other upslope areas. This runoff concentrates on site and has created several rills and a large gully. Also, there is no stable drainage or spreading area to discharge flows to the adjacent forested area.		
USE PATTERN DESCRIPTION *(any trails, roads, ongoing access requirements?)*	Site is alongside well-used road. No ongoing vehicle access is needed and no trails are present in the area.		
PHOTO POINT ID AND FILE NAMES *(important to record in field)*	PPA (img0347), PPB (img0348), PPC (img0349)		
GPS COORDINATES *(Lat, Lon)*	N 39 15.861, W 120 07.697		
LANDSCAPE POSITION *(upland, meadow/flat, riparian, wetland)*	upland	LANDSCAPE SHAPE *(concave, convex, undulating)*	Slightly convex
SLOPE ANGLE *(degrees)*	5-7 degrees	ASPECT *(degrees and direction)*	285 degrees (WNW)
ELEVATION *(feet)*	6,435 ft	SOIL PARENT MATERIAL	Volcanic (andesite)
PROJECT/TREATMENT AREA *(dimensions and total square feet)*	~25' x 876' (21,908 sq ft)	MONITORING PLOT AREA *(dimensions and total square feet)*	~20' x 60' (1,200 sq ft)
PROJECT AREA MAP COMPLETED?	(yes/no)	EVIDENCE OF RODENT ACTIVITY?	(yes/no)
SOLAR INPUT *(% direct sunlight in August)*	82%	TREE CANOPY COVER (%)	0-5%
HYDROLOGIC CONDITION ASSESSMENT COMPLETE?	(yes/no)	SOIL CONDITION ASSESSMENT COMPLETE?	(yes/no)
VEGETATION CONDITION ASSESSMENT COMPLETE?	(yes/no)	REFERENCE SITE CONDITION ASSESSMENT COMPLETE?	(yes/no)

Site Assessment Map Template (EXAMPLE)



Project Map Checklist

- ✓ North Arrow
- ✓ Project/Treatment Area Dimensions
- ✓ Monitoring Plot Locations (including Reference Site)
- ✓ Photo Point Locations
- ✓ Soil Sample Locations
- ✓ Water Flow Areas
- ✓ Trails, Roads
- ✓ Snowmaking, Other Utilities
- ✓ Landmarks (e.g. Signs)

Tool 4 - SUCCESS CRITERIA

Definition

Success criteria are a set of numerical values or condition descriptors that are measured or observed in the field to determine whether or not project goals have been achieved. Success criteria must be linked to project goals if they are to be valid and useful. Success criteria may be direct measurements or indicator measurements of project outcomes.

Purpose

Success criteria serve as the specific standards that are used to objectively assess project performance and outcomes. Success criteria help to define monitoring methods and techniques that will be used to measure success. Robust and defensible success criteria are measurable, or at least clearly observable, in a manner that minimizes subjectivity.

Developing Defensible Success Criteria

Success criteria must be identified and defined before a project is implemented, typically during a project's design phase. Success criteria may include a range of acceptable values, or may have a threshold that sets an upper or lower value for success, such as "plant cover of no less than (at least) 20%." At a minimum, defensible success criteria should have the following characteristics:

- Specific and detailed
- Linked to the project goals
- Understandable
- Quantitative and measurable (specify monitoring method and statistical confidence level as appropriate)
- Time element (when will criteria be measured/assessed?)
- Able to be used to improve the project and/or future projects

Direct vs. Indirect Measurements

Some success criteria are direct measurements of project success, such as the number of healthy plants that are growing on a site or the absence (or presence) of rills and gullies on a project site immediately following a rainstorm or runoff event. Other criteria are indicators of a site condition that can be directly or indirectly linked to success. For instance, in an erosion or sediment source control project, simulated rainfall can be used to directly measure sediment yield and demonstrate the site's propensity for eroding over a range of non-saturated conditions. Another success criterion that is often used is cone penetrometer readings. A cone penetrometer measures a soil's resistance to applied force. This measurement is used as a surrogate for soil density, which is an indicator of infiltration capacity. Thus, cone penetrometer readings are indirectly linked to infiltration but may be a more cost-effective and appropriate monitoring method than direct measurement with a rainfall simulator. See Tool 16, Monitoring, for more information on monitoring methods such as simulated rainfall and cone penetrometer.

Direct Measurements

Many project elements are not easy to measure directly, especially within the time or resource constraints of most project timelines. For instance, if a project is designed to reduce erosion through source control, erosion processes and rates can be difficult (or impossible) to measure in any meaningful way, at least during a relatively short time frame of one to three years, thereby limiting our ability to assess project success or failure. Other limitations of direct erosion measurement include the wide range of inputs and site conditions that affect erosion. For instance, it is not reasonable to expect a project to be able to withstand ALL rainstorm intensities. A rainstorm of 5 to 8 inches per hour (or equivalent) may be beyond the possible performance range of even a native site. Further, each rainstorm and runoff event will be different, with different raindrop size, intensity, and duration. Therefore, artificial assessment of a site to withstand erosion within a specific and reasonable range of storm intensities may be the most useful and achievable method of monitoring.

Where direct measurements are possible, those techniques should be utilized. Examples of direct measurements include the number of plants present in a given area or presence of rills or gullies directly after a storm. However, even direct observation of signs of erosion can be misleading. For instance, if presence of rills is used as a success criterion, and the site does not receive the type of rainfall event that would develop rills for several years, the project might be considered "successful" based on that criterion. However, while that site may be prone to rilling, it may not develop rills until a larger storm occurs, which may be beyond the project's monitoring period. Therefore, some criteria, such as rilling and gullying, may be considered as supplemental (but not primary) criteria. If rills are present, then there is a problem. However, the lack of rills does not necessarily indicate "success."

Indirect Measurements

Indirect, indicator, or index criteria are more likely to produce usable results within the constraints and time frame of most project cycles. Examples of types of indirect measurements are presented in Table 4.1.

Table 4.1: Examples of Indirect Measurements

Measurement Type	Intended to Measure	Difficulty of Direct Measurement	Rationale for Indirect Measurement
Cone Penetrometer	Soil density as indicator of infiltration	Soil density is difficult and expensive to measure directly and is highly variable, thus requiring many measurements.	Quicker that bulk density measurements and, while variable, can be conducted more quickly. Can also provide an intuitive "feel" for soil physical conditions.
Surface Mulch	• Resistance to splash detachment • Resistance to shear forces inherent in overland, surface flow	Splash detachment and surface flow/shear force are event-dependant and are impossible to measure without of research-level assessment techniques.	Mulch cover percentage is relatively quick to measure. Multi-year monitoring can also provide mulch longevity values.
Soil Nutrients	• Amount of nutrients available for plant growth • Amount and type of organic matter available for self-sustaining system	Sustainable plant community development requires measurement over many years and then can still be difficult to determine.	Measurement of nutrients and organic matter shows the ability or *potential* of a site to sustain long-term vegetation growth.

Defining and Measuring Success Over Time

Sustainable sediment source control is achieved by rebuilding site conditions and repairing functions that are part of a dynamic and ever-changing ecosystem. In a robust ecosystem, soil and vegetation conditions are in a constant state of flux (as illustrated by Figure 4.1). It is therefore difficult and often misleading to define and measure "success" at a single point in time without considering the longer-term trajectory of the site. The example success criteria matrix (Table 4.2) provides an example of how success can be defined based on a desired *trajectory* rather than at a single point in time. These success criteria are linked to the following treatment goals:

- Minimize erosion and sediment movement at the source
- Establish a robust and self-sustaining native plant community
- Recapitalize soil nutrients and organic matter to sustainable levels

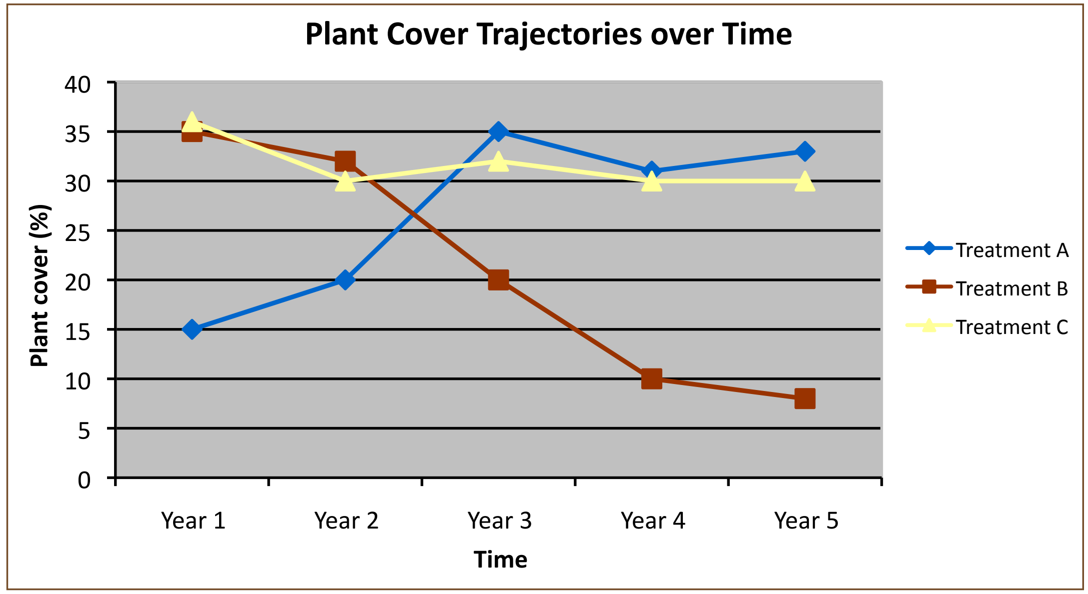


Figure 4.1: The conceptual graph illustrates different plant cover trajectories over time following three different treatments. Trajectories must be considered when attempting to define or determine the success of any ecosystem-based restoration or erosion control project. In this example, if success was set at 30% total plant cover in Year 2, Treatments B and C would have been determined to be "successful." However, in Year 3, that status would be quite different, as Treatment A exhibited a notable increase in plant cover while plant cover at Treatment B decreased greatly. The unsuccessful trajectory of Treatment B is one that is commonly observed when fertilizer and/or irrigation is used to help establish and sustain plants at sites where soil conditions are not adequate to sustain a robust plant community over time.

Table 4.2: Example success criteria matrix.

Monitoring Parameter	Year 1	Year 2	Year 3	Year 4	Year 5
Penetrometer Depth	12" @ ≤ 200 psi	12" @ ≤ 250 psi	12" @ ≤ 300 psi	12" @ ≤ 350 psi	12" @ ≤ 350 psi
Total Cover	98%	95%	90%	85%	85%
Vegetative Cover *(90% confidence level)*	10%	20%	20%	25%	30%
Native Species	10% of target species present	40% of target species present	50% of target species present	70% of target species present	90% of target species present
Bare Areas	No areas larger than 3 square meters bare	No areas larger than 3 square meters bare	No areas larger than 3 square meters without vegetation	No areas larger than 3 square meters without vegetation	No areas larger than 3 square meters without vegetation
Visible Erosion	Any visible signs of erosion addressed, such as rotational failures, rilling, gullying, or other deposition. Any ongoing problems, such as on-site drainage, would require remedial action. If erosion persists, this area will be re-treated. Specifics for this follow-up treatment will be developed in a measurable fashion.				
% of Target Total Soil Nitrogen	90-100%	85-90%	80%+	80%+	80%+

A Word About Statistics in Measuring Success

Statistics can be a daunting subject for those not well versed in using them. In the simplest terms, statistics help us to understand complex issues in simple ways. When we need to ascertain the total plant cover on a site, for instance, it is difficult or even impossible to measure every square inch of a site. Therefore, we only measure parts of the site. This is described as "sampling." Statistical assessment simply tells us how close our data are to the actual cover of the site. We need to know if we have a relatively high or low level of confidence that our data are accurate. In other words, is it a sure thing or not? Statistics, if used properly, will make the results of a project more defensible. Many statistical software packages are available for technicians who have a basic (not comprehensive) understanding of statistics, thus making analysis relatively simple and useful.

Tool 5 - MANAGEMENT RESPONSE

Definition

Management response refers to pre-defined actions that are taken if a treatment does not meet the project goals and associated success criteria. A management response is intended to adjust or repair specific project elements so that the project can continue to move toward the achievement of project goals. Here, the term *manager* refers to the person or parties responsible for a project's outcome.

Purpose

Management response is the accountability element of the adaptive management process. Adaptive management includes setting goals, defining success in measurable terms, and monitoring after project implementation to assess whether goals have been met. If the goals have not been met, a pre-defined management response is implemented to adjust project elements and move the project closer to those goals.

Developing Management Responses

Management responses must be developed during the planning phase of a project if true adaptive management is to be employed. That way, if outcomes are not in line with expectations, managers can respond and implement solutions quickly and efficiently. Some management responses may also be developed during or after implementation and monitoring, because some sources of the problem may not be apparent during project planning. In addition, some solutions will not become obvious until after the project has been implemented. Effective management responses are explicitly linked to success criteria and monitoring, which ultimately determine whether project goals have been met and whether a management response is necessary. Without pre-defined management responses, a project is not using an adaptive-management-based approach.

Adaptive management allows for flexibility in *how* goals are met and broadens the manager's options for achieving goals. It also allows trials and experiments to be incorporated into a project, adding even more options to a manager's toolbox. However, with increased flexibility comes increased accountability, as management responses are the manager's commitment to follow through on achieving the goals if the first attempt does not succeed. The development of a management response is based on the following question: *"If the project does not achieve these specific goals, what actions will be taken to ensure that the goals are met?"* The answer to this question may take the form of sequential actions, such as increasing application rates of seed or soil amendments, or may include a completely different approach to the problem, such as changing from a vegetated slope to rock slope protection. In the following example, note how the management response is embedded within the planning process.

Step 1: Identify the Need for Action

A drainage swale is identified as eroding and delivering sediment to a nearby creek.

Step 2: Set Goal

To minimize erosion and sediment delivery to creek.

Step 3: Develop Plan

A rock-lined ditch is designed to minimize erosion within the swale.

Step 4: Define Success Criteria and Monitoring Methods

Success criteria include no down-cutting of the swale itself and no significant sediment greater than 10 NTUs (nephelometric turbidity units) in the water being discharged, as measured by grab sampling and turbidity analysis.

Step 5: Develop Pre-Defined Management Response

If down-cutting is measured, it will likely be due to increased flow velocities. As alternatives, management response will include: additional rock, larger rock, and/or broadening of the flow path to reduce flow velocities. If sediment is measured in the water column (greater than 10 NTUs), potential sediment sources will be assessed and appropriate source control treatments will be implemented. Treatments may include additional protection of upslope flow areas and diversion of some of the inflow water, if necessary.

This abbreviated planning process demonstrates how and where management responses should be formulated during the planning stage. In this way, a regulatory agency or project owner can identify what and when specific remedial actions will need to be taken. Additional management responses can be developed during monitoring as other alternatives and problem sources are identified.

In essence, a management response says:

"If the project does not achieve these specific goals, this is the action we will take to ensure that the goals are met."

Case Study: Management Response to Road Cut Slope Failures

In 2005, a long road segment was constructed at a ski area in Truckee, CA. Road cut and fill slopes were tilled, topsoil was re-incorporated, and fertilizer, seed, and mulch were applied. A success criterion was defined (sediment movement not to exceed levels at reference site). However, no management responses were developed to respond if this success criterion was not met. Several months after treatment and one week after the ski resort opened, the area received 4 inches of rain in a 24-hour period, which completely saturated the soil. Due to a shallow subsurface layer of rock, this saturation resulted in lateral overland flows that moved over and through the recently tilled soil. This combination caused several mass failures (slides) that displaced large amounts of soil. To respond to the mass failures, management was forced into "crisis mode" to develop appropriate responses, both to protect water quality and to keep slides from blocking the main access road for skiers traveling to mid-mountain. It took several weeks to develop and implement the responses. These immediate responses included remedial work to temporarily stabilize the sites. The following summer, many of the slope failure areas were rebuilt (using much of the soil that had been displaced) and stabilized with temporary irrigation to encourage deep plant root penetration. These areas have now withstood normal winter conditions for several seasons. This project has since met the success criterion and is now considered to be a model for similar projects in the area.

Slope failures following large storm event – December 2005.

Responding to slope failures using subsurface "scalloping" and temporary irrigation – Summer 2006.

Repaired slope exhibiting long-term stability – Summer 2008.

Epilogue

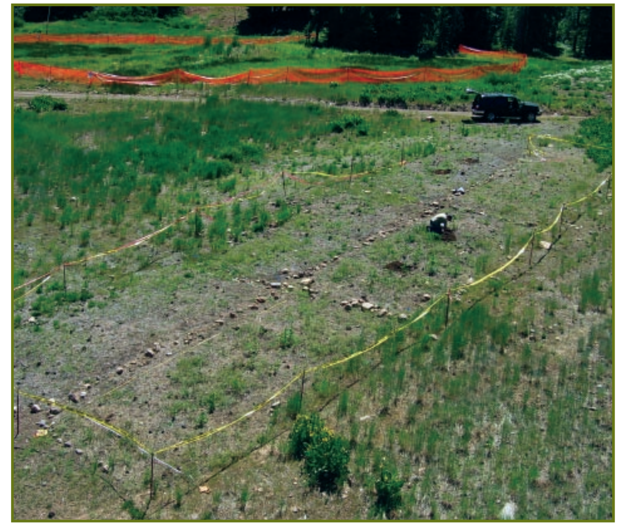
This example illustrates the importance of anticipating the range of potential failure modes during project planning and pre-defining how management will respond. If these management responses had been included in the restoration plan, the fixes could have been implemented more efficiently and management could have avoided a great deal of headache and reactive problem solving. The project owner now understands the value of adaptive management, and management response is now built into the planning process for most new projects. One of the most successful management responses was to conduct further site assessment to determine the root causes of the failures and how treatments can be adjusted to reduce risk exposure on future projects. Several similar projects have been implemented along the same stretch of roadway using modified treatment techniques that are tailored to the unique conditions of the site and designed to reduce the risk of slope failure, such as "scalloping" the subsurface material during tilling and applying irrigation earlier in the growing season to establish deep plant roots.

NOTES

Tool 6 - TEST PLOT DEVELOPMENT

Test plots at Heavenly

Test plots at Mammoth



Test plots at Northstar-at-Tahoe

Definition

Test plot development describes the process of applying treatments to areas that are used to test or demonstrate specific treatments or treatment variables. Typically, test plot development involves deliberately changing one or more treatment variables in order to compare results and fill information gaps. Test plots can be an extremely powerful tool that can help determine both environmental and cost effectiveness of a treatment or treatments before large-scale application is undertaken.

Purpose

The purpose of developing test plots is to evaluate the site-specific environmental and cost effectiveness of different treatments prior to large-scale implementation. New types of treatments may need to be demonstrated before they are accepted by those who are unfamiliar with them. Test plots can be a cost-effective way to inform a question or debate over a particular treatment by applying several treatments side by side and then comparing the outcomes. This approach can resolve many hours of debate and can save money that might be spent on a treatment or product that is not actually effective. While many manufacturers or consultants claim that particular treatments or products are highly effective, implementing test plots can be an efficient and objective way to determine how they actually perform at your site.

Appropriate Uses and Applications

- Field testing a new idea or product at your site
- Replicating a treatment that was successful somewhere else to evaluate its effectiveness at your site
- Implementing test plots the season before a large or challenging project to determine the most effective treatment for the site before spending a large sum of money on something that has not been tested
- Building credibility with regulatory personnel who are cautious or skeptical about a treatment approach
- Resolving opinion-based debates and issues about the "best" treatment approach for a site

Scheduling Considerations

- When permits are required, consider implementing test plots the season before the permitting process begins. This can help to build credibility, develop cost-effective treatment plans, and in some cases lead to a smoother and quicker permitting process.
- Consider the steps required to isolate and document the variables of interest. This typically includes flagging or otherwise marking off the test areas in the field, drawing a treatment map, and reviewing the test design and test questions on site with the field crew before construction begins. Also be sure to designate someone to document test plot construction.
- Calculate the amounts of different materials you will need for the tests (e.g. seed, amendments, mulch) and allow adequate lead time to source materials and coordinate delivery.

Implementation Guidelines

Developing test plots does not have to be difficult, but is does have to be planned, implemented, and documented very carefully in order to be useful. The guidelines below provide a road map for successful test plot development.

1. Clarify test questions.
2. Develop success criteria to define desired outcomes in quantitative terms (see Tool 4, Success Criteria).
3. Design test plots and prepare treatment map. Replications of different treatments are helpful but not critical unless the goal is to produce "defensible" results that will be acceptable to a range of potential skeptics.
4. Develop a monitoring plan that is linked to success criteria to measure key parameters and answer test questions (see Tool 16, Monitoring). The more quantitative and repeatable the monitoring, the more defensible the results.

Test plots were integrated into this post-construction restoration treatment following installation of a waterline at Heavenly. The treatment area was simply divided in half and two different soil amendments were used.

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5. Conduct site condition assessment (pre-treatment monitoring) at treatment area before construction of test plots (see Tool 3, Site Condition Assessment). This is very important. If baseline site conditions are not assessed prior to implementation, treatment outcomes will be difficult to interpret.
6. Review test plot design, treatment map and test questions with field crew before construction.
7. Designate someone to oversee and document all elements of test plot construction and prepare an as-built.
8. Measure and mark off treatment test areas.
9. Construct test plots.
10. Protect treatment areas from further disturbance (see Tool 15, Protecting Treatment Areas).
11. Complete as-built using information and data recorded during construction. An example as-built and template is provided in Tool 14, Documenting Treatments.
12. Conduct post-construction monitoring during the season after treatment (and over subsequent seasons whenever possible) to assess results and treatment effectiveness over time.
13. Share information and results with other practitioners. If multiple entities with similar challenges all engage in testing various treatments and sharing information, the result is a large body of useful knowledge.

Measuring tilling depth with a cone penetrometer immediately after test plot construction.

Case Study: Restoration Project

The removal, re-contouring, and restoration of a diversion levee in Incline Village, Nevada, was completed in 2007. At just over 4 acres in total, it was the largest contiguous upland restoration project completed to date in the Lake Tahoe Basin. However, the project began in 2005 with a small 4,000-square-foot test area.

Test Plot Approach

The treatment included re-contouring of the levee and creation of steep, decomposed granite soil slopes. Soil testing indicated extremely low soil organic matter and nutrient levels. Tub grindings (shredded stumps) were proposed to be used as the soil amendment due to the drastic difference in cost between tub grindings and compost. While compost would have been preferable in this case, the project budget did not allow for it. This was the first project proposing to use tub grindings as a soil amendment on large scale. However, this treatment approach was based on measured results from several previous test plot areas that all indicated that tub grindings were very promising as a soil amendment when combined with organic fertilizer. The Tahoe Regional Planning Agency (TRPA) agreed to implementation of a small test area to evaluate how the tub grinding/organic fertilizer-based treatment would perform. Because no similar projects had been implemented in the area, test plots were critical as a proof of concept before scaling up. TRPA also agreed to waive the vegetation-only success criteria and consider a more systematic approach to defining project success that included additional elements such as soil density, infiltration, soil stability, and direct measurements of erosion (rainfall simulation). Year 1 monitoring results from the test plot areas were extremely promising—both from an erosion reduction and vegetation standpoint—and the larger project (4+ acres) was allowed to be constructed using the proposed treatment approach.

Results

Monitoring results for the full project were extremely surprising in that vegetative cover exceeded expectations and the slopes were exceptionally stable. This treatment was designed with a specific vegetation trajectory in mind. That trajectory included initial (grass with some shrubs for stability and soil development, 1 to 3 years), developing (grasses, a wider variety of shrubs and some tree seedlings, 3 to 5 years) and mid-seral (greater dominance by shrubs and trees, 5+ years) stages. This project demonstrated a cutting-edge restoration approach that saved money, met success criteria, and exceeded the expectations of all parties involved. Most importantly, this unusual approach was developed, approved by TRPA, and implemented based on site-specific tests and measured results rather than "best guesses" and opinions.

Test area — before treatment, 2005.

Test area — after treatment, 2006.

Large-scale restoration — after treatment, 2008.

Tool 7 - TOPSOIL SALVAGE AND REUSE

A tale of two soils. Native topsoil on left, subsoil from ski run surface on right.

Definition

Topsoil is the uppermost and most biologically active layer of native soil. It is typically darker in color and richer in organic matter than the subsoil layer beneath it. Topsoil also tends to contain a large store of native seeds, called the seed bank. This seed bank can contain over 5,000 seeds per square meter.

Topsoil salvage and reuse refers to the process of removing topsoil prior to grading activities, then re-applying it to the finished soil surface after grading is complete.

Manufactured or *artificial topsoil* refers to any material that is marketed and sold as a topsoil replacement, but is not actually topsoil. This material was developed as a response to the landscape industry's requirement for topsoil on many projects. Actual topsoil cannot be manufactured.

Purpose

Topsoil is an irreplaceable resource that is often removed and hauled off site or simply buried during grading and excavation activities, despite the fact that topsoil salvage is commonly noted on construction plans. The removal of topsoil has a large negative impact on the ability of the soil to sustain itself, to support healthy vegetation, and to resist the erosive forces of wind and water. Of all types of soil material, topsoil has the highest organic matter content, the most stable soil structure, and offers the most optimal seedbed for germinating and establishing vegetation. Removing topsoil also reduces the water-holding capacity of the soil and eliminates the primary source of nutrients for plants and soil microbes. In addition, topsoil salvaged from a project site can contain native seeds and beneficial soil microorganisms. Additional off-site inputs, such as compost and other amendments, are often costly to import and do not contain the soil microbes, seed bank, and stable nutrients contained in topsoil. Most soil-disturbing projects have only one opportunity to save topsoil. If that opportunity is missed and topsoil is buried or lost, achieving the goal of sustainable sediment source control can be very expensive. While it requires foresight and some additional planning, topsoil salvage and reuse can lead to great cost savings on projects where sustainable sediment source control is the goal.

Appropriate Uses and Applications

Topsoil salvage and reuse can be utilized to improve restoration project success and reduce costs anywhere topsoil is present and soil disturbance is planned. Common ski area projects that tend to disturb soil include ski runs, building development, snowmaking and lift installation, and road construction. Topsoil salvage can be especially useful in areas where high-quality compost is not readily available or in cases where transporting material to the project location is not practical. In alpine environments with short growing seasons and drastic fluctuations in temperature, topsoil is an especially important resource to conserve, as topsoil can take several centuries or longer to rebuild naturally.

Scheduling Considerations

The removal of topsoil must occur before any grading or other heavy equipment work has begun. A topsoil salvage plan should be designed into construction project plans and schedules whenever possible. A topsoil salvage plan should identify the extent and depth of the topsoil to be removed, typically 2-6 inches depending on site and soil type. As part of the topsoil salvage plan, appropriate on-site staging areas should be identified for storage during site preparation and grading. The salvage plan should also identify measures to protect topsoil during storage. Soil samples should be collected to evaluate the nutrient content of the salvaged topsoil. Soil lab analysis can take up to two weeks and should be factored into the project schedule. Undecomposed organic material, such as pine needles or other woody debris, should be completely raked off and stored separately for reuse as surface mulch.

Implementation Guidelines

Topsoil Removal

Once a qualified individual[1] has identified the extent and depth of topsoil to be salvaged (and the surface debris/mulch has been removed), the topsoil material should be removed using appropriate equipment. Equipment can include backhoe, excavator, loader, skid-steer, or other bucket-equipped machine. A dozer-type machine with a flat blade can remove topsoil if operated by an experienced operator. However, that type of removal technique tends to mix topsoil with subsoil, compromising topsoil quality and subsequent restoration success. The depth of the topsoil layer can vary greatly depending on a number of site-specific factors, but will rarely exceed 4-6 inches in alpine environments.

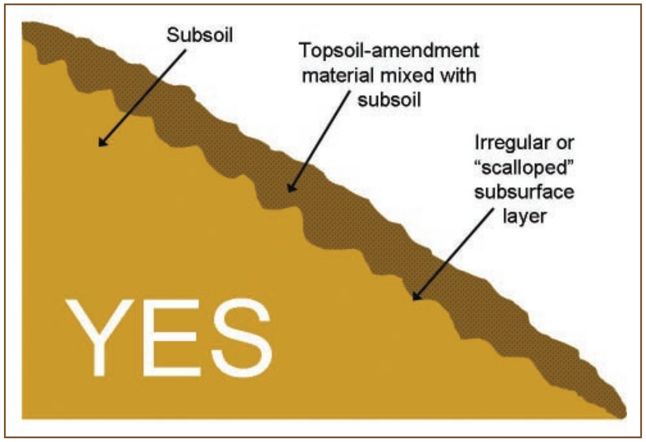
Topsoil Storage and Protection

Once topsoil has been removed, it should be stored on site with a minimum of handling. Stockpiled topsoil should not be piled or compacted in a manner that significantly alters its inherent density, water-holding capacity, or infiltration. For example, if a loader is used to pile and store topsoil, that equipment should under no circumstances drive onto the pile, which would compact the topsoil and compromise its quality. Topsoil should be stockpiled in an area where it will not be exposed to direct sunlight, as this may reduce soil moisture and biological activity. Topsoil piles should always be covered to maintain adequate soil moisture and to prevent saturation during rainstorms or from snowmelt. Topsoil should be stockpiled for as short a period of time as possible. Storage periods of over three months have been

Topsoil Salvage Plan Checklist

- ✓ Soil sample collection and analysis
- ✓ Extent and depth of topsoil to be salvaged
- ✓ Method(s) to remove topsoil
- ✓ Appropriate on-site staging areas
- ✓ Measures to protect topsoil during storage

TOOLKIT



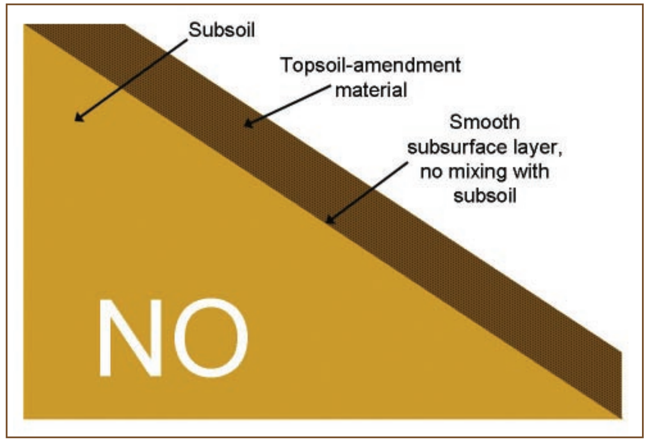


Figure 7.1: Topsoil amendment applied and mixed with subsoil, creating a "scalloped" subsurface layer (left). Typical topsoil-amendment application without mixing with subsoil (right).

shown to be detrimental to soil organic matter quality (Smith et al. 1987). Topsoil should never be compacted or used as temporary fill.

Topsoil Application

After grading and slope shaping are completed, salvaged topsoil should be re-applied to the soil surface. The appropriate depth of re-applied topsoil should be determined by taking soil samples of the salvaged topsoil, the remaining subsoil, and a reference soil and comparing the relative differences in nutrient and organic matter content (see example calculation on pages 90-91). Once applied, topsoil should be mixed with the upper 6-12 inches of subsoil (as shown in Figure 7.1) prior to the application of fertilizer, seed, and mulch, rather than simply placed on the surface of the finished slope. Additionally, topsoil should never be left on the soil surface without a functional mulch cover (see Tool 12, Mulches), as this nutrient-rich material is easily transported by wind and water and can contribute to water quality degradation.

Maintenance and Inspections

Topsoil stockpiles should be inspected for evidence of disturbance, compaction, or mixing with subsoil or other spoils materials. If covered, the covering material should be intact, weighted throughout, and secured at ground level.

Suggested Success Criteria

- Appropriate depth of topsoil is removed (as determined by qualified professional)
- Topsoil is stored in appropriate location and out of direct sunlight

NOTES

- Topsoil is not disturbed or compacted during storage
- Adequate soil moisture levels are maintained in topsoil stockpiles through covering and/or watering
- During removal and storage, topsoil is not mixed with subsoil or other spoils materials such as rock
- Quantity of salvaged topsoil applied to treatment areas achieves total organic matter and/or nutrient levels comparable to reference levels

Ultimately, the success of a project where topsoil is being salvaged and re-applied is interconnected with other treatment elements such as soil loosening, vegetation, and mulch.

Measurement Methods for Success

- Soil sampling

Management Response to Lack of Success

- Topsoil contaminated with undesirable materials may be unusable and off-site amendments my need to be imported to meet treatment goals.
- Inadequate storage or protection of topsoil piles may reduce topsoil viability, but in most cases, topsoil should still be re-applied.
- If soil nutrient levels or plant growth do not meet success criteria, additional topsoil or other soil amendments should be incorporated into the soil.

Observed or Measured Results

Removal and salvage of topsoil has proven to be a highly successful treatment element on a range of projects in the Sierra.

- Topsoil was salvaged and re-applied on steep cut-and-fill slopes along a 4-mile stretch of Highlands View Road at Northstar-at-Tahoe (see photo). No off-site soil amendments were required. One year following slope treatment, the slopes contained robust native vegetation, high infiltration rates, and minimal erosion potential. Also worth noting: the wood chips used as surface mulch on this project were generated from on-site chipping of trees removed along the road alignment.
- Topsoil was salvaged and re-applied during the construction of Sierra College's new campus in Truckee, CA. More than 10,000 cubic yards of topsoil were salvaged from this forested site, which more than met the soil amendment needs of this large development project.

Highlands View Road at Northstar-at-Tahoe, one year following treatment. Topsoil was salvaged and re-applied along 4 miles of cut-and-fill slopes.

TOOLKIT

Example Calculation: How Much Topsoil Should I Re-Apply?

The amount of topsoil that should be re-applied depends on three main factors:

- Nutrient and organic matter (OM) content in nearby reference soil
- Nutrient and OM content in subsoil following grading/shaping
- Nutrient and OM content of salvaged topsoil

While there are many soil chemical, physical, and biological elements to consider, soil OM is the driving force behind long-term plant growth and nutrient supply. For simplicity, soil OM is recommended as the main soil element to be considered in topsoil and amendment calculations.

For example, soil samples were collected from the top 12 inches of soil in an adjacent native reference area, from the treatment area following grading, and from the salvaged topsoil, then sent to a lab for analysis. Lab results reported the following soil OM levels: 8% for the reference soil, 4% for the subsoil in the treatment area, and 16% for the salvaged topsoil.

Scenario 1

The revegetation manager wondered if incorporating 2 inches of topsoil would increase the total soil OM to the target of 8%, as determined by the soil samples from an adjacent undisturbed reference site. Assuming a tilling depth of 12 inches, the revegetation manager performed the volumetric calculations in Table 7.1. His calculations indicated that 2 inches of topsoil would not provide enough OM to achieve the target of 8% OM (See Figure 7.2) that would be adequate to support robust, long-term plant growth. The revegetation manager was committed to achieving success the first time to avoid ongoing re-treatment and maintenance issues, so he adjusted his calculations for 4 inches of topsoil, increased the amount of topsoil, and recalculated.

	Material Depth (inches)	% of Tilling Depth (12 inches)	OM Content	Total OM Contribution
Subsoil	10	83%	4%	3.3%
Topsoil	2	17%	16%	2.7%
			Total OM	6.0%
			Target OM	8.0%

Table 7.1: Calculations indicating inadequate amount of topsoil.

Scenario 2

His calculations confirmed that 4 inches of topsoil, when mixed with 8 inches of subsoil (total depth of 12 inches), would add enough OM to the soil at this site to reach the goal of 8% total OM (see Table 7.2) and support a healthy soil-plant system similar to that of the reference area. He then proceeded with topsoil re-application confident that the hour he had spent planning out the soil treatment was time well spent and that project goals would be met.

	Material Depth (inches)	% of Tilling Depth (12 inches)	OM Content	Total OM Contribution
Subsoil	8	67%	4%	2.7%
Topsoil	4	33%	16%	5.3%
			Total OM	**8.0%**
			Target OM	8.0%

Table 7.2: Calculations indicating adequate amount of topsoil.

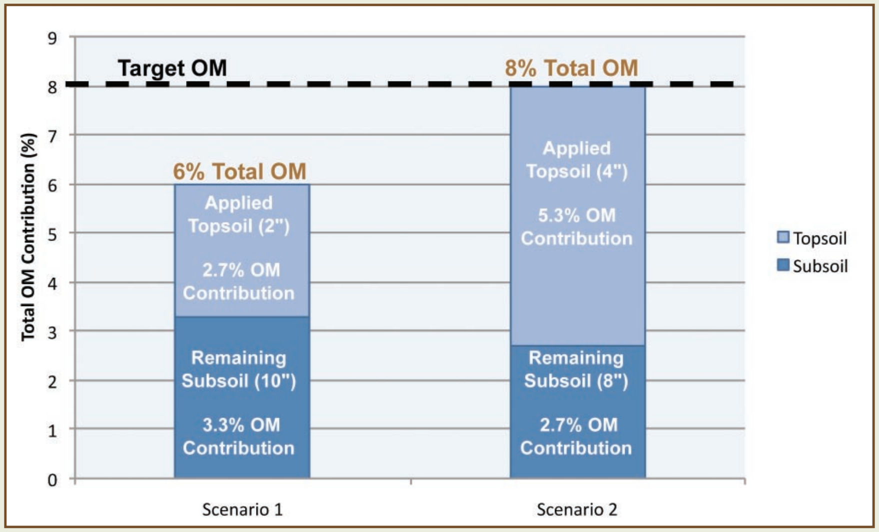


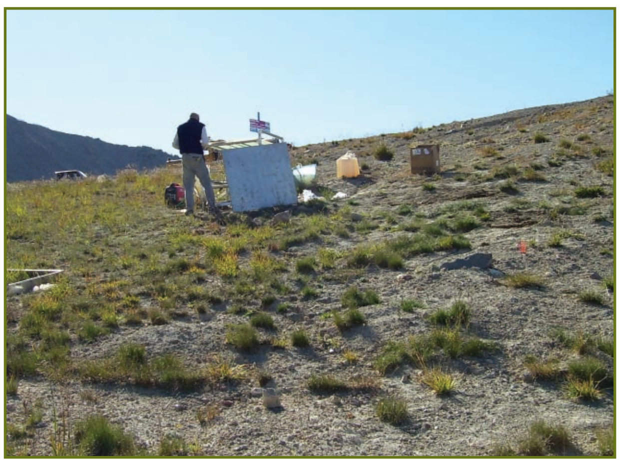
Figure 7.2: Graph showing OM contributions of different amounts of topsoil and resulting in total soil OM compared to target soil OM.

TOOLKIT

Case Study: Topsoil Buried During Ski Run Construction

While conducting an erosion assessment at a Sierra ski resort, a gully revealed an unusually dark soil layer buried beneath lighter-colored nutrient-poor soil (see photo, right). Further investigation confirmed that the topsoil layer had been buried during construction of the ski run. This is a common occurrence at ski resorts, since topsoil is seldom removed prior to grading. Soil testing indicated that the buried topsoil contained an organic matter content that was four times higher than the surface soil (which was actually subsoil). Rainfall simulation measured sediment concentrations in runoff that were nine times higher from this ski run, as compared to the adjacent native area, where natural topsoil was present. The resort's revegetation manager has already made several unsuccessful attempts at establishing vegetation and reducing erosion on this ski run with surface applications of seed and fertilizer (see photo, below left). Since the opportunity to salvage the buried topsoil has long since passed, sustainable/successful sediment source control on this ski run will likely require importing a large amount of compost or other soil amendments, applying soil loosening treatments, reseeding, and mulching.

Buried topsoil layer revealed by gully on Sierra ski run.



Conducting rainfall simulation to measure erosion on ski run after repeated attempts at revegetation by applying surface treatments.

Topsoil Endnote

[1] Any person responsible for identifying topsoil and interpreting soil analysis results should have at least 5 years of experience with soil science, soil morphology, and applied restoration with the specific type(s) of soils in question. Professional organizations such as the Society for Ecological Restoration International (SERi) or their California Chapter (SERCAL) can provide you with recommendations of soil scientists and restoration specialists in your project area.

"Now I know a refuge never grows
from a chin in a hand in a thoughtful pose,
gotta tend the earth if you want a rose."
– Emily Saliers (Indigo Girls)

Tool 8 - SOIL PHYSICAL TREATMENT

A low-density soil, such as this one, shows how roots can easily penetrate to access nutrients and water deeper in the soil profile. The darker color in the upper 25 cm indicates a high level of organic matter, which also supports a robust microbial community. Healthy soils such as this one can hold up to 40% water, thus reducing or eliminating runoff. Photo courtesy of NRCS from the Soil Survey of the Tahoe Basin, 2007.

Definition

Soil physical treatment includes a variety of methods used to break up or loosen high-density soils which have been compacted or otherwise disturbed.

Purpose

Compaction, or high soil density, is one of the main limiting factors for a large range of soil functions. Root penetration, water infiltration, runoff, oxygen exchange, microbial activity, and nutrient cycling are all affected by soil density/compaction. Soil physical structure, including soil density, affects all aspects of the terrestrial ecosystem including water movement into or across soil, plant establishment and growth, water storage, and nutrient movement. Drastically disturbed sites such as road cuts, ski runs, abandoned dirt roads, and construction sites often exhibit high levels of compaction and high-density soils. For example, road cuts in the Sierra Nevada typically expose an extremely dense subsoil layer.

Soil physical treatment is used to de-compact the soil to allow increased infiltration, root penetration, gas exchange, microbial activity, and water storage. When combined with the application of organic-matter-rich soil amendments such as compost or aged wood chips, soil physical treatment can also improve the "sponge effect" of soil by significantly increasing the soil's ability to infiltrate and store water over long periods of time. This type of soil physical treatment has also been shown to increase microbial activity and root penetration within the soil.

A range of mechanical methods can be used to loosen soil, including tilling, ripping, infiltration tines, and augering/drilling. The determination of which method to use depends on the treatment goal for the site, accessibility, and available equipment. For example, infiltration tines or augering may be the most practical option on very steep, inaccessible, and/or unstable slopes, where a major disruption of the soil strength may result in a mass soil movement. If a healthy, well-vegetated soil has been compacted, ripping or infiltration tines may be the best option, as these techniques can de-compact soil without turning soil over and may minimize disturbance to existing vegetation. Tilling tends to be an extremely effective method for incorporating soil amendments to a specific depth. Table 8.1 on the next page provides a more detailed comparison of soil physical treatment types.

Table 8.1: Soil Physical Treatment Alternatives Matrix

Treatment Type	Definition	Advantages	Disadvantages	Photos
Machine Tilling	Soil loosening using the bucket of a backhoe or excavator	• Can be extremely cost-effective for larger projects • Mixes amendments into the soil • Most consistent break-up of dense soil • Can be used to scallop or roughen sub-surface to minimize mass soil movement	• May destabilize very steep slopes if vegetation is not established quickly or if subsurface is not roughened/scalloped • Access to some sites can be difficult	
Ripping/ Subsoiling	Using ripper shanks with or without subsoil teeth to penetrate, de-compact, and loosen soil without inverting it	• Can be relatively fast to implement • Can be efficient for large areas • Can be used to loosen dense soil with minimal vegetation disturbance	• Does not always mix soil as completely as tilling • Steeper slopes may require a winch	
Infiltration Tines	Using ripper shanks or other tines, typically mounted on an excavator or backhoe bucket, to break up dense soil without inverting it	• Can be highly effective in rocky soil • Loosens soil on steep slopes with minimal impact on slope stability and soil strength • Can loosen soil without disturbing existing vegetation • Can be quicker than other mechanical methods	• Tines typically require custom fabrication	
Hand Tilling	Tilling soil using hand tools such as pulaskis or pick mattocks to loosen and mix dense soil	• Can be used around plant roots • Can be used where machines are not available or where access is limited	• Tilling depth limited to how deep tools can penetrate (~6 inches) and enthusiasm of hand crew • Can be impractical for larger projects	
Augering/ Drilling	Drilling channels though extremely dense substrate using hammer drill or equivalent tool	• Can increase infiltration and root penetration in areas with extremely dense soil or shallow bedrock • Can be implemented without destabilizing extremely steep slopes	• Does not directly contribute to soil health • Can be difficult for plants to establish under gravel or rocks • Commonly displaced by vehicles • Unwashed gravel may present storm water quality issues	
Rototilling	Turning over the soil using a rotary tine attachment on either a hand-operated machine or a tractor	• Requires minimal expertise and common equipment	• Limited usefulness in mountainous areas due to rocky nature of soils • Tilling depth typically limited to 4-6 inches • Can be dangerous and/or difficult to operate on side slopes and rocky ground	

TOOLKIT

Appropriate Uses and Applications

Soil physical treatment can be used wherever soil density is high enough to limit plant growth and infiltration. The cost effectiveness of implementation will depend heavily on the experience and care of the equipment operator. The best way to determine whether the soil is artificially dense is to measure density on a nearby native or highly functional site as a reference (see below) using a cone penetrometer. If site soil density is 20% higher than the native site (or greater), root penetration, infiltration, nutrient exchange, and microbial activity have been shown to be adversely affected. In this case, it is advisable to loosen the soil through soil physical treatment. See Tool 16, Monitoring, for guidance on measuring soil density. Note that soils with low organic matter content will usually re-compact within one or two seasons unless an organic amendment is incorporated to reinvigorate soil nutrient cycling and plant growth.

Scheduling Considerations

In a revegetation or erosion control project, soil physical treatments should be implemented after completion of grading and slope shaping and application of soil amendments. Fertilizer, seed, and mulch should be applied after soil physical treatment.

Table 8.2: Site Suitability Matrix

	Machine Tilling	Ripping/ Subsoiling	Infiltration Tines	Hand Tilling	Augering/ Drilling	Machine Tilling
Steep slopes	X		X		X	
Ski runs	X					
Road decommissioning	X	X	X			
Road cut and fill slopes	X					
Shallow bedrock			X		X	
Well-vegetated areas		X	X	X		
Landscaping				X		X
Tree root zones			X	X		

Site Suitability

Selecting the most appropriate soil physical treatment methods depends on treatment goals, site conditions, and available equipment. Using the appropriate size and type of equipment generally saves time and money. The Site Suitability Matrix, Table 8.2, provides some general guidelines for selecting treatment methods for different site conditions and project types.

Protect Treatment Areas From Re-Compaction

Areas where soil has been loosened are extremely sensitive to re-disturbance/re-compaction. Once loosened, treatment areas should be vigilantly protected from further vehicle, equipment, and foot traffic. Protection can include perimeter blockage, site blockage (rocks, logs, high surface relief), and, in areas where traffic will continue, development of a designated road or trail so that users stay off the treated areas. See Tool 15, Protecting Treatment Areas, for more information.

Implementation Guidelines

Specific implementation guidelines for each type of soil physical treatment are listed below.

Suggested Success Criteria

- Low soil density (loosened soil) to specified depth (e.g. resistance to force no greater than 200 psi to a depth of 12 inches, using a cone penetrometer with psi gauge)
- Infiltration rate equal to or greater than native or high-function reference site
- High surface roughness (e.g. 4-8 inches of relief over a 24-inch distance)
- High subsurface roughness (e.g. penetrometer depth varies 4-8 inches over a 24-inch distance)

Measurement Methods for Success

- **Soil density**: cone penetrometer with psi gauge
- **Infiltration**: many infiltration measurement devices available (see Tool 16, Monitoring, for more information).
- **Surface roughness**: measurement using straightedge or estimate
- **Subsurface roughness**: use cone penetrometer or rod to assess irregularity beneath surface

Management Response to Lack of Success

- Re-loosen soil to adequate (or specified) depth
- Add organic matter if soil tests indicate lack of adequate nutrients and organic matter

Maintenance and Inspections

- Check treatment areas regularly for evidence of re-disturbance/re-compaction
- Recently loosened soil is extremely sensitive to redisturbance and easily compacted by vehicle, foot, hoof, and paw traffic
- Measure soil organic matter by soil testing if organic matter is in question. If adequate soil organic matter is present in the loosened soil—either naturally or from amendment additions—the soil will be more resilient following disturbance

Observed or Measured Results

- Increase in infiltration and thus reduction in runoff. In some cases, soil physical treatment has produced measured infiltration rates greater than 4 inches per hour
- Decrease in sediment yield (largely due to reduction in runoff)

How Deep Should Soil Be Loosened?

Soil loosening depth should be determined based on depth of compaction and plant needs. Some shrub species, for instance, may need as much as 3–5 feet of loosened soil to access adequate nutrients and water. In general, 12 inches should be considered a minimum depth of loosening. 12–18 inches can easily be loosened in most situations with a backhoe or excavator. Deeper loosening may not always be practical.

What effects does loosening have on soil hydrology? Many compacted soils exhibit as low as 5% pore space. That pore space may be able to hold approximately 16,300 gallons in the top 12 inches of soil. A site that has been tilled to 12 inches may hold up to 65,200 gallons, an increase of 400 percent. Calculations suggest that for each inch of loosening, the soil will be able to hold an additional 0.25 gallons of water per square foot, or almost 11,000 gallons per acre. Note that this water is infiltrating and/or being stored in the soil for plant growth and not running off on the soil surface, carrying sediment into nearby streams.

- Increase in water holding capacity and thus reduction in the need for irrigation
- Increase in organic matter content and nutrient cycling, if combined with organic matter application
- Increase in oxygen exchange through the soil, which is a key element of both microbial activity and disease suppression
- Increased soil respiration (difficult to measure—see Figure 8.1 below)

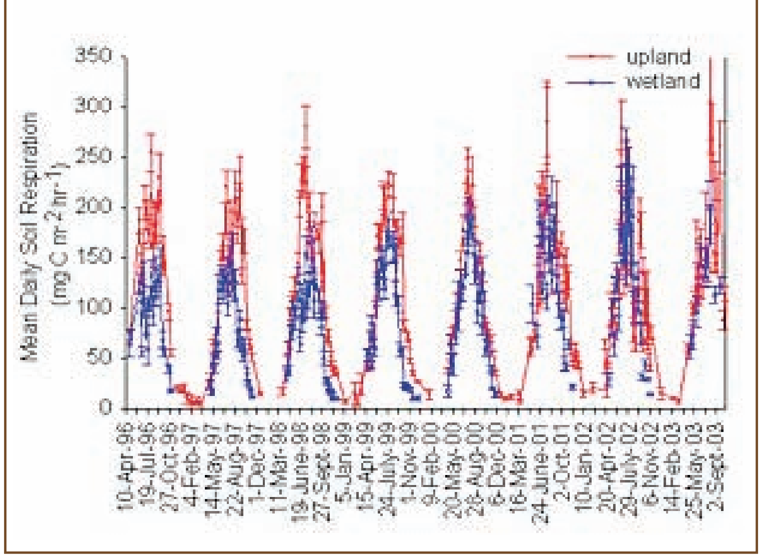


Figure 8.1: This soil respiration graph from Howland Forest shows how soil actually "breathes." The graph shows CO2/respiration measurements over eight years. The peaks are summer maximums. Of special interest is the fact that uplands respire at a higher rate than wetlands, indicating the importance of upland soils for nutrient cycling and general microbial activity. http://www.whrc.org/new_england/Howland_Forest/soil_respiration.htm

To Compact or Not to Compact—That Is the Question

Most engineers recommend that soil be compacted to provide soil strength. In areas where settling of soil is problematic, such as on a roadbed or structural foundation, this will always be the case. In other areas where vegetation, infiltration, and/or sediment source control is desired, loose soil is essential for success. One of the most cost-effective ways to provide low-density soil on a construction site is not to compact the soil in the first place. Some roadside treatments may include compaction of the structural fill, application of 12–24 inches of loose soil material and then scalloping the initial compacted structural fill so that the overlaying loose soil is less prone to sliding. This treatment will require early establishment of vegetation through irrigation on any slope angles greater than 50%. Monitoring data have shown that this type of integrated soil and vegetation treatment can provide rapid plant growth and high levels of infiltration and site stablility/ sediment source control when compared to most other treatment types.

Loosening Depth and Amendment Concentration

When treating disturbed soils it is critical to achieve an adequate concentration of amendments in the upper 12-18 inches of soil in order to establish and sustain high infiltration rates and robust vegetation. Additionally, deeper loosening can encourage deeper root penetration and can increase the drought tolerance of many plant species. At sites with high soil density and low water availability for plants, one option is to loosen soil to a depth of 24-36 inches to promote deep root penetration, then incorporate amendments into the top 12-18 inches to achieve the desired amendment concentration. Soil testing should be used to determine the most appropriate type and concentration of amendments for soil nutrient conditions at each site.

What Does It Cost to Achieve the Goal?

Soil physical treatment is often considered to be expensive or more costly than typical surface treatments, such as hydroseeding. When planning a project, one needs to clearly identify goals and desired outcomes. The treatment alternatives should be designed to achieve those outcomes. Therefore, if a site is highly compacted, which is the case for most road cuts and fills, many ski runs, and dirt roads, it is unlikely or impossible for a surface treatment to adequately address the site limiting factors that exist (especially compaction). Furthermore, if a site is severely nutrient limited, hydroseeding or other simple fertilizer applications are unlikely to replenish the nutrients needed to create a self-sustaining nutrient regime that can support robust vegetation over time.

NOTES

Soil Physical Treatment: Machine Tilling

Constructing test plots on ski run at Heavenly Mountain Resort

Definition

Soil loosening using the bucket of a backhoe or excavator.

Site Suitability

- Highly or moderately compacted sites
- Wide slope range (0-50% no irrigation, 50-100% with irrigation)
- Road decommissioning
- Ski runs
- Road cut and fill slopes

Advantages

- Can be extremely cost-effective for larger projects
- Mixes amendments into the soil
- Most consistent break-up of dense soil
- Should be used to scallop or roughen sub-surface to minimize mass soil movement

Disadvantages

- May destabilize very steep slopes if vegetation is not established quickly or if subsurface is not roughened/scalloped
- Access to some sites can be difficult

Implementation Guidelines

- Spread soil amendments on top of soil first
- Loosen soil to desired depth (minimum 12 inches)
- Till soil in a manner that achieves high subsurface roughness, leaving the subsoil "scalloped" (as shown in Figure 8.2). High subsurface roughness decreases the chance of slumping or slope failures by anchoring" loosened soil and amendments until plant roots are established well enough to provide adequate soil strength.
- If incorporating soil amendments, consider first tilling soil deeply (24+ inches), then applying amendments and incorporating into top 12 inches of soil. This method encourages deep root penetration and infiltration as well as adequate amendment concentration near the surface.
- Leave the soil surface rough. Do not smooth soil surface following loosening.
- Tilling often brings rocks to the soil surface. However, skilled operators can roll rocks into nearby depressions or pat them down into loosened soil to ensure that the finished surface does not exceed the maximum relief required for grooming.

Observed or Measured Results

- Shown to reduce erosion and increase infiltration by as much as several orders of magnitude when used in combination with soil amendment and vegetation treatments.
- **Northstar Bearpaw tilling depth test plots:** no sediment production at 6-inch or 18-inch tilling depth; 100% infiltration during simulated rain event of 4.7 in/hr.

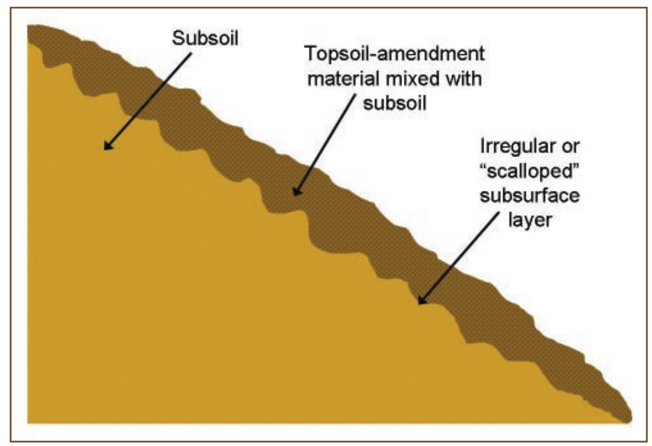


Figure 8.2: Topsoil-amendment material applied and mixed with subsoil during tilling, creating a roughened or "scalloped" subsurface layer.

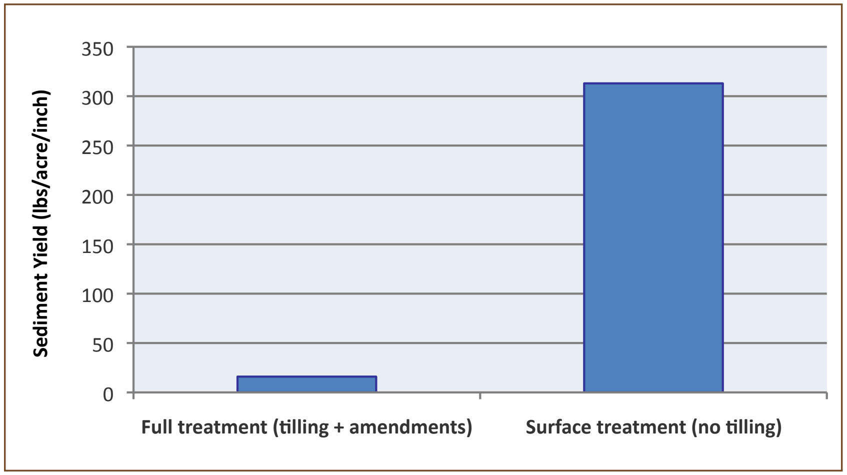


Figure 8.3: Heavenly Gunbarrel test plots. Sediment yield was 20 times higher at the "surface treatment" plot (313 lbs/acre/in) than at a "full treatment" plot (16 lbs/acre/in). "Full treatment" included 4 inches of wood chips tilled to a depth of 18 inches, 2,000 lbs/acre Biosol fertilizer, upland seed mix, and 2 inches of pine needle mulch. Surface treatment included application of fertilizer, seed, and straw mulch at unknown rates with no tilling (no treatment documentation).

Cost Considerations

Tilling time depends on a number of factors, including equipment size, operator experience, desired finished relief, presence of rocks, slope angle, configuration of treatment area (large and contiguous, tight and patchy), slope reshaping/re-contouring, etc. However, depth of tilling does not tend to significantly affect treatment cost. A comparison of different tilling depths at Northstar-at-Tahoe found that there was no significant difference in implementation time or cost between 6-inch, 12-inch, and 18-inch tilling depths. In fact, with larger equipment, it is often difficult to till to less than 18 inches.

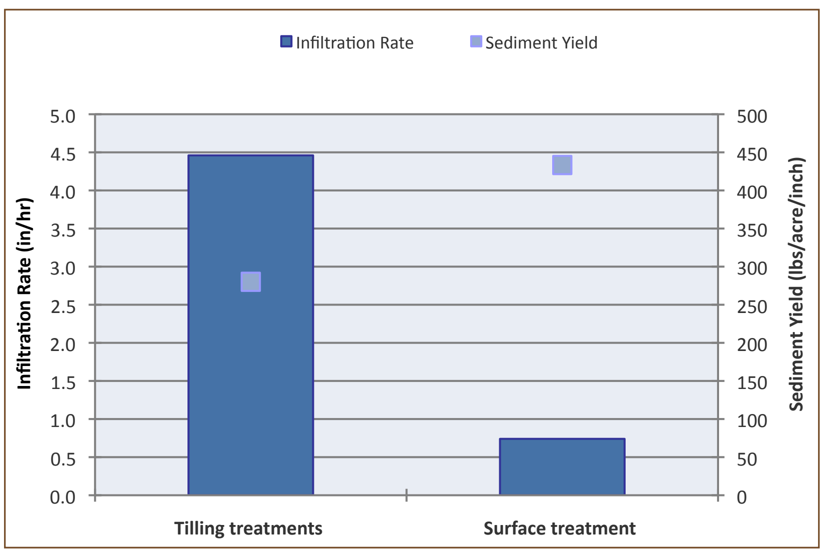


Figure 8.4: Mammoth Mountain Stump Alley test plots. Tilling treatments with incorporated amendments exhibited infiltration rates more than 5 times greater than the adjacent surface treatment. On average, sediment yield from the tilled test plots was 1.4 times lower than the surface treatment plots—280 lbs/acre/inch compared to 433 lbs/acre/inch.

TOOLKIT

Soil Physical Treatment: Ripping/Subsoiling

Tractor-mounted subsoiler being used to mix amendments into soil.

Definition

Using ripper shanks with or without subsoil teeth to penetrate, de-compact, and loosen soil without inverting it.

Site Suitability

- Road decommissioning
- Well-vegetated areas

Advantages

- Can be relatively fast to implement
- Can be efficient for large areas
- Can be used to loosen dense soil with minimal vegetation disturbance

Disadvantages

- Does not always mix soil as completely as tilling
- Steeper slopes may require a winch

Implementation Guidelines

- Ripping should be conducted so that a first pass in one direction is followed by a second pass perpendicular to the direction of the first pass. This is called cross-ripping. Ripping along a single axis often does not adequately incorporate amendments and can create linear surface and subsurface channels that can concentrate water flow.

Observed or Measured Results

Ripping vs. Tilling – These methods have been tested side by side at two different sites with inconsistent results. At the Meyers Airport test plots, deeper penetrometer depths (used as an index of soil density) were measured in the tilled plots compared to the ripped plots. At the Truckee Bypass test plots, there was no measurable difference in penetrometer depths between tilling and ripping.

NOTES

Soil Physical Treatment: Infiltration Tines

Infiltration tines mounted on excavator bucket being used to loosen soil and incorporate wood chips.

Definition

Using ripper shanks or other type of shanks or tines to break up dense soil without inverting it.

Site Suitability

- Steep slopes
- Road decommissioning
- Shallow bedrock
- Well-vegetated areas
- Tree root zones

Advantages

- Can be highly effective in rocky soil
- Loosens soil on steep slopes with minimal impact on slope stability and soil strength (if done properly)
- Can loosen soil without disturbing existing vegetation

Disadvantages

- Tines typically require custom fabrication

Implementation Guidelines

- Spread soil amendments on top of soil first
- Use tines and bucket for targeted loosening of dense soil areas
- Tines should be robust, made from high-carbon or tungsten steel, and should be spaced far enough apart so that they do not exert more break-out force resistance than the machine can handle.

Observed or Measured Results

Infiltration tines have been used effectively to loosen dense soil while controlling the amount of amendment mixing such that a higher concentration of amendments are left near the surface, thus mimicking organic matter stratification in native soils. Tines have also been used on extremely steep slopes where targeted loosening increases infiltration without completely destabilizing the hillslope.

NOTES

Soil Physical Treatment: Hand Tilling

Loosening soil by hand using pick mattocks.

Definition

Tilling soil using hand tools such as pulaskis or pick mattocks to loosen and mix dense soil.

Site Suitability

- Tree root zones
- Well-vegetated areas
- Landscaping

Advantages

- Can be used around tree/plant roots
- Can be used where machines are not available or where access is limited

Disadvantages

- Tilling depth limited to how deep tools can penetrate (typically 6 inches or less) and enthusiasm of hand crew
- Can be impractical for larger projects
- Time-consuming and generally not cost-effective compared to machine tilling

Implementation Guidelines

- Safety is primary consideration. Spread people out and create clear work spaces.
- Pointed end of a pick mattock is used to loosen soil, followed by more complete break-up and mixing using blade portion.
- Use momentum of tool to do the bulk of the work. Don't force the tool.
- Wear steel-toed boots.

Observed or Measured Results

Generally, hand tilling is not adequate to loosen soil deeply enough on highly compacted sites. Hand tilling was used in early test plot development at several Tahoe Basin sites (Dollar Hill, Brockway). Ultimately, soil physical conditions at those sites did not allow for adequate rooting depth to sustain native grasses and shrubs, and the plant communities are now dominated by non-native, invasive species such as cheatgrass.

There have been examples where hand crews have been able to loosen large areas of compacted soil to 12+ inches. However, the time and labor resources required to accomplish this on a large scale make hand-tilling cost-prohibitive on most projects.

Soil Physical Treatment: Augering/Drilling

Drilling holes using hammer drill to increase infiltration on extremely dense cut slope in Squaw Valley.

Definition

Drilling holes through extremely dense substrate and/or on very steep slopes using a hammer drill or equivalent tool.

Site Suitability

- Steep slopes
- Areas with shallow bedrock or other shallow impeding layer

Advantages

- Can increase infiltration and root penetration in areas with extremely dense soil or shallow bedrock
- Can be implemented without destabilizing extremely steep slopes

Disadvantages

- Drilling on steep slopes typically requires extensive safety measures
- Can be time-consuming and impractical for larger projects

Implementation Guidelines

- Drilling angle at 30 degrees of perpendicular, downward, to encourage water and root movement
- Holes at 12 to 24 inch centers, depending on bit size
- Drill holes to at least 12 inches deep
- Clear bit (remove during drilling operation) often to avoid burying in soil

Observed or Measured Results

Case Study: Painted Rock Slope Stabilization Project in Squaw Valley, California

This slope had previously failed, due to a mass failure or landslide. An erosion control contractor had applied the standard engineering approach, which included straw wattles, erosion control fabric covering of the slope, and application of fertilizer and seed. Subsequently, the slope failed again underneath the fabric (Image 1). Site assessment indicated that the soil density was high and soil nutrients were low. Therefore, to increase infiltration and soil nutrients without compromising slope stability, a drilling/augering treatment was applied using a hammer drill at a hole density of approximately 36 inches on center (Image 2). After drilling, wooden stakes were inserted into drilled holes, 2 inches of compost was applied, and the slope was drilled again at a hole density of 12 inches on center (Image 3). This treatment loosened the soil and allowed for compost to be incorporated into the drilled holes as the drill was removed. Pick mattocks were used to lightly incorporate the remaining compost into the top 2 inches of soil to minimize the potential for mass failure. Seed, fertilizer, and pine needle mulch were each applied separately and the slope was tackified to hold the mulch in place. A low-flow/long-duration irrigation regime was used to encourage rapid vegetation establishment and deep root penetration, which helped to further stabilize the slope (Image 4). As Images 5 and 6 show, grasses and shrubs were established during the first season and increased in the following year with no additional irrigation. This slope withstood the extensive flooding events of December 2005 without damage.

TOOLKIT

1– Project site with failing BMPs in 2002, before treatment.

2– Drilling holes in slope with hammer drill.

3– Wooden stakes were hammered into slope to increase infiltration and provide anchors to hold compost in place.

4– Irrigation was used to encourage rapid plant establishment and deep root penetration.

5– Project site one month after completion of treatment.

6– Project site one year after treatment.

Soil Physical Treatment: Rototilling

Loosening soil with hand-operated rototiller.

Definition

Turning over the soil using a rotary tine attachment on either a hand-operated machine or a tractor.

Site Suitability

- Landscaping
- Flat, rock-free sites with minimal, surface-only 0–4 inches of compaction

Advantages

- Requires minimal expertise and common equipment

Disadvantages

- Limited usefulness in mountainous areas due to rocky nature of soils
- Tilling depth typically limited to 4–6 inches
- Not useful on slope gradients over 10%
- Can be dangerous and/or physically taxing due to "kickback" tendency on rocky and compacted soils
- May not be able to penetrate highly compacted areas

Implementation Guidelines

- Rocky areas should be avoided, as kickback can be dangerous
- Till across slopes rather than up and down

Observed or Measured Results

While useful for gardening and small-scale landscaping, rototillers are not capable of loosening soil to depths necessary to achieve effective sediment source control on most disturbed sites.

NOTES

TOOLKIT

Tool 9 - SOIL AMENDMENTS

Wood shreds and compost are two types of organic materials that can be used as soil amendments.

Definition

A *soil amendment* is a material that is used to change or enhance soil physical, chemical, or biological properties, such as nutrient availability, pH, water infiltration, permeability, water retention, drainage, aeration, and structure.

Purpose

Soil amendments are used to improve soil physical, chemical, or biological properties. Each amendment has a specific use. Compost is primarily used to replace organic matter lost in topsoil removal or burial. Wood chips are primarily used to increase infiltration and lower soil density. Some aged wood chips mimic compost and can be a cost-effective method to replace lost organic matter. Lime is often used to alter soil pH. Generally, for disturbed areas such as graded ski runs, road cut/fill slopes, and areas associated with construction, high-carbon organic materials (amendments) are used to enhance soil functions lost during construction. Such amendments include manure, compost, and/or wood byproducts such as fresh or aged wood chips or tub-ground wood chips.

Organic Amendments vs. Topsoil

Organic amendments are often used to restore topsoil, nutrient levels, and/or soil infiltration capacity that is altered during grading activities. Actual topsoil takes many years to develop and contains types and amounts of organic matter and microbes that cannot be mimicked in compost. Actual topsoil also contains a large seed bank and diverse microbial community which cannot be directly replaced by compost or other organic amendments. Thus, topsoil salvage is one of the most important actions that can be taken on a construction project to minimize or eliminate the need for additional soil amendments. See Tool 7, Topsoil Salvage and Reuse, for more information.

Table 9.1: Soil Amendments Alternatives Matrix

Amendment Type	Definition	Indicators for Use	Advantages	Disadvantages
Compost	Material derived from the breakdown of organic matter that has the unique ability to improve the chemical, physical, and biological characteristics of soils or growing media. See compost (page 117) for a more complete description.	• Low soil organic matter and total nitrogen • Removed or buried topsoil	• Demonstrated ability to increase water infiltration, soil water holding capacity, and plant growth	• Can be expensive • Quality can be highly inconsistent from one producer to another • May not be available in all areas
Wood Chips	Generally small, uniformly shaped pieces of wood created by a standard wood chipper.	• Dense, compacted soil	• Long-lasting source of nutrients • Shown to increase infiltration and water storage • Relatively inexpensive and easy to obtain • Can be produced on site in conjunction with tree clearing/thinning	• May take several years before wood chips can contribute nutrients to support plant growth (aging can accelerate this process)
Wood Shreds	Wood shreds are unevenly shaped and sized fibrous pieces of wood that are typically produced by grinding up stumps, root wads, and other large woody debris using large wood grinding machines, such as a hammer-mill-type tub grinder. Wood shreds are also often known as tub grindings or tub-ground wood chips.	• Dense, compacted soil	• Long spear lengths help convey water through soil • Long-lasting source of nutrients • Increase infiltration and water storage • Often rich in fungi and beneficial microbes from stumps and roots • Relatively inexpensive • Can be produced on site in conjunction with tree clearing/thinning	• May take several years before wood shreds can contribute nutrients to support plant growth (aging can accelerate this process)
Organic Fertilizer	Any material that adds nutrients to the soil, usually with the intention of increasing the soil's capacity to support plant growth. See Tool 10, Fertilizers Toolkit (page 124) for additional information.	• Low-nutrient soil • Typically used in conjunction with high-carbon amendments OR used alone where nutrients are substandard but not critically low	• Easily applied • Relatively inexpensive • Known amount of N,P,K • Longer lasting than mineral fertilizers • Less prone to leaching than mineral fertilizers	• Cannot replace large bank of nitrogen in soils • Some may contain waste by-products or concentrated metals (manures, etc.)
Mycorrhizal Inoculant	Mycorrhizal inoculant is intended to re-introduce a type of fungi into the soil that is an important element for growth in many types of plants.	• Used in nursery stock and outplantings; not recommended for general inoculation since fungi will recolonize naturally if soil edaphic factors are maximized.	• Can increase survival rates of seedlings and outplantings • Inexpensive to purchase • Can be collected from native areas	• Questionable long-term benefits (see Literature Review) • Can reduce growth of plants in soils with adequate or high phosphorous • May introduce non-indigenous strains of fungi into soil community

Table 9.1: Soil Amendments Alternatives Matrix (continued)

Amendment Type	Definition	Indicators for Use	Advantages	Disadvantages
Soil Conditioners	The term *soil conditioners* refers to a broad category of manufactured products aimed at enhancing soil physical and chemical properties. Soil conditioners are commonly used in agriculture and gardening. Common soil conditioners include lime, gypsum, humates, peat, manure, fertilizers, compost, and crop residues. Soil conditioners vary greatly in their composition, application rate, and expected or claimed performance. With the diversity of soil conditioners on the market today, it is important to understand the nature, use, and practical benefits of these products. *For more information on soil conditioners:* *http://attra.ncat.org/attra-pub/PDF/altsoil.pdf* *www.oznet.ksu.edu/library/CRPSL2/ncr295.pdf*	Specific to each conditioner	• Can improve soil conditions if used appropriately	• Can be a source of pollution or toxicity if used excessively or improperly • Most are not appropriate for non-agricultural applications
Seaweed Products	Seaweed products are added to a soil or compost pile to increase nitrogen and other minerals. For more information on seaweed products, see: *http://attra.ncat.org/attra-pub/PDF/altsoil.pdf*	• Rarely appropriate for non-agricultural applications	• Available at most nurseries and garden supply stores	• Seaweed products may contain salts that can be harmful to plant growth
Humates	Humates or "humic acids" are intended to mimic the "active" part of soil humus. *For more information on humates, see:* *http://www.humate.info/* *http://attra.ncat.org/attra-pub/PDF/altsoil.pdf* *http://www.teravita.com/Humates/Chapter6.htm*	• Low levels of humus in soil	• Widely available at nurseries and garden supply stores	• The sheer volume of organic matter in moderately rich soils suggests that affordable applications of humates may not produce significant, long-term improvements in drastically disturbed soils

Appropriate Uses and Applications

Soil amendments are widely used and recommended for any number of situations where soil has been disturbed or is lacking certain physical, chemical, or biological properties. Soil assessment is critical prior to application of amendment material. Assessment is used to determine the condition of the soil at a particular site and which amendments should be added to improve specific soil conditions (refer to Table 9.1, Soil Amendments Alternatives Matrix).

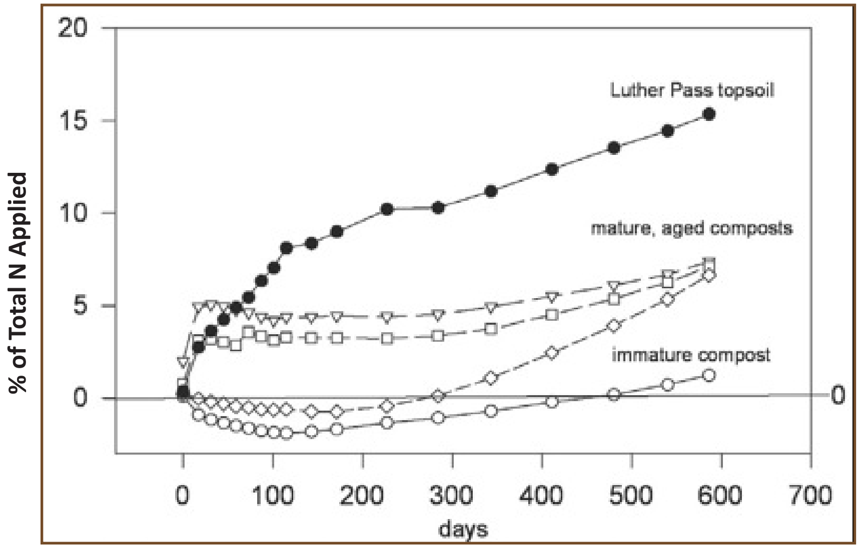


Figure 9.1: shows the differences in compost nitrogen (N) release over time. This chart indicates the importance of matching the appropriate compost or soil amendment to a specific site condition. For instance, immature compost actually removed or "locked up" nitrogen, and thus would tend to reduce or eliminate plant growth, whereas mature compost releases a greater amount of N for plant growth. From Claassen and Hogan (1998).

Soil Amendments – A Capital Investment

Building a business typically requires an initial capital investment in order to generate enough revenue to sustain itself. If you were considering investing in a struggling business that needed $100,000 to get back on its feet, it would be a foolish decision to invest only $25,000 and lose that money when it goes bankrupt two years later. Had you invested $100,000, the business would likely have been successful and given you a return on your investment for long into the future.

Restoring a disturbed site is much the same. A healthy ecosystem is like a profitable business, and in a soil ecosystem, organic matter (carbon) is the capital that sustains the "business." Much of that "capital" is held in the topsoil. If topsoil is removed or buried during construction, the capital is gone and the business can no longer sustain its basic operations. To achieve the goal of sustainable sediment source control, a treatment must recapitalize the system by adding the appropriate types and quantities of amendments (organic matter/carbon) to rebuild and sustain the soil and vegetation conditions that control erosion. This is determined by soil testing. Savvy investors understand that if a capital investment is likely to develop into a growing and profitable enterprise—be it a soil or a business—it is a smart investment.

TOOLKIT

Scheduling Considerations

In a revegetation or erosion control project, soil amendments are typically spread on the soil surface following completion of grading and slope shaping. They are then incorporated into the soil using tilling or another loosening method. Nutrient-rich amendments such as compost should be incorporated as soon as possible following application because compost can be easily transported from the soil surface and become a source of water pollution.

Implementation Guidelines

- Test soil for nutrients, organic matter, and pH prior to determine soil amendment type and amount
- Match soil amendment type and amount to site-specific soil and vegetation needs
- Apply amendments on soil surface prior to soil loosening
- Incorporate amendments into soil by tilling or other soil physical treatment
- Amendments are typically mixed into the top 12 inches of soil, with the greatest concentration near the surface
- Nutrient-rich amendments, such as compost, should always be mixed into the soil, rather than left on the soil surface where they can be easily mobilized by flowing water or wind and become a source of water quality pollution

Maintenance and Inspections

Regular inspections of areas treated with soil amendments should include (at a minimum) photo point monitoring to assess the relative change in plant growth over time, soil density monitoring with a cone penetrometer, and visual inspection for erosion. These types of monitoring can be conducted quickly and can provide valuable information that is useful for assessing general site conditions. This information can also be used to inform future projects.

Suggested Success Criteria

- **Chemical (nutrient):** Soil total nitrogen and organic matter are within 10 % of nearby reference site
- **Physical:** Low soil density to specified depth (e.g. resistance to force no greater than 200 psi to a depth of 12 inches using a cone penetrometer)

Measurement Methods for Success

- **Chemical (nutrient):** Soil sampling and lab analysis. Soil analysis should, at a minimum, include total nitrogen (TKN), macronutrients, organic matter, and pH.
- **Physical:** Soil density monitoring with cone penetrometer

Management Response to Lack of Success

- **Chemical (nutrient):** Conduct soil sampling and lab analysis to determine what additional amendments may be needed to achieve success criteria
- **Physical:** Re-till (loosen) soil and add additional organic amendments if soil organic matter targets were not achieved

Observed or Measured Results

Given the broad spectrum of soil amendments and wide range of site conditions where they have been tested, it is difficult to generalize about measured results. However, incorporation of high-carbon soil amendments has been shown to reduce soil density and increase infiltration, water storage, and plant growth in most disturbed soils. Refer to the results for specific soil amendments (on the following pages) for more information.

Case Study: Soil Amendment Tests at Northstar-at-Tahoe's Lookout Mountain

Treatment test plots were constructed in 2003 on Northstar-at-Tahoe's Lookout Mountain to test several compost blends as soil amendments. Each treatment was replicated in three different test plots. On average, all treatments that included soil amendments exhibited higher vegetation cover by seeded species, higher TKN, and higher OM than plots without soil amendments. The photos on the next page (Table 9.2) were taken three years after treatment (2006). In addition to visible differences in plant cover *between* treatment types, note the high variability in plant cover *within* each treatment type. Despite being located on the same ski run within 100 feet of each other, identical treatments yielded different results. Replicated tests like this illustrate the natural variability in treatment outcomes and the value of monitoring.

Calculating Amendment Volume

As a general rule, 1 cubic yard of compost or wood chips will cover about 325 square feet of ground at a depth of 1 inch. For larger projects, plan on about 135 cubic yards of material per acre per inch of application depth desired.

NOTES

Table 9.2: Northstar-at-Tahoe treatment test plots

Control, No-Till	Control, Till	2" Fine Compost + Fertilizer	2" Northstar Compost + Fertilizer	6" Coarse Compost + Fertilizer	6" Fine Compost + Fertilizer
					
					
					

Soil Amendments: Compost

Definition

The US Composting Council (USCC) defines compost as "the product resulting from the controlled biological decomposition of organic material that has been sanitized through the generation of heat and Processes to Further Reduce Pathogens (PFRP), [as defined by the US EPA Code of Federal Regulations Title 40, part 503, Appendix B, Section B] and stabilized to the point that it is beneficial to plant growth."

In general terms, compost essentially consists of materials derived from the breakdown of organic matter that have the unique ability to improve the chemical, physical, and biological characteristics of soils or growing media. However, the type of compost and breakdown process can affect project outcome and should be carefully considered, especially if construction specifications are being prepared.

Description

Compost tends to bear little resemblance to the raw material from which it originated. Other organic amendments such as aged manure, aged wood chips, and a broad range of other materials can be used in place of compost. However, it is difficult to know what effect they might have on the soil without adequate testing. Some materials may not have the desired effect and others may have a greater effect than desired (for instance, excess N or P). The use of the above definition of compost will at least allow us to use the same term for similar products.

Compost products have a wide range of physical characteristics (see photos below). Most garden compost is screened to remove woody material used in the composting process. The coarse woody material that is typically screened out and sold separately as a ground cover has also proven to be a cost-effective soil amendment for increasing infiltration and plant growth in wildland settings. Some compost suppliers are beginning to offer compost blends with different proportions of fine and coarse materials for different applications.

Fine-textured compost blend — 100% fines (<3/8")

Coarse-textured compost blend — 50% coarse overs (3/8" — 3"), 50% fines (< 3/8")

Composted coarse overs (3/8" - 3")

Site Suitability/Indicators for Use

Most disturbed soils with low organic matter and total nitrogen will benefit from incorporation of some sort of composted material. In wildland settings, fine-textured composts have been shown to encourage the establishment of weedy and undesirable plant species, especially where weed seed is present in the seed bank. For wildland applications, research indicates that coarse-textured compost blends with at least 75% coarse overs (composted woody material) tend to provide the greatest overall benefit in terms of infiltration and plant growth without encouraging establishment of weeds, due to their slow release of available nitrogen. If coarse-textured compost is not available, fine-textured compost can be combined with wood chips or tub grindings to achieve similar results.

Advantages

- Demonstrated ability to increase water infiltration, soil water holding capacity, and plant growth

Disadvantages

- Can be expensive
- Quality can be highly inconsistent from one producer to another
- May not be available in all areas

Suggested Material Specifications

- Compost should consist of at least 75% composted coarse wood overs ranging in size from 0.5 inches to 3 inches.
- Compost feedstock (raw material inputs) should consist of vegetation, wood products, and horse or cattle manure. Vegetation and wood products should be sourced locally whenever possible.
- Compost derived from treated sewage sludge (biosolids) should not be used.
- Compost should be processed so that an internal temperature of at least 57 degrees C (135 degrees F) is maintained for 15 continuous days, piles/wind rows are turned a minimum of 5 times during the composting process, and compost goes through a minimum 15-day curing period after the 15-day thermophyllic process is completed.
- Deleterious materials such as plastic, glass, metal, or rocks should not exceed 0.1 percent by weight or volume.

Observed or Measured Results

- Incorporation of compost has been shown to increase plant cover, soil OM and TKN, microbial activity, and infiltration rates.
- Compost texture (percent woody versus fine material) can affect soil and plant response to treatment. Fine-textured compost tends to result in high plant growth but can also encourage the growth of weeds when a seed source is present (see Figure 9.2 on the next page). Coarse-textured, woody compost tends to maintain lower soil density and higher infiltration rates than fine-textured compost while still increasing plant growth.
- **Northstar-at-Tahoe Lookout Mountain, long-term test plots:** Several types and textures of compost were tested. Four years after treatment, test plots amended with

Know Your Compost

Before using any compost, it is important to know what it was made from and whether application of that material is approved by the Regional Water Quality Control Board. Some municipal composts are made from sewage sludge. Even though sludge-derived compost has been approved in some agricultural and forestry settings, this material can contain large amounts of available nitrogen and potentially heavy metals and pathogens, which may present a threat to water quality.

coarse-textured compost (75% coarse overs) exhibited lower soil density than plots amended with fine-textured compost (100% fines).

- **Resort at Squaw Creek, T3 test plots:** One year after treatment, plant cover was, on average, approximately three times higher (28.5%) at plots amended with 100% composted coarse overs as compared to plots amended with wood chips (10.5%).
- **Tahoma Soil Boxes:** Fine-textured compost (75% fines) was applied at two different depths (2 inches and 6 inches) and tilled to a depth of 18 inches. Four years later, treatments with the 6-inch compost application had higher plant cover and soil TKN.
- **Truckee Bypass test plots:** Two years after treatment, plots amended with a coarse-textured compost blend (75% coarse overs) had the highest plant cover by seeded perennial species and highest soil TKN compared to plots amended with wood shreds or 100% composted coarse overs. Additionally, all amended and tilled plots infiltrated 4.7 inches of rain per hour during simulated rainfall, producing no runoff or sediment yield.

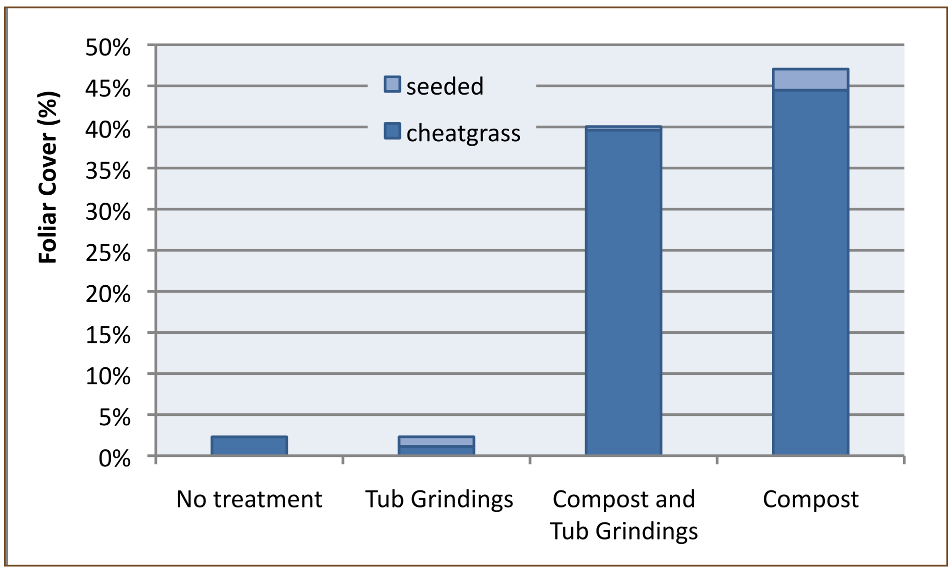


Figure 9.2: Compost is known to encourage the establishment of weedy and undesirable plant species, especially where weed seed is present in the seed bank. At Brockway Summit, cheatgrass outcompeted the native (seeded) species on all plots where a fine-textured compost blend was used as a soil amendment.

NOTES

TOOLKIT

Soil Amendments: Wood Chips

Definition

Wood chips are generally small, uniformly shaped pieces of wood created by a standard wood chipper. Wood chips are commonly generated through tree clearing, thinning, and forest fuels reduction treatments.

Site Suitability

Wood chips can be used to increase infiltration and maintain low soil density for compacted or otherwise dense soils. Since the decomposition of wood chips can limit plant growth in the short term, it can be a useful amendment for sites where weeds are present.

Advantages

- Long-lasting source of nutrients
- Shown to increase infiltration and water storage
- Relatively inexpensive and easy to obtain
- Can be produced on site in conjunction with tree clearing/thinning
- Can inhibit weed growth

Disadvantages

- May take several years before they contribute nutrients to support plant growth (aging can accelerate this process)
- First-year plant growth tends to be extremely low (however, increased plant growth has been measured and observed in subsequent years)

Suggested Material Specifications

Wood chips should:

- Be derived from clean, disease-free trees or tree stumps, not from construction or building materials, since paint, metal, and other toxic/inorganic materials can harm soil and water quality
- Be produced by a standard wood chipper and of relatively even consistency.
- Contain no more than 5% pine needles, leaves, or other non-wood-chip material
- Be aged for at least six months prior to application whenever possible. Aging for one year is preferable. Aging helps to inoculate organic acids naturally released by wood and encourage microbial growth and decomposition

Observed or Measured Results

- **Mammoth Mountain Stump Alley plots:** Tilling 4 inches of wood chips to a depth of 18 inches increased infiltration rates by six times (4.5 inches per hour) compared to an adjacent disturbed/untreated area, despite the disturbed/untreated area having higher plant cover.
- Over time (2–3 years), treatments including incorporation of wood chips have been shown to support native perennial plant cover similar to compost treatments (Heavenly Gunbarrel). The rate at which nutrients are released from wood chips varies greatly from site to site and is largely

dependent on microbial activity, perature, moisture, and other site conditions.

- Incorporation of wood chips with a high concentration of pine or fir needles (see photo right) into the soil has been shown to inhibit plant growth (Mammoth Mountain, Squaw Valley). For soil amendment applications, it is recommended that wood chips be free of needles.
- **Mammoth Mountain Little Bird plots:** Tilling with wood chips resulted in lower soil density after four years (two of three plots) compared to plots tilled with no amendments. Additionally, four years after treatment, high plant cover (44%) was observed (ocularly estimated) at plots treated with wood chips/tilling/organic fertilizer, which was four times higher than plant cover at surface treatment plots with no tilling.
- **Heavenly Gunbarrel plots:** Plant cover increased dramatically at plots with tilled-in wood chips between one year after treatment (no measurable cover) and two years after treatment (~40% by ocular estimate).

Wood chips produced from branches and slash often have a high concentration of fir needles. When used as an amendment, this material can inhibit plant growth.

Tip

Wood chips and shreds that are aged for at least one year can be far more valuable as soil amendments. Additionally, mixing biologically active compost or compost tea with wood chips before aging may help to accelerate the breakdown process and inoculate the wood chips with fungi and beneficial microorganisms.

NOTES

TOOLKIT

Soil Amendments: Wood Shreds

Definition

Wood shreds are unevenly shaped and sized fibrous pieces of wood typically produced by grinding up stumps, root wads, and other large woody debris using large wood grinding machines, such as a hammer-mill-type tub grinder. Wood shreds are also often known as tub grindings or tub-ground wood chips. Wood shreds are commonly generated through tree clearing, thinning, and forest fuels reduction treatments.

Site Suitability

Wood shreds can be used to increase infiltration and maintain low soil density for compacted or otherwise dense soils. Since the decomposition of wood shreds can limit plant growth in the short term, slow-release fertilizer can be added to support first-year plant growth.

Advantages

- Long spear lengths help convey water through soil
- Long-lasting source of nutrients
- Shown to increase infiltration and water storage
- Often rich in fungi and beneficial microbes from stumps and root wads
- Relatively inexpensive
- Can be produced on site in conjunction with tree clearing/thinning

Disadvantages

- May take several years before wood shreds contribute nutrients to support plant growth (aging can accelerate this process)

Suggested Material Specifications

Wood shreds should:

- Be derived from clean, disease-free trees or tree stumps, not from construction or building materials, since paint, metal, and other toxic/inorganic materials can harm soil and water quality
- Be produced by a machine capable of shredding large woody debris into pieces of uneven shapes and sizes (such as a hammer-mill-type tub grinder)
- Have spear lengths ranging from 2 to 10 inches with the following size classifications: no greater than 25% of material less than 2 inches in length; at least 50% of material between 2 and 8 inches in length; no greater than 25% of material greater than 8 inches in length
- Contain no more than 5% pine needles, garbage, or other non-wood-shred material
- Be aged for at least six months prior to application whenever possible. Aging for one year is preferable. Aging helps to inoculate organic acids naturally released by wood and encourage microbial growth and decomposition

Observed or Measured Results

- Incorporation of tub grindings reduces soil density and increases infiltration and water storage.
- Over time (2–3 years), treatments including incorporation of tub grindings as primary soil amendment can support

native perennial plant cover similar to compost treatments (see photo below right).

- **Brockway Summit test plots:** Two years after treatment, plots tilled with tub grindings maintained lower soil density than plots tilled with a fine-textured compost blend.
- Tub grindings and organic fertilizer were the only soil amendments used for a large-scale restoration project on a site with decomposed granite soil. Two years after treatment, high plant cover was observed and there was no evidence of erosion (see photo).

Tub grinders are used to grind stumps, root wads, and other large wood material that is too large for a chipper.

Two years after treatment with tub grindings and organic fertilizer, the site is supporting high native plant cover.

NOTES

TOOLKIT

Tool 10 - FERTILIZERS

"Results of Fertilizer" Demonstration. Tennessee Valley Authority, 1942.

Definition

A fertilizer is any material that adds nutrients to the soil, usually with the intention of increasing the soil's capacity to support plant growth.

Type and Purpose

Two main types of fertilizers exist: mineral (synthetic) and organic. Mineral fertilizers generally provide nutrients directly to plants in mineral form, which is readily available for plant uptake. Mineral fertilizers include products such as ammonium nitrate (NH_4NO_3) or other mineral (synthetic) nitrogen forms. Organic fertilizers provide nutrients in the form of organic compounds, which must be broken down by microbes and converted into mineral nutrients before the nutrients are available for plant uptake.

The difference between fertilizers and soil amendments is sometimes indistinct, in that some soil amendments provide nutrients and thus act as fertilizers by delivering nutrients to the soil. Conversely, some organic fertilizers can actually change the soil's physical structure and thus act as a soil amendment. See Tool 9, Soil Amendments, for more information.

Mineral nitrogen fertilizers are largely synthesized from atmospheric nitrogen using the energy-intensive Haber-Bosch process.[1] Other types of mineral fertilizers are derived from a number of sources including rocks, seashells, and bones. These fertilizers contain most of their nutrient load in a form that is available for immediate uptake by plants. However, plant-available minerals, especially nitrogen (N), tend to be highly mobile and thus are prone to leaching and do not tend to persist in the soil. Therefore, if mineral fertilizers are used, application rates should match expected plant uptake. Frequent and repeated applications are typically required for mineral fertilizers to be effective. An exception to this rule is slow-release fertilizer, which is designed to release nutrients slowly over time. Slow-release fertilizers vary widely in nutrient release rate, depending on how the fertilizer controls the release. Typically, the manufacturer will state the expected release rate. However, actual release rates can vary depending on temperature, moisture, and other environmental factors. For a description of slow-release fertilizers, see http://www.ext.vt.edu/departments/envirohort/articles/misc/slowrels.html.

Organic fertilizers derive some or all of their nutrient load from organic (carbon-based) sources. Organic fertilizers tend to offer a broader range of benefits to the soil because of their ability to enhance microbial activity. Some organic fertilizers are derived from industrial farming waste products such as chicken manure or blood meal. At the other end of the organic fertilizer spectrum are those that have undergone the rigorous scrutiny of organic certification programs such as CCOF (www.ccof.org) or Oregon Tilth (www.tilth.org). These products are derived from clean, non-GMO (genetically modified organisms) organic sources and must be free of specific chemical residues. Between these two extremes exist the most common organic fertilizers, such as manures, various compost-type materials, and others. Organic fertilizers typically last longer than mineral fertilizers but generally do not persist longer than one season.

Appropriate Uses and Applications

Not all fertilizers will function the same or perform with the same nutrient release rate. It is important to understand as much as possible about the particular material in use to ensure that it will meet treatment objectives. For instance, if you were implementing a revegetation project in the late fall and you used a highly mobile mineral fertilizer, most of the fertilizer would have leached from the soil by late spring, when most plant growth occurs. In this case, it would be more effective to apply that fertilizer in the spring when plants begin to grow.

A key factor of effective fertilizer use is understanding the nutrient content of the soil and matching fertilizer input and release rate to the needs of the intended soil-plant community (see Tool 3, Site Condition Assessment). If rapid nutrient release is desired, mineral fertilizers should be used. If a slightly slower nutrient release rate is needed, an organic or coated mineral fertilizer may be more appropriate. Excessive, under-, or improper application of fertilizer is economically and environmentally inefficient. In severely degraded soils, fertilizers may produce short-term increases in plant growth. However, fertilizer alone cannot rebuild drastically disturbed soil.

Determining Fertilizer Need

Soil sampling and analysis is used to determine the amount of nutrients that are present and deficient at a particular site.

Type	Description	Advantages	Disadvantages
Organic Fertilizers	Derived from plant or animal sources	• Slower release rate (longer lasting) • More stable (lower leaching potential) • Feeds soil	• Higher cost • May contain undesirable residual materials • Can be more difficult to apply
Mineral Fertilizers	Derived from synthetic and/or mined sources	• Low cost • Widely available • Rapid plant uptake	• Less stable (higher leaching potential) • Can "burn" plants • Do not build soil • Production is energy-intensive
Slow-Release Mineral Fertilizers	Mineral-coated material (some organic fertilizers are also considered slow-release)	• More predictible release rate • Relatively inexpensive	• Actual release rates can very • Moderate leaching potential

Table 10.1: Fertilizer Alternatives Matrix

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Soil samples should be taken in an adjacent native or undisturbed area (reference area) for comparison to the treatment area. Interpretation of soil sample results requires skill and experience. Soil labs typically interpret sample results from an agricultural perspective, which can be misleading for wildland applications (particularly in alpine areas) where ongoing fertilizer application is often not practical or desirable. Fertilizer application rate should be calculated based on the difference between existing soil nutrient conditions in the treatment area and target nutrient conditions (from a nearby reference area). Fertilizer application calculations should always take into consideration the nutrient requirements and expected uptake of the intended plant community.

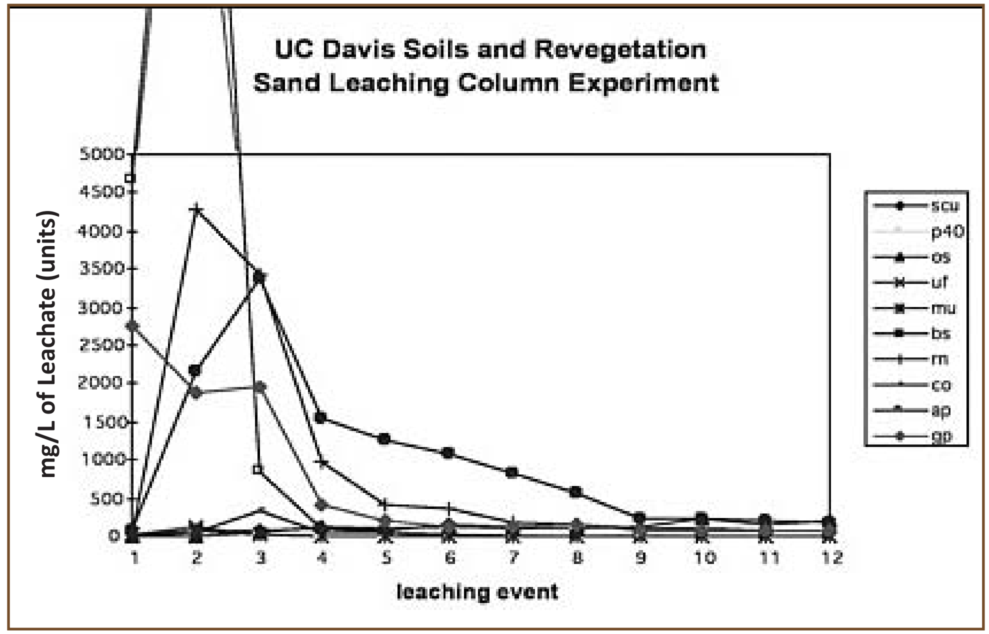

Figure 10.1: Leaching data for a number of mineral and organic fertilizers. The horizontal (X) axis represents leaching events (water leached through a sand column containing one form of fertilizer or soil amendment). The vertical (Y) axis represents the amount of nitrogen (N) leached from the sand column. Some fertilizers released most of their nitrogen in three leaching events whereas others released N over a much longer period of time. This information suggests that fertilizer release rate must be matched with plant-soil need. Further, some fertilizers, such as "ap" (ammonium phosphate), may present a runoff and pollution threat if not absorbed by plants immediately. From Claassen and Hogan (1998).

Scheduling Considerations

Time fertilizer application with plant growth/ uptake (spring-summer). Limit late-season (fall-winter) applications.

Implementation Guidelines

- Test soil for nutrient content to determine appropriate type and amount of fertilizer to apply.
- Match fertilizer type, amount, and scheduling to plant-soil needs.
- After soil loosening treatment is complete, spread fertilizer on soil surface.
- Rake fertilizer into soil approximately one inch so that it is not in direct contact with seed. *Direct contact between fertilizer and seeds is not recommended because it can reduce germination and plant growth.*
- After fertilizer application, apply seed, then mulch.

Maintenance and Inspections

Yellowing leaves or other visual indicators may suggest that nutrient needs are not being met. Many online resources are available that can provide help in identifying visual symptoms of plant nutrient deficiencies.[2]

Suggested Success Criteria

- **Minimal soil nutrient loss** – This can be difficult to measure. Fertilizer application should be matched with plant-soil needs. Excessive fertilizer application can harm plants, degrade water quality, and increase costs.
- **Adequate plant growth** – This is often subjective, but if quantitative success criteria are developed for plant cover or density, those criteria can be used to determine whether or not plant growth is "adequate." See Tool 11, Vegetative Treatments.
- **Species composition (presence of desired and undesired species)** – Weed growth and excessive annuals can be an indication of excess available nitrogen.

Measurement Methods for Success

- Soil nutrient sampling
- Cover point monitoring or ocular estimates to determine percent plant cover
- Plant count (census) to determine plant density and/or seedling survival rate

Management Response to Lack of Success

Additional fertilizer applications may be appropriate if a plant nutrition specialist determines that plants are nutrient-deficient. However, lack of success is more likely due to improperly matching the amount and/or type of fertilizer to actual plant-soil nutrient deficiencies. A useful management response may be to determine soil nutrient levels and match the type and quantity of fertilizer applied.

International Fertilizer Industry Association	http://www.fertilizer.org/ifa/
Organic Fertilizer Association of California	http://www.organicfertilizerassociation.org
California Fertilizer Foundation	http://www.calfertilizer.org/
Organic Fertilizer and Amendment Resource List (searchable database), National Sustainable Agriculture Information Service	http://attra.ncat.org/attra-pub/orgfert.php
UC Davis publication about organic fertilizers for crops; good general information	http://anrcatalog.ucdavis.edu/pdf/7248.pdf

Table 10.2: Fertilizer Information Resources

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Observed or Measured Results

- **Fertilizer application tends to increase soil nutrient levels and support plant growth, at least in the short run.** At a test site at Northstar-at-Tahoe's Lookout Mountain at North Lake Tahoe, California (volcanic soils), test plots with organic fertilizer exhibited higher total Kjeldhal nitrogen (TKN), organic matter, and perennial plant cover three years after treatment when compared to test plots without fertilizer.
- **Fertilizer alone is not likely to restore soil function and sustain robust plant growth in the long run, especially for soils with low organic matter.** At soil test boxes in Tahoma, California (granitic soil), the organic-fertilizer-only treatment produced very high first-year biomass, but biomass decreased sharply in subsequent years. Three years after treatment, the organic fertilizer plus amendment treatment produced eight times more biomass than the fertilizer-only treatment. At the Canyon test plots at Heavenly Mountain Resort in South Lake Tahoe, California (granitic soil), treatments that included a combination of organic fertilizer and amendments such as compost and wood chips had higher TKN and higher organic matter, and produced twice as much plant cover as fertilizer-only treatments. At the Northstar-at-Tahoe long-term plots (volcanic soil), organic fertilizer plus amendment treatments also maintained higher TKN levels than organic-fertilizer-only treatments after three growing seasons (see Figure 10.2).
- **Excessive fertilizer application rates may encourage the establishment of undesirable plant species, especially where a weed seed source is present.** At the Truckee, California, bypass test plots, different fertilizer application rates were tested using an organic, slow-release fertilizer.

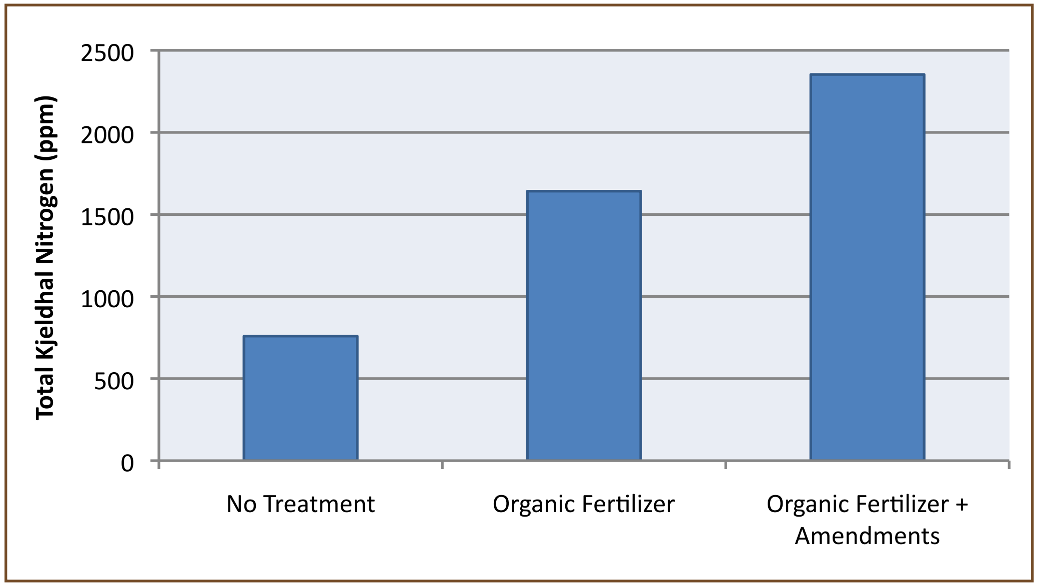

Figure 10.2: The graph shows soil total Kjeldhal nitrogen (TKN) levels for a treatment test area at Northstar-at-Tahoe. Three years after treatment, soil TKN levels were highest where a combination of organic fertilizer and amendments were used, as compared to application of fertilizer alone and an untreated area. Similar results have been measured at other test sites as well, indicating that a combination of fertilizer and long-lasting amendments may be the most useful treatment approach for establishing and sustaining adequate soil nutrients over time.

As shown in Figure 10.3, plots with fertilizer application rates of 2,000 lbs/acre exhibited higher cover by seeded perennial species after two years as compared to plots with twice the fertilizer application rate (4,000 lbs/acre). In a similar test of fertilizer rates at the Resort at Squaw Creek (Squaw Valley), fertilizer rates of 2,000, 4,000, and 8,000 lbs/acre were compared. Two years after treatment, the 2,000 lbs/acre rate produced the highest cover by seeded species (38%) and high overall plant cover (41%). The 4,000 lbs/acre rate had the lowest cover by seeded species (26%) and the highest percentage of annual species (10%). The highest fertilizer rate—8,000 lbs/acre—produced the highest overall plant cover (50%), but this was largely due to the presence of annuals and other undesirable species.

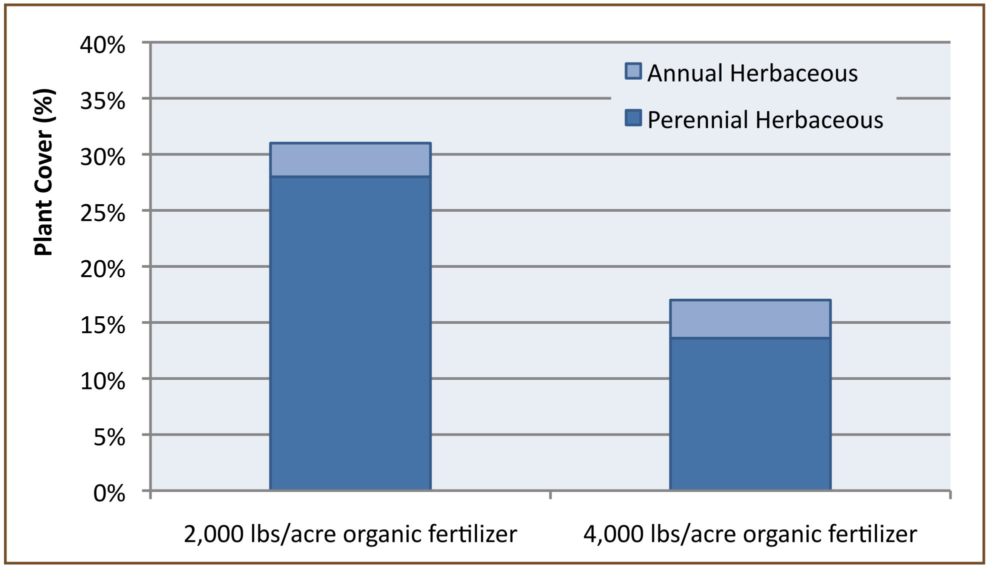

Figure 10.3: Truckee Bypass test plots. On average, plots treated with the lower fertilizer rate (2,000 lbs/acre) exhibited higher cover by seeded, perennial species than those plots treated with the higher fertilizer rate (4,000 lbs/acre).

NOTES

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Fertilizers Endnotes

[1] *Haber-Bosch process – http://en.wikipedia.org/wiki/Haber_process*

[2] *Recognizing Plant Nutrient Deficiencies – www.unce.unr.edu/publications/files/ho/2002/fs0265.pdf*

Tool 11 - VEGETATIVE TREATMENTS

Seed mix of Sierra native perennial grasses and shrubs.

Definition

Vegetative treatments are used to establish or enhance vegetation cover and include two general application methods: *seeding* and *planting.* Seeding is the application of seed to the soil surface or topsoil, generally via mechanical broadcasting or by hand. Planting is the installation of live plant material.

Purpose

Vegetative treatments assist in the development of a plant community at a treatment site. Seeding and planting both help develop the soil-plant-microbial community, thus enhancing soil nutrient cycling and long-term site sustainability.

Seeding: Treatment sites are often disturbed sites that have little topsoil remaining. Topsoil contains the soil seed bank, which is the seed that has accumulated over time. At native sites, those seeds will germinate when appropriate conditions exist. Without this seed bank, a disturbed site is unlikely to produce adequate vegetative cover. Seeding on wildland sites is designed to partially and artificially replace that seed bank and provide enough plant material to achieve treatment goals.

Planting: Planting is designed to provide specific, pre-grown plant material that is in a later growth phase (typically 1–5 years old) or to establish plants that are difficult to grow from seed.

The Role of Soil in Plant Communities

Soil is the critical underpinning of plant growth. Soil that is compacted or nutrient-poor, has low water-holding capacity, or is otherwise significantly impaired is unlikely to develop and support a robust plant cover. While practitioners have long been searching for a plant that will grow and flourish in drastically disturbed conditions to control erosion, this plant has not yet been found. Soil and plants exist as a complex, interdependent system that cannot be separated (except in hydroponic gardens, which are not self-sustaining). Therefore, strict attention must be paid to soil conditions if a desired plant community is to be successfully established and sustained over time.

Understanding Plant Types

There is a great deal of controversy regarding the type of plant material to use for erosion control and restoration treatments. There are three main categories of plants: *native, indigenous,* and *non-native.*

Native and indigenous plants are similar but possess a subtle difference. The term *native* refers to plants that grow naturally in a given geographic area or region. The term *indigenous* refers to plants that originate from the specific area under consideration. For example, Squirreltail (*Elymus elymoides*) is native to the Sierra Nevada. Squirreltail of the same genus and species is also native to Oregon. However, if seeds from Oregon were planted in the Sierra, the resulting plant would be considered native but not indigenous.

Non-native plants are those that originate from a different geographic area or region. Non-native plants that have adapted to the local region and are able to sustain themselves are known as *adapted*. Non-native plants that consistently outcompete native species for water and nutrients are known as *invasive* (http://www.invasivespeciesinfo.gov/). A common example of a plant that is non-native, adapted, and invasive is cheatgrass (*Bromus tectorum*). Cheatgrass originated in Europe and parts of Africa and Asia but is now one of the most widespread and problematic invasive grasses in North America. While this Handbook generally does not recommend one category of plant over another, the use of invasive species is highly discouraged. Many jurisdictions, including the US Forest Service, Environmental Protection Agency, California Regional Water Quality Control Boards, and other local and regional agencies have issued directives regarding the use of native species, and many encourage or require them for restoration projects. Typically, natives, and especially indigenous natives, are adapted to the local climate and have the genetic information to respond to the typical range of local conditions. Natives also tend to allow other natives to coexist and establish a diverse plant community, whereas invasive species can be aggressive and preclude other species from becoming established.

Annual or Perennial?

Annual: Annual plants have a life cycle of one year or less and proliferate by producing seed during the growing season. Annual plants only grow from seed and do not regenerate from roots.

Perennial: Perennial plants have a life cycle of two or more years and are able to grow from seed, or, after dying back in the winter, can regenerate from the root stock in the spring. These plants may or may not produce seed during the first season of growth, but are generally deeper-rooting than annual plants.

NOTES

TOOLKIT

Table 11.1: Vegetative Treatment Alternatives Matrix

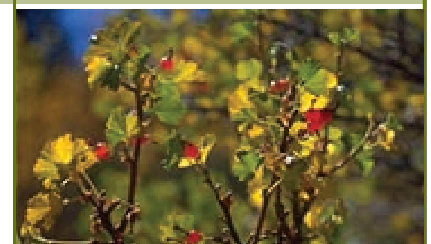
Seed/Planting Type	Definition	Advantages	Disadvantages	Photos
Native Perennial Grasses	Any perennial grass that is native to the local area	• Native plants are an essential component of the local ecosystem • Most native perennial grasses are deeply rooted and add strength to the soil • Native grasses can help start the successional process toward a mature native plant community • Native grasses do not require long-term irrigation • Native plants support wildlife	• Following low-water years, seeds for some native grasses can be expensive or difficult to find • May be considered to be less aesthetically pleasing than some non-native species	
Native Forbs	Any herbaceous plant other than a grass or shrub that is native to the local area	• Native plants are an essential component of the local ecosystem • Native plants can help start the successional process toward a mature native plant community • Native forbs with showy and attractive flowers can be selected for areas where aesthetics are important • Native forbs do not require long-term irrigation • Native plants support wildlife	• Following low-water years, seeds for some native forbs can be expensive or difficult to find	
Native Shrubs	Any woody plant other than a tree that is native to the local area	• Native plants are an essential component of the local ecosystem • Native plants can help start the successional process toward a mature native plant community • Native shrubs with showy and attractive flowers can be selected for areas where aesthetics are important • Native shrubs do not require long-term irrigation • Native plants attract wildlife	• Many native shrubs can be difficult to grow from seed	
Native Trees	Any tree that is native to the local area	• Native trees do not require long-term irrigation	• Survival rate may be variable	
Non-native Species	Any species that is not native to the local area; can include invasive species	• Can be fast-growing and aesthetically pleasing • May require long-term irrigation	• Can outcompete native species • Do not enhance wildlife habitat • Non-native grasses may not foster natural successional processes • May spread to other areas	

Table 11.2: Vegetative Treatment Alternatives Matrix

Application Methods	Definition	Advantages	Disadvantages	Photo
SEEDING	Applying seeds on top of (or just beneath) the soil	• Seed is easy and efficient to apply, especially on large projects • Grass seeds can be fast-growing and provide cover and slope stabilization during the first growing season	• Many native shrubs have hard-coated seeds that will not readily germinate • Do not provide structural diversity in short term	
PLANTING	Installing live plants into the soil	• Mature grasses, shrubs, or trees can be aesthetically pleasing • Can ensure greater species diversity than seeding (because it is difficult to predict which seeded species will actually germinate) • Can create greater structural diversity in the short run	• Planting alone will not provide sediment source control at very disturbed sites without soil treatments, seeding, and mulch • Expensive and labor-intensive • Survival rates tend to be low • Can look unnatural • Often require long-term irrigation	

Planning Considerations

- Temporary irrigation can be used to encourage seed germination and deep root penetration, which can increase slope stability (see Tool 13, Temporary Irrigation).
- Plant growth may be slow during the season of treatment if the site is not irrigated.
- Irrigation should not be applied late in the growing season, as frost can kill recently germinated seedlings, leading to decreased plant cover the following season.
- Green or fresh woody soil amendments or mulch may limit plant growth during the season of treatment and the first season after treatment. Irrigation may be used to help increase plant growth.
- Most native seed can be applied during late fall and left to germinate in the spring, when soil moisture and air temperatures are adequate. It is critical that seed placed late in the season is protected with a functional mulch cover (see Tool 12, Mulches), or it may be displaced during snowmelt and runoff.

Selecting Species

In general:

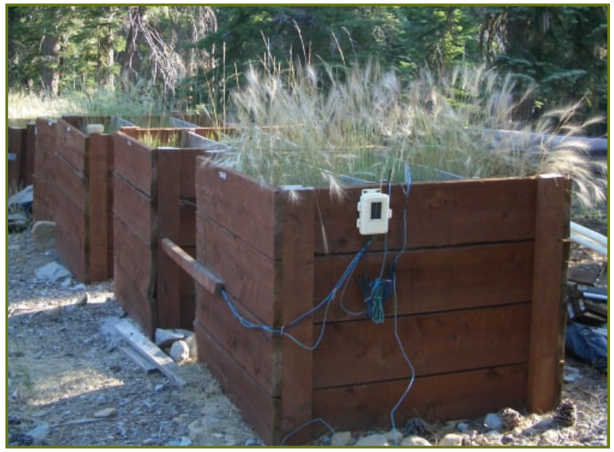
- Species that are appropriate for site conditions will be most successful. At a minimum, consider soil type, solar exposure, and soil moisture levels (Table 11.3) when selecting species.
- Some shrubs may be difficult to grow from seed since their hard-coated seeds need to be scarified (e.g. exposed to low-intensity fire or passed through an animal's digestive system). These are not recommended for seeding.

TOOLKIT

- The US Forest Service has taken the lead on eliminating invasive and unwanted species and has mandated the use of weed-free seed in revegetation projects on USFS land. Private landowners may wish to follow suit to reduce the proliferation of undesirable species.
- Consider purchasing seed species that have high viabilities and purities. Viability multiplied by purity equals the amount of *pure live seed* (see sidebar).

For native species:

- Identify native species in the project area or at a nearby native area to help with selecting appropriate seed and plant species.
- Seeds can be collected from the project area before disturbance or from surrounding areas for application.
- When choosing native species, consider indigenous varieties, as these will be acclimated to local soil and climatic conditions.



How deep are native plant roots? At a study site in Tahoma, California (Lake Tahoe), the roots of native perennial grasses extended to 46 inches deep in research boxes filled with uncompacted soil from nearby areas.

Pure Live Seed

Ordering, specifying, and applying seed should always be considered in the context of pure live seed (PLS). PLS is the amount of seed that can actually be expected to grow within a batch of bulk seed. Bulk seed usually contains non-seed material such as chaff and awns. Further, not all seed will germinate. Therefore, when ordering seed, purity (percent of pure seed) and germination (percent of seed that will germinate) is critical information. Seed is typically tested to state and local standards and is typically required to include "purity" and "germ" test results on the label. For instance, if 20% of a 50-pound bag of seed is made up of impurities and non-viable seed, then only 40 pounds of that bag is seed that can be expected to grow. Therefore, if one needed to apply 40 pounds PLS per acre, 50 pounds of bulk seed would be required. Similarly, if a seed supplier had an old bag of seed in which only 10 percent was still viable and 100 pounds of seed was applied to an acre, you would only be applying 10 pounds of actual live seed on that acre. Ultimately, understanding PLS allows all parties to better interpret plant response outcomes by knowing exactly how much viable seed is being applied as part of a revegetation treatment.

Note: Seed should be tested within one year of use and always stored in a cool, dry place.

Seeding Considerations

- It is important that seeds are distributed evenly throughout the treatment area to ensure consistent plant cover.
- Seeds can be broadcast either by hand or with a seed spreader.
- Grass seeds should be lightly raked to just below the soil surface to improve germination.
- Hydroseeding can be used, but it is difficult to incorporate the seed into the soil after this type of application.
- Drill seeders, which are commonly used in agriculture, can be impractical for projects with steep slopes, uneven terrain, or difficult access.
- Even seed application over large areas may be easier to achieve if smaller sections are marked off and seed is applied proportionately to each section.
- In large areas with considerable variation in soil conditions or solar exposure (Table 11.3), different seed mixes can be prepared and applied to the different areas.

Determining Seed Rate

- Seed rates should always be calculated and specified in *pure live seed* (see sidebar)
- Seeding rates for revegetation and restoration projects tend to range between 25-125 PLS pounds per acre for grass-dominated seed mixes.
- Higher seeding rates may be necessary for species that have larger seeds (such as some shrubs) to obtain the same seed density as species with smaller seeds (such as grasses).
- Lower seed rates may be appropriate for treatment areas that are in close proximity to well-vegetated native areas, as vegetation establishment is often aided by "volunteer" seeds from native areas.

Planting Considerations

- Soil loosening and preparation can be critical for plant performance. The looser the soil around a plant, the more water and nutrients that plant can access. Compacted soil can stunt plant growth or cause root circling that will eventually kill the plant.
- Ensure proper plant spacing while planting, which is dependent on mature plant size.
- Expect that some plants may die, and overplant accordingly.
- Cuttings of some plants, such as willows, may be planted. These are best cut and planted in late fall, after dormancy.

	Mountain brome (*Bromus carinatus*)	**Blue wild rye** (*Elymus glaucus*)	**Squirreltail** (*Elymus elymoides*)	**Needlegrass** (*Achnatherum occidentale*)
Full Sun			X	X
Full Shade	X	X		
Sun/Shade Mix	X		X	X
Wet Soil Conditions	X	X		
Dry Soil Conditions			X	X

Table 11.3: Favorable site conditions for selected northern and central Sierra grass species that have been successfully used in revegetation and erosion control projects.

TOOLKIT

Seedling Storage

- Seedlings should be well cared for before planting to ensure optimum survival.
- Establish a regular watering schedule during seedling storage.
- Install seedlings before they become root-bound.
- Ensure appropriate amount of sun or shade during storage.

Planting Guidelines

- Dig a planting hole at least twice as wide and twice as deep as the root ball.
- Loosen soil around the planting holes and throughout the planting area to encourage higher survival rates (see Tool 8, Soil Physical Treatment). Trees and shrubs have very low survival rates when planted in compacted soil.
- Fill planting hole with water to its rim. Allow hole to drain and refill the hole a second time and allow water to fully drain.
- Mix a small amount of organic fertilizer (1 tablespoon to ½ cup, depending on size of planting hole) with soil and place at bottom of planting hole. Then cover fertilizer-soil mixture with an additional 1-2 inches of soil.
- Place plant in hole, ensuring that the plant is upright and vertical. Do not attempt to loosen the rootball or otherwise handle seedling roots.
- Backfill the planting hole and gently tamp down the soil. Do not cover the crown (where the roots end and the trunk begins) with soil. Do not construct a berm around the planting hole. Berms tend to capture and concentrate water and often cause erosion problems.
- Apply 2-3 inches of mulch on planting area and adjacent areas disturbed during planting.
- Re-water each plant to saturate the soil without displacing mulch or creating surface runoff.
- Continue to irrigate planting area during the first growing season.

Maintenance and Inspections

Periodic site visits are necessary to determine whether further seeding, planting, or maintenance is necessary. Uneven growth or lack of growth could require further action.

Seed application methods — hand seeding (left), hydroseeding (center), drill seeding (right).

Suggested Success Criteria

As with any restoration project, it is important to determine vegetation success criteria during the planning phase (see Tool 4, Success Criteria).

Seeding: Defining success for seeding applications can take many different forms, depending on project goals. Success criteria may include total plant cover, cover by seeded species, percent of perennials vs. annuals, presence of target species, presence of weeds or invasive species, or other considerations.

Example success criteria for seeding:

- Year 1 – 15% total plant cover
- Year 2 – 20% total plant cover
- Year 3 – 25% total plant cover

Planting: Success criteria for planting usually focuses on plant survival rate.

Example success criteria for planting:

- Year 1 – 75% of plants alive and robust
- Year 2 – 65% of plants alive and robust
- No visible signs of erosion in planting area

Measurement Methods for Success

Seeding: Plant cover can be measured across the entire treatment area using either visual assessment or cover-point monitoring method (see Tool 16, Monitoring).

Planting: Plant survival is typically measured by conducting a plant census (or plant count).

Photo points are a simple and useful method for assessing and documenting change in a plant community over time.

Management Response to Lack of Success

Seeding: Re-apply additional seed at specified rate in areas that do not meet success criteria.

Planting: Where success criteria are not met, re-plant seedlings at a ratio of 2:1. If visible signs of erosion are present, apply additional mulch and/or loosen soil.

Observed or Measured Results

- In several seed rate tests, different seed rates produced similar plant cover and species composition. Instead, plant cover and species composition appear to be more closely linked to local site conditions such as solar exposure, aspect, and soil physical and nutrient conditions.
- Selecting vegetation species that are well suited to project site conditions is a critical element of establishing a robust plant community. See Table 11.3 for an example site suitability matrix.

Planting holes should be filled with water and allowed to drain before planting (left). Adequate mulch cover reduces evaporation and protects soil during post-planting irrigation (right).

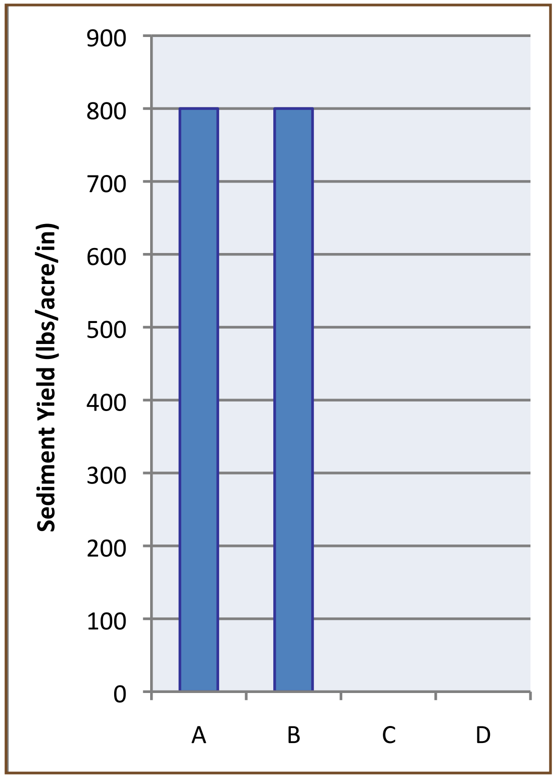
TOOLKIT

Case Study: Does Plant Cover Control Erosion?

There are many misconceptions about plant cover and its direct effect on controlling erosion. Many believe that plant cover is the primary determinant of erosion control. High vegetation cover is often considered to be the main indicator of a successful erosion control project; however, current research shows that plant cover is just one of many factors that contribute to the capacity of a site to control erosion. High cover by plants does not necessarily indicate low surface runoff, low sediment yields, or a functioning soil and plant ecosystem. While plant cover is an important element of the long-term sustainability of site conditions that minimize erosion, it should not be considered the sole indicator of success in erosion control projects.

A (top), B (bottom)

Figure 11.1



C (top), D (bottom)

The above photos show four sites with different treatments. Figure 11.1 shows sediment yield measured by rainfall simulation at each site. Site A is well-vegetated, while Site B has a high proportion of bare soil and low cover by plants. The sediment yield, approximately 800 lbs/acre/in, was equally high for both sites. Conversely, Sites C and D have varying vegetation levels and the same sediment yield: zero. The difference? Surface treatment only was applied at Sites A and B, while full soil restoration treatments were applied at Sites C and D. All four sites were highly disturbed before treatment, but treatments at Sites C and D were designed to improve soil function and infiltration, which achieved the goal of sediment source control. In the case of Sites A and B, where the compacted and nutrient-poor soil conditions were not addressed by surface treatments, high erosion rates persisted, despite the establishment of high plant cover at Site A.

TOOLKIT

"A thing is right when it tends to preserve
the integrity, stability and beauty
of the biotic community.
It is wrong when it tends otherwise." – Aldo Leopold

Tool 12 - MULCHES

Definition

In the context of restoration and erosion control, *mulch* is broadly defined as a protective layer of material that is spread on the soil surface. In natural systems, mulch is made up of fresh and decaying organic litter and detritus from plants such as branches, leaves, needles, and small twigs or by gravel and small rocks in arid environments.

Purpose

Mulch provides the first line of defense against soil erosion by physically buffering the soil from disturbance, intercepting raindrop energy, slowing surface runoff, and capturing sediment. Mulch also mitigates soil surface temperatures, thus reducing evaporation during hot seasons, minimizing or eliminating frost heave during freezing temperatures, and protecting seeds from the effects of extreme hot and cold temperatures. In revegetation projects, mulch is used to protect seeded areas and to aid in establishing vegetation. As they decompose, organic mulches provide nutrients to the soil and become the primary source of soil nutrients in forests and other upland environments. When soil is disturbed, such as during construction projects, the mulch layer is often removed or displaced. When this occurs, many of the valuable services provided by mulch (described below) are compromised or eliminated.

Mulch provides countless environmental services and benefits, including:

- Protecting soil from erosion by both water and wind
- Conserving soil moisture by reducing evaporation, thus providing more available water for plants and reducing the need for watering and/or irrigation
- Capturing sediment in runoff (pine needles and wood shreds have proven to be most effective)
- Helping maintain an even soil temperature and improve growing conditions for plants and soil microbes
- Preventing "crusting" of the soil surface, thus improving the absorption and movement of water into the soil
- Preventing soil compaction
- Reducing weed growth
- Providing nutrients as it decomposes (amount of nutrients and nutrient availability varies widely among different mulch types)
- Providing organic matter that encourages microbial activity, which in turn keeps the soil loose. This improves root growth, increases the infiltration of water, and improves the water-holding capacity of the soil.

While mulch alone provides many benefits, it must be used in combination with other soil and vegetative treatments to achieve sustainable, long-term sediment source control on disturbed sites.

Case Study: Mulch Cover and Sediment Yield

Mulch has a direct effect on how much sediment leaves or remains in place at a site. The photos below show three different research plots with similar slopes in close proximity to one another at a project site at North Lake Tahoe. Mulch cover varied greatly between the plots, and the graph below shows the amount of sediment present in the runoff from each plot during simulated rainfall. Sediment yield was an order of magnitude (ten times) higher from the plot with the lowest mulch cover (10%) than the plot with the highest mulch cover (95%).

The bottom line: adequate mulch cover is a critical element of preventing erosion and sediment yield.

~95% mulch cover

~60% mulch cover

~10% mulch cover

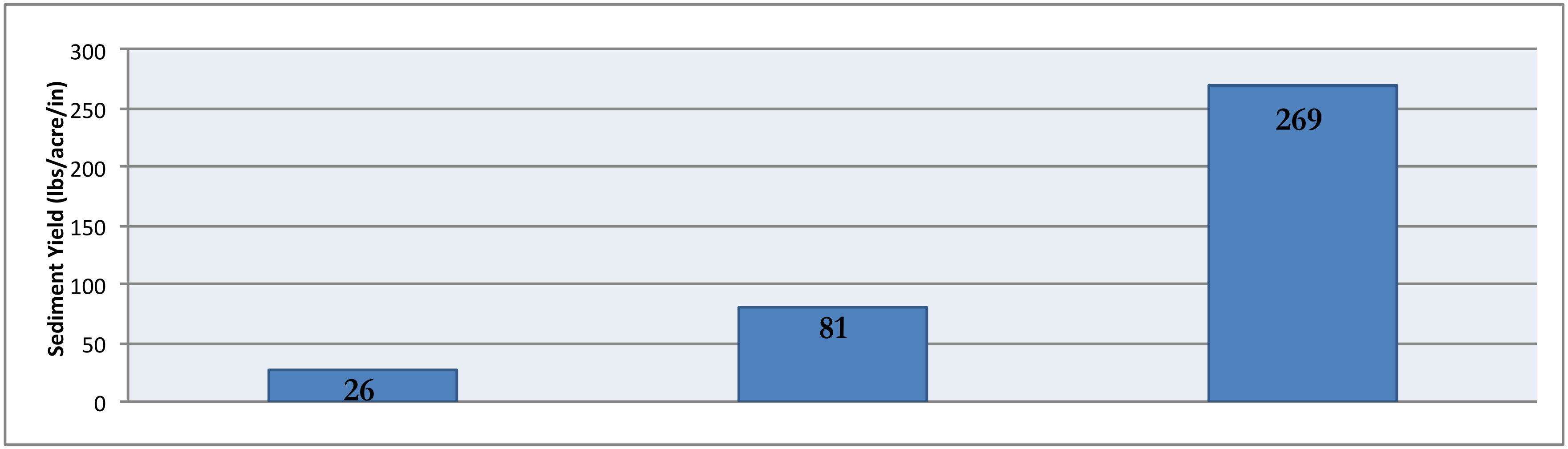


Figure 12.1: Mulch cover and sediment yield. Sediment in runoff increased as mulch cover decreased, as measured using rainfall simulation at an erosion control project at North Lake Tahoe, CA.

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Table 12.1: Mulch Alternatives Matrix

Mulch Type	Definition	Advantages	Disadvantages	Photos
Pine Needles	The foliage shed by pine trees (needle cast)	• Ubiquitous throughout Sierra • Requires no processing or packaging • High sediment capture capability • Resists displacement • Mimics natural forest processes in Sierra • Matches native aesthetic of forested areas in Sierra • Reduces landfill inputs	• Low availability later in the season due to high demand • Not durable enough to withstand frequent vehicle traffic	
Wood Chips	Generally small, uniformly-shaped pieces of wood created by a standard wood chipper	• Can be produced on site in conjunction with tree clearing/thinning • High-carbon material builds soil as it breaks down • Long-lasting, durable mulch • Effective in high-traffic areas	• Can be displaced by flowing water due to generally small sizes and consistent, geometric shape • Can temporarily reduce nutrient availability during decomposition • May not blend in with natural aesthetic of Sierra forested landscape	
Wood Shreds (also known as tub grindings or tub-ground wood chips)	Unevenly shaped and sized fibrous pieces of wood produced by grinding up stumps, root wads, and other large woody debris using grinding machines, such as a hammer-mill-type tub grinder.	• Can be produced on site in conjunction with tree clearing/thinning • Extremely durable and resistant to displacement • High sediment capture capability • Effective in high-traffic areas • High-carbon material builds soil as it breaks down • Often rich in fungi & beneficial microbes	• Can temporarily reduce nutrient availability during decomposition • May not blend in with natural aesthetic of Sierra forested landscape	
Agricultural Straw	Wheat, barley, oat, rice, or other types of straw used as temporary mulch to protect bare or disturbed soil areas.	• Relatively inexpensive material • Widely available from erosion control supply companies • Reasonably effective temporary mulch while it remains in place	• Easily displaced by wind and water • Requires matting, crimping, punching, or other methods to hold it in place • Provides very short-term protection • Often leads to establishment of undesirable species • Does not blend in with natural aesthetic of Sierra forested landscape	
Rock or Gravel	Rock material ranging from small gravels to larger stones or rocks that are used to protect the soil surface.	• Effective in high-traffic areas • Resistant to displacement by wind • Larger rock can be effective in water flow paths	• Does not directly contribute to soil health • Can be difficult for plants to establish under gravel or rocks • Commonly displaced by vehicles • Unwashed gravel may present storm water quality issues	

A few other types of mulch and surface protection are worth briefly mentioning. These mulches and surface protection treatments are generally considered less desirable alternatives than the mulches described in Table 12.1 for the purposes of sediment source control in alpine environments. When choosing a mulch, all natural materials are ecologically preferable.

Wood strands – long, thin, uniform pieces of dry wood that are created as a byproduct of veneer manufacturing. Not known to be easily accessible in the Sierra at this time, and their effectiveness at controlling erosion in alpine environments has not been verified or field tested.

Bark mulch – ground cover comprised of ground tree bark (typically fir, redwood, or cedar) and other wood materials commonly used as a permanent ground cover. Can provide effective soil protection for some smaller-scale landscaping projects but must be re-applied regularly due to rapid decomposition. Not recommended for use in larger-scale restoration projects or wildland settings.

Compost – compost is commonly used as a mulch in residential landscaping but is not suitable as a surface mulch for larger erosion control and revegetation projects. Most types of compost are high in plant-available nutrients and should be mixed into the soil to prevent this material from being transported by runoff and contributing to water quality pollution. For more information on compost, see Tool 9, Soil Amendments.

Erosion control blankets – synthetic and natural blankets are often used as a mulch substitute. A large amount of information currently exists regarding the effectiveness of blankets at controlling erosion, most of which has been developed and produced by blanket manufacturers or their research agents. Blankets may provide adequate temporary cover for disturbed soils. Manufacturer's directions should be followed closely. The following points should be considered when using blankets:

- Blankets are intended to provide temporary stabilization and, in most cases, should be removed or replaced with a permanent mulch material within one season.
- Blankets that contain synthetic materials such as plastic netting may not be appropriate where wildlife, including birds, rodents, snakes, and other species exist. Plastic netting has been shown to have detrimental effects on a number of species.
- Blankets must maintain complete contact with the underlying soil to be effective, which can be difficult or impossible to accomplish in many situations. Erosion commonly occurs beneath blankets but is not readily observed (see photo below).
- Some blankets, such as those made from coir/coconut fabric, may be left in place to decompose.
- Jute blankets are designed for very short-term treatment due to their relatively quick breakdown and lack of substantial tensile strength, especially when wet.

Clear evidence of significant erosion occurring underneath erosion control blankets.

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Scheduling Considerations

Mulching is typically the last step in an erosion control or revegetation project, occurring immediately after seeding and/or planting. For temporary soil protection during construction, mulch should be applied immediately after soil disturbance. Within the Tahoe Basin, mulching for winterization purposes must be completed by October 15th. For seasonal or general re-application, mulch should be applied in the fall, before snow arrives.

Appropriate Uses and Applications

Mulch should be applied in all areas where the soil surface is bare or unprotected for any length of time. The Site Suitability Matrix, Table 12.2, identifies the recommended uses for each type of mulch.

	Pine Needles	Wood Chips	Wood Shreds	Agricultural Straw	Rock or Gravel
Flat or low slope areas	X	X	X	X	X
Steep slopes	X		X		
Vehicle traffic/parking areas		X	X		X
Water flow paths	X		X		X
Tree/brush clearing areas		X	X		
Walking paths		X	X		X
Drip lines			X		X

Table 12.2: Site Suitability Matrix

How Much Mulch Do I Need?

As a general rule, 1 cubic yard of mulch will cover about 325 square feet of ground at a depth of 1 inch. For larger projects, plan on approximately 135 cubic yards of mulch per acre for a 1-inch application depth.

Keep in mind that actual application depth and percent surface cover will depend on mulch material, site conditions, and application method.

Implementation Guidelines

In general, the more direct contact mulch has with the soil surface, the more effective it is likely to be. Typically, mulch should be applied to a depth of 1-2 inches, depending on the density of mulch material and project goals. If the goal of the project is to develop vegetative cover, a loose material, such as dry pine needles, should be initially applied at a depth of 2 inches, while wood chips should be applied at a depth of 1 inch. If the goal of the project is temporary protection or winterization, mulch should be applied at a depth of at least 2-3 inches.

All mulches can be effectively applied by hand for small applications. However, for larger applications, some mulches can also be applied efficiently and effectively using a specialized blower, loader, or other machinery. Blowing mulch that contains large quantities of fine particulates (such as soil) should be avoided, as this can generate dust and create air quality concerns.

Maintenance and Inspections

All mulched areas should be inspected regularly, especially before rain events and in the fall before snowfall begins. Durable mulches typically require little or no maintenance, provided that they have not been displaced. In contrast, straw and other mulches that degrade rapidly often need to be re-applied roughly every one to two years to maintain effectiveness. For temporary soil protection applications, mulch should be inspected daily during construction, as well as before, during, and after storm events. Look for bare and/or disturbed areas, or signs of erosion, and re-apply mulch to these areas immediately. Mulch applied to vehicle travel or parking areas may need to be re-applied frequently, depending on the frequency and intensity of disturbance.

Spreading pine needles.

Suggested Success Criteria

- Soil cover as measured across the entire treatment area using either a visual/ocular assessment or cover-point monitoring method, should be at least:
  - 98% in Year 1
  - 95% in Year 2
  - 90% in Year 3
- No bare areas larger than 6 square inches
- No visible signs of soil erosion (e.g. rills, gullies, sediment movement)

Measurement Methods for Success

- Cover-point monitoring (more accurate)
- Ocular estimation of cover (less accurate)

Management Response to Lack of Success

Re-apply mulch to achieve specified level of surface coverage.

Don't Forget!

Pine needles can be hard to find by late summer or fall. If planning a late-season project, secure a supply of pine needles early in the season.

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Mulches: Pine Needles

Definition

Pine needles are the foliage shed by pine trees and are a naturally occurring mulch in Sierra forests. Pine needles from Jeffrey and Ponderosa pines are the preferred mulch material in the Sierra because of their long spears. Lodgepole, Sugar Pine, and Western White Pine needles are shorter and are therefore not ideal for mulching applications. Until recently, excess and/or collected pine needles have been managed solely as a waste product. Pine needles are now gaining broader acceptance and recognition as a highly effective mulch, with unique sediment capture capabilities and natural aesthetic qualities.

Site Suitability

- Flat, low slope, or steep slope areas
- Water flow paths

Advantages

- Ubiquitous throughout Sierra and in many mountain regions
- Requires no processing or packaging
- High sediment capture capability
- Needles naturally lock together and resist displacement
- Mimics natural forest processes in Sierra
- Matches native aesthetic of forested areas in Sierra
- Reduces landfill inputs and can reduce project costs if salvaged and reused on site
- May contain native seed if collected locally

Save and Reuse Native Mulch

When pine needles are available on site before construction begins, this natural mulch should be raked and stockpiled for future use. However, pine needles should only be gathered from within the limits of project clearing and grading.

Disadvantages

- Low availability later in the season due to high demand
- Not durable enough to withstand frequent vehicle traffic

Suggested Material Specifications

- Pine needle mulch shall consist of pine needles and associated duff material, containing no more than 10% impurities such as pine cones, twigs, or other woody organic material.
- Garbage shall represent no more than 0.5% of the total volume of material. Where visible garbage exists, it shall be removed.
- Mulch shall contain no more than 0.5% by volume mineral soil and no more than 10% decomposed organic matter.
- Pine needle length shall be as follows: 25% less than 1 inch in length; 50% between 1 inch and 3 inches; 25% greater than 3 inches.
- Needles from Jeffrey and Ponderosa pines are preferable to Lodgepole and other short-needled pine species due to their longer spear length.

Implementation Guidelines

- Rake and stockpile any existing pine needles prior to construction.
- Application should cover at least 98% of soil surface (generally 1-2 inches deep).

Application depth depends on application method. Generally, 1-inch depth if applied with a blower and 2-inch depth if applied by hand or other means. When applied with a blower, pine needles are broken into shorter and more uneven lengths, which tends to increase surface contact and provide greater initial erosion protection.

Observed or Measured Results

- Pine needle mulch applied to bare, disturbed soils in the Tahoe Basin has been shown to reduce sediment concentrations and yields by 30-50% (Grismer and Hogan 2005b).
- Rainfall simulation at test plots at Brockway Summit at North Lake Tahoe suggested that high mulch cover (>80%) contributed to low sediment yields (Grismer et al. 2008).
- Pine needles have been shown to be an effective and persistent mulch. Following initial applications of 2 inches of pine needles (~98% mulch cover), 89% mulch cover remained after two years at a site near Truckee, CA, and greater than 80% mulch cover remained after three years at Heavenly Mountain Resort. Some single applications of pine needle mulch in the Tahoe Basin have lasted more than six years.

But Nothing Grows Under Pine Needles, Right? Wrong!

A great deal of discussion has taken place about what, if anything, grows beneath pine trees. Many long-time Sierra residents swear that nothing grows beneath pine trees. However, a quick look at almost any pine forest will allow an observer to see that in fact, pine forest understories are often full of a wide variety of species. This wildland myth may have been derived from overstocked, closed-canopy forests where light cannot penetrate. But where an open stand exists, you may sometimes find understory vegetation so thick you cannot see the pine needles.

NOTES

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Mulches: Wood Chips

Definition

Wood chips are generally small, uniformly shaped pieces of wood created by a standard wood chipper.

Site Suitability

- Flat or low slope areas
- Vehicle traffic/parking areas
- Walking paths
- Anywhere tree or brush removal takes place

Advantages

- Can be produced on site in conjunction with tree clearing/thinning
- High-carbon material builds soil as it breaks down
- Long-lasting, durable mulch
- Effective in high-traffic areas

Disadvantages

- Can be displaced by flowing water due to generally small sizes and consistent, geometric shape
- Can temporarily reduce nutrient availability during decomposition
- May not blend in with natural aesthetic of Sierra forested landscape

Suggested Material Specifications

- Derived from clean, disease-free trees or tree stumps, not from construction or building materials, because paint, metal, and other toxic/inorganic materials can harm soil and water quality
- Produced by a standard wood chipper and of relatively even consistency
- Contains no more than 5% pine needles, leaves, or other non-wood-chip material
- Chipped and aged for at least six months prior to application whenever possible (one year is preferable)—this helps to inoculate organic acids released by wood naturally and encourages microbial growth and decomposition

Implementation Guidelines

1. Complete final grading of soil and any soil treatments.
2. Spread wood chips by hand, loader, or other equipment until at least 98% of the soil surface is covered (approximately 1-2 inches in depth). Can also be applied with blower if wood chips are free of soil and other fine particulates.

Observed or Measured Results

- At Heavenly Mountain Resort, 4 inches of wood chips were applied to a bare soil ski run as a temporary soil stabilization measure. Mulch application alone (no soil treatment) led to increased infiltration and reduced runoff compared to the adjacent control (bare) area.
- At a project site at North Lake Tahoe, high mulch cover (~95%) was associated with sediment yields that were an order of magnitude (10 times) less than plots with low mulch cover (~10%).
- Small wood chips can be highly mobile, resulting in poor erosion control performance on steep slopes and during high-runoff events.
- At some erosion control project sites in the Lake Tahoe Basin, wood chips have persisted for upwards of eight years.

Mulches: Wood Shreds

Definition

Wood shreds are unevenly shaped and sized fibrous pieces of wood typically produced by grinding up stumps, root wads, and other large woody debris using large wood grinding machines, such as a hammer-mill-type tub grinder. Wood shreds are also often known as tub grindings or tub-ground wood chips.

Site Suitability

- Flat or low slope areas
- Steep slopes
- Water flow paths
- Vehicle traffic/parking areas
- Walking paths
- Drip lines
- Anywhere tree or brush removal takes place

Advantages

- Can be produced on site in conjunction with tree clearing/thinning
- Extremely durable and resistant to displacement because of uneven shapes and sizes produced by most grinders
- Long, fibrous pieces that are effective in capturing sediment in runoff
- Effective in high-traffic areas
- High-carbon material builds soil as it breaks down
- Often rich in beneficial microbes and fungi when produced from stumps and root wads

Disadvantages

- Can temporarily reduce nutrient availability during decomposition
- May not blend in with natural aesthetic of Sierra forested landscape

Suggested Material Specifications

- Derived from clean, disease-free trees or tree stumps, not from construction or building materials, because paint, metal, and other toxic/inorganic materials can harm soil and water quality
- Produced by a machine capable of shredding large woody debris into pieces

NOTES

TOOLKIT

of uneven shapes and sizes (such as a hammer-mill-type tub grinder)

- Have spear lengths ranging from 2 to 10 inches with the following size classifications: no greater than 25% of material less than two inches in length; at least 50% of material between two and eight inches in length; no greater than 25% of material greater than eight inches in length
- Contains no more than 5% pine needles, garbage, or other non-wood-shred material.
- Ground and aged for at least six months prior to application whenever possible (one year is preferable)—this helps to inoculate organic acids released by wood naturally and encourages microbial growth and wood decomposition

Implementation Guidelines

1. Complete final grading of soil and any soil treatments.
2. Spread wood shreds by hand, loader, or other equipment until at least 98% of the soil surface is covered (approximately 1 inch in depth). Can be applied with a blower if wood shreds are free of soil and other fine particulates. Use a 2-3 inch depth for temporary soil protection, winterization, or to prevent establishment of vegetation.

Observed or Measured Results

Recent research by Foltz and Copeland (2007) found that wood shreds less than 25 mm (1 inch) in length did not form the three-dimensional mats useful in reducing sediment movement. Erosion control effectiveness is also diminished in wood shreds larger than 200 mm (8 inches), as longer shreds have less ground contact on uneven surfaces, resulting in the formation of fewer "mini dams" to slow runoff and trap sediment. Similar research by Foltz and Dooley (2003) suggests that optimum wood shred lengths for erosion control effectiveness range from 60 mm to 240 mm (approximately 2 to 10 inches).

A 2-inch application depth of wood shreds can provide functional mulch cover for five to six years or longer.

Did You Know?

Wood shreds generated from on-site stumps, branches, and root wads make great food for your soil. They are rich in carbon and contain beneficial microbes and fungi that will help keep your soil happy and healthy.

Mulches: Agricultural Straw

Definition

Agricultural straw includes wheat, barley, oat, rice, or other types of straw used as *temporary* mulch to protect bare or disturbed soil areas. Straw mulch is no longer recommended for use as mulch in the Lake Tahoe Basin and other areas of the Sierra because other types of mulch are readily available that have proven to be more durable and effective at preventing sediment movement.

Site Suitability

- Flat or low slope areas only

Advantages

- Relatively inexpensive material
- Widely available from erosion control supply companies
- Reasonably effective temporary mulch while it remains in place

Disadvantages

- Easily displaced by wind and water
- Requires matting, crimping, punching, or other methods to hold in place
- Only provides very short-term protection
- Often leads to establishment of undesirable (weed) species
- Does not blend in with natural aesthetic of Sierra forested landscape

Suggested Material Specifications

- Use clean, certified weed-free wheat, barley, oat, or rice straw only
- Must not be moldy or compacted
- Must be anchored by crimping/track packing, tackifying, or covering with netting

Implementation Guidelines

1. Complete final grading of soil and any soil treatments.
2. Obtain clean and certified weed-free wheat, barley, oat, or rice straw in order to prevent the spread of noxious weeds. Avoid moldy, compacted straw as it tends to clump and is difficult to distribute evenly.
3. Evenly distribute straw by hand or blower until at least 98% of the soil surface is covered (approximately 1 inch in depth).
4. Anchor straw using an acceptable method (crimping/track packing, tackifying, or covering with netting).

Observed or Measured Results

Even when properly applied and anchored, straw mulch rarely maintains its functional integrity longer than 1 season in the alpine climate of the Sierras.

Did You Know?

If you must use straw, rice straw is the most durable (it contains silica and has high cellulose content). It also tends to contain fewer weeds and seeds because the rice seed heads are harvested as a food crop.

TOOLKIT

Mulches: Rock or Gravel

Definition

Rock or gravel mulch includes rock material, ranging from small gravels to larger stones or rocks, used to protect the soil surface.

Site Suitability

- Flat or low slope areas
- Water flow paths
- Vehicle traffic/parking areas
- Walking paths
- Drip lines

Advantages

- Effective in areas with foot and vehicle traffic
- Resistant to displacement by wind
- Larger rock can be effective in armoring water flow paths

Disadvantages

- Does not directly contribute to soil health
- Can be difficult for plants to establish under gravel or rocks
- Commonly displaced by vehicles
- Unwashed gravel may present storm water quality issues
- Can be expensive

Suggested Material Specifications

- Use only clean, washed rock or gravel that is free of debris.
- For armoring water flow paths, rock shall be adequately sized to resist hydraulic relocation (as specified by an engineer).
- Rock and gravel shall match local geology and soil types whenever possible.

Implementation Guidelines

1. Complete final grading of soil and any soil treatments.
2. Spread or place gravel or rocks so that at least 98% of the soil surface is covered.
3. Gravel should be applied to a depth of 1-2 inches for general soil surface protection and foot paths and 2-4 inches in high disturbance areas (parking lots, unpaved roads).

Observed or Measured Results

- Gravel can be effective at protecting unpaved road surfaces against erosion for a limited period of time, but must typically be re-applied every one to two years to remain effective.
- Rock and gravel has been used effectively to protect soil surface against erosion along roof driplines and under decks.

"When we try to pick out anything by itself,
we find it hitched to everything
else in the Universe.."
–John Muir

Tool 13 - TEMPORARY IRRIGATION

Restoration and erosion control treatments are generally designed to be self-sustaining over the long run. Irrigation, as described here, is designed to help establish vegetation and then to be removed. When used in combination with soil restoration treatments, temporary irrigation can be extremely effective. Several studies have shown that long-term irrigation can result in vegetation failure after its removal. Additionally, irrigation used on compacted or otherwise high-density soils seldom helps to achieve the goal of sediment source control and may actually cause erosion.

The two main objectives of temporary irrigation for sediment source control projects are:

1. To assist with initial germination of seeded plantings
2. To encourage deep root penetration

Definition

Temporary irrigation includes a range of methods used to apply water to treatment areas to assist with vegetation establishment and growth.

Purpose

Irrigation is used for a number of purposes and in many settings. Typically, landscape plantings and lawns receive irrigation because they have been installed in areas where they would not normally be able to survive with the natural rate of precipitation. These manipulated landscapes typically are not designed for the control of erosion and/or sediment source control. In fact, recent data suggests that improper installation of plantings can actually increase sediment transport from a site if the installation is not implemented correctly.

Table 13.1: Temporary Irrigation Alternatives Matrix

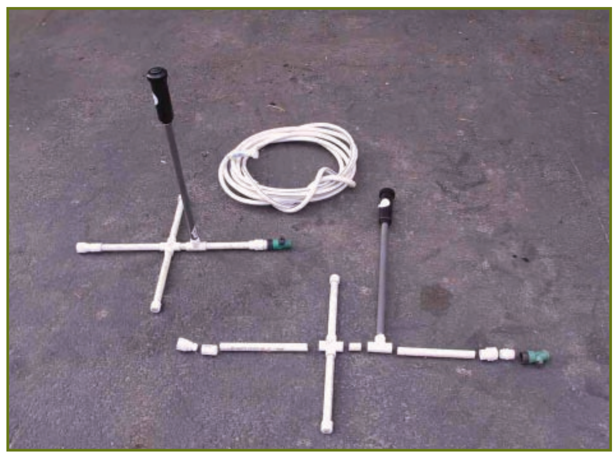
Type	Definition	Advantages	Disadvantages	Photos
Low-flow Overhead Irrigation	Sprinkler types that produce a low precipitation rate, typically less than 2.5 gallons per minute	• Low potential to cause erosion or displace mulch • Potential for deep penetration of water into soil, thus encouraging deep rooting • Water input similar to natural rain and snowmelt events • Required equipment is common and accessible	• Sprinkler heads more likely to clog than high-flow heads • May require more heads and piping than high-output heads	
High-flow Overhead Irrigation	Typical irrigation heads including impact type (rain birds) and many stream rotor heads	• Fewer heads required • Can apply large amounts of water in short time periods	• Can result in erosion if not used carefully • Large drop size can result in mulch and soil displacement, damage to plants • High precipitation rate can impede infiltration, thus minimizing deep water penetration	
Water Truck/ Water Trailer	Water applied from spray nozzle or hose mounted on water truck or other type of tank	• Does not require sprinkler installation • Can be used in remote locations • Can be useful for small, discontiguous treatment areas	• Can be expensive • Requires full-time operator • May not infiltrate deeply enough to encourage deep root growth • Often results in erosion (although with proper equipment and operator training, it can be effective)	
Soaker Hoses	A type of low-flow surface irrigation	• Encourages deep watering • Highly efficient use of water (minimizes evaporation)	• Very localized delivery of water; must be placed carefully • May require a large supply of hoses and connections	
Drip Irrigation	True drip uses a number of devices that place drops of water at precise locations, typically used for plants (not for seeding)	• Highly efficient use of water (minimizes evaporation) • Relatively inexpensive and easy to install	• Unsuitable for use in high-pressure systems • Prone to leakage and blowouts • Not appropriate for large seeding installations	

Appropriate Uses and Applications

- Temporary irrigation can be used effectively, when combined with full soil treatment, to produce a deep-rooted plant community capable of holding soil together and providing long-term protection against erosion.
- Temporary irrigation is often used on steeper slopes where relatively rapid plant establishment is needed to protect the site from erosion and mass failure.
- Native (and other) grass seeds commonly germinate within two weeks and are fully established within 30 days.

Design Considerations

- Important design considerations to ensure proper function of irrigation systems include appropriate flow rates, head spacing and distribution, overall site precipitation rate, and head type. Design should be carried out by a trained and experienced irrigation specialist.
- Reusable, modular irrigation systems (see images this page) can be cost-effective and highly adaptable when used over many years.
- Pressure in pipe, typically described in pounds per square inch (psi), must be matched to the specific head requirement. A long run of pipe can reduce water pressure significantly. Make sure that the appropriate pipe size is used. Typically, the longer the run length, the larger the pipe diameter. (A common misconception is that as a run gets longer, the pipe diameter should get smaller. In fact, the opposite is true. A smaller-diameter pipe will produce more *pressure* but less water volume. Pipe that is too small will produce excessive internal friction, thus slowing water.)
- High precipitation rate impact heads and stream rotor heads can produce large droplet size, thus delivering a large amount of force to the ground, which can cause erosion.



Examples of reusable, modular irrigation systems. Yellowmine pipe (left) is easy to assemble and disassemble, which can reduce material waste and save money. At 2-inch diameter, it is ideal for larger sites. Another option is to construct sprinkler stands out of ¾-inch PVC pipe (center and right) and connect a series of them in-line with hoses.

- Low precipitation rate (< 2.5 gpm for full-circle heads with radius of 25 feet) stream rotor or equivalent spray heads can be ideal for temporary irrigation systems.
- If using a water truck or hydroseeder, make sure that it is capable of producing an adjustable fine mist spray pattern.
- Potential water sources can include snowmaking lines, water pumped from streams, fire hydrants, water trucks, etc.
- Irrigation systems should be operated manually unless it can be shown that a timed system is 100% fail-safe and cannot fail at any point in the system. An automatic system can be damaged between cycles by animals, vehicles, etc., and when switched on by a timer can create an erosion problem.

Scheduling Considerations

- Timing/seasonality: in mountainous areas, irrigation for seeded areas should be started no later than the end of August because late-season seed germination can result in young plants being killed by frost or freezing temperatures.
- Exact irrigation timing and duration depend on air and soil temperatures as well as natural precipitation. The most accurate method of determining whether irrigation is adequate is to dig a small soil pit approximately 8-12 hours after irrigation to determine exactly how deep the water has penetrated (also known as the "wetting front" or "wetting depth").

Highly adjustable fire hose nozzles can be attached to water trucks to produce a wide range of spray patterns and flow rates ideal for irrigation applications. Many water trucks that are equipped for dust control applications actually displace mulch and create erosion when used for irrigation.

- A typical irrigation cycle could be as follows:

1. After soil treatment is complete, irrigate two to three days per week for approximately two weeks in order to keep the seedbed moist for seed germination.
2. Once seed has begun to germinate, irrigate approximately one day per week for at least four to six weeks OR as needed to wet soil to a depth of at least 12 inches. This low- frequency, long-duration irrigation approach is designed to encourage plant roots to "chase" water down deep into the soil, thus producing a deep, robust root system.

Implementation Guidelines

- Finish soil and vegetation treatments and ensure that adequate mulch cover is present.
- Design, set up, and test the irrigation system.
- Proceed with regular irrigation schedule (described above).

Maintenance and Inspections

- Above-ground temporary irrigation systems should be inspected before and after each irrigation cycle when system is turned on and off (irrigation systems should be operated manually).
- Clogged irrigation heads are common, and most low-flow heads are easy to clean.
- Always have extra heads and irrigation spare parts/tools accessible when conducting inspections.

Suggested Success Criteria

- Water is applied evenly throughout the treatment area.
- Water penetration (wetting depth) is at least 8-12 inches below the ground surface within 12 hours of irrigation.
- No visible erosion or mulch displacement.

Measurement Methods for Success

Soil moisture meters can be used to measure moisture levels at different depths. A simpler and more reliable method is to dig 8-12 inches into the soil with a pick or trowel and assess wetting depth in multiple locations throughout irrigated area.

Improper irrigation can cause (rather than help prevent) erosion if the precipitation rate exceeds the soil's infiltration capacity. These photos show rills created after 4 hours of high-flow overhead irrigation at a previously treated site with compacted soil.

Management Response to Lack of Success

- If water is not being applied evenly, adjust sprinkler head configuration, number of heads, or type of head to ensure even irrigation coverage.
- If water is not penetrating to specified depth, either 1) increase duration of irrigation cycles (as long as this does not cause erosion) or 2) re-till and incorporate coarse organic amendments into soil to increase infiltration capacity (see Tool 8, Soil Physical Treatment).
- If irrigation is causing erosion or displacing mulch, either 1) reduce precipitation rate, 2) change head type (e.g. switch to sprinkler head with finer spray pattern), or 3) re-till and incorporate coarse organic amendments into soil to increase infiltration capacity (see Tool 8, Soil Physical Treatment).

Observed or Measured Results

Northstar-at-Tahoe Superpipe

Soil and vegetation restoration treatments were applied to stabilize previously treated, steep (50%) slopes at the superpipe, which had persistent erosion issues. The treated slopes were irrigated to encourage rapid vegetation establishment and deep root growth. Several weeks after treatment, the irrigation system was accidentally left on overnight, which saturated the loosened soil and caused several slope failures. After the failures were repaired, irrigation was re-applied and closely monitored. Two seasons later, a robust and deeply rooted plant community was established and the superpipe slopes exhibited no slumps or slope failures for the first time since their construction.

Northstar Superpipe — failure caused by over-irrigation (top); repaired slopes with proper irrigation (center); stabilized slopes two years after treatment (bottom).

NOTES

TOOLKIT

Truckee Bypass Irrigation Treatment Plots (Caltrans)

Long-term irrigation was studied at a surface treatment site (no soil treatment) with limited infiltration. After a few seasons of irrigation, the irrigation system was removed and plant cover decreased from 48% to 12%, suggesting that the plants were dependent on artificial irrigation for growth. Annual species, such as Spanish clover, were dominant during irrigation seasons. In contrast, native perennial bunchgrasses were dominant at a nearby site with full soil treatment and no irrigation during the same time period. Despite the higher plant cover, rainfall simulation at the irrigated site measured an average sediment yield of 110 lbs/acre/in, compared to no runoff (infiltration rates >4.7 in/hr) and no sediment yield at the site with full soil treatment and no irrigation.

Highway 267 Slope Restoration

A full soil and vegetation restoration treatment with temporary, first-year irrigation was applied to this road cut slope. Three years later, the treated slope was supporting high native plant cover and had no signs of erosion.

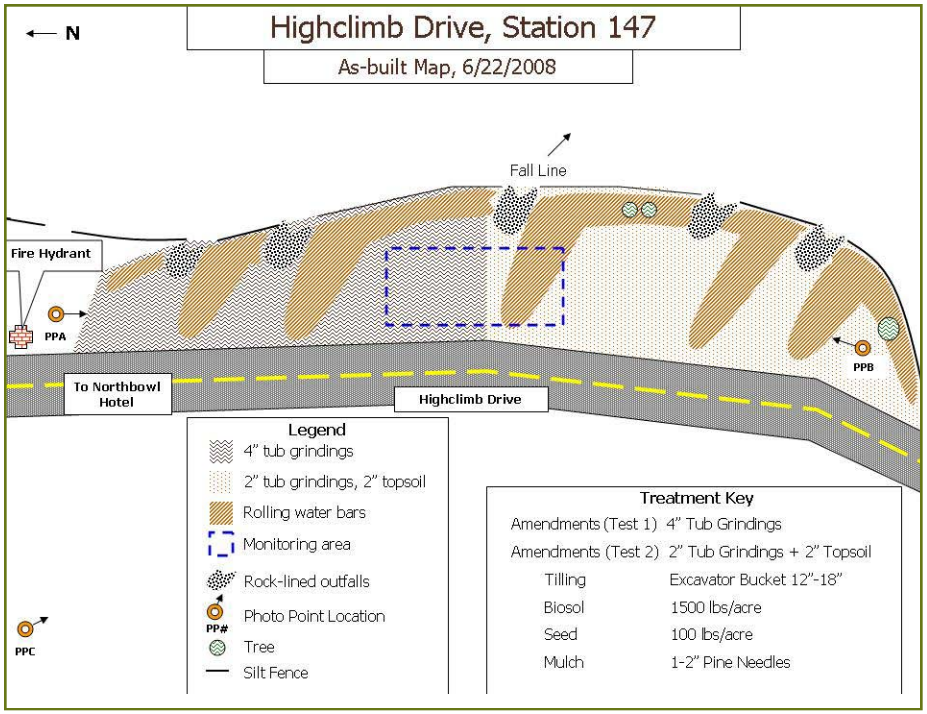
Highway 267 slope, three years after treatment.

"The nation that destroys its soil, destroys itself."

- Franklin Delano Roosevelt

TOOLKIT

Tool 14 - DOCUMENTING TREATMENTS



Definition

Documenting treatments refers to the process of recording specific project and treatment information, usually in the form of an as-built report.

Purpose

Careful documentation of treatments provides information that is critical to understanding the treatments that were implemented on a project. This information, which is typically documented in an as-built report, can be referenced by individuals looking at the project in the future, monitoring personnel, agencies, staff, and other interested parties. Most importantly, as-builts can be used by future implementers and cross-referenced with monitoring data to continually improve project success.

Overview

As-builts are prepared during and immediately following treatment to in order to document the specific treatments implemented, materials used, construction dates, project personnel, project goals, site description, photo points, and other information. Recording this information requires additional effort up front but can reduce frustration and repeated mistakes later. Documentation allows one to repeat successful treatments and learn from unsuccessful treatments by clearly documenting the details of implementation. Robust documentation is highly useful for interacting with regulatory or other agencies. Further, as-built data builds institutional knowledge in an organization. In other words, if a project manager leaves the organization, the treatment information does not leave with him. Treatment documentation should follow a standard format for ease of understanding and consistency between projects. An as-built template and example as-built are included at the end of this Tool.

Appropriate Uses and Applications

- All sediment source control treatments should have some level of documentation
- Information sharing between practitioners
- Institutional memory from one year to the next
- Project as-builts are the basis for interpreting project results

Scheduling Considerations

- Start the documentation/as-built process *before* beginning implementation, continue documentation each day *during* implementation, then finish up the details immediately *after* project completion.
- Spending the time to document treatments is likely to save time later on by learning from project successes and avoiding repeated mistakes.
- Documenting treatment information using a pre-defined as-built format should take one person no longer than 10-15 minutes per day during treatment implementation on most projects. Test plots may require additional time for documentation.

Implementation Guidelines

1. Upper management and project leadership should clearly communicate that documentation is a priority
2. Develop a standard as-built format/template (see example at the end of this Tool)
3. Develop an organizational system (electronic and physical) for organizing, storing, and accessing as-built information
4. Designate a single person to oversee and document all treatment elements (or to ensure that they are documented)
5. Start treatment documentation *before* implementation begins (site description, project goals, etc.)
6. Assess and describe existing site conditions using the Site Assessment Information Sheet (see Tool 3, Site Condition Assessment).
7. Begin project implementation
8. Document treatments at least once per day during implementation
9. Complete the as-built within 48 hours of completing a project

Maintenance and Inspections

Take the as-builts for past projects into the field and visit past projects at least once per year to compare differences in treatments and outcomes. Be sure to print the photo points for each project and visually assess how each treatment area is changing over time. Are there signs of erosion? How does plant cover compare from project to project? Is there evidence of re-disturbance?

Suggested Success Criteria

As-builts should:

- have enough detail that treatments could be replicated by someone else
- be able to be easily understood by someone who is not familiar with the project
- be in a consistent format
- be organized and stored (both electronically and physically) in a manner in which others can find the information

Measurement Methods for Success

Ask a new employee to find the as-built for a project completed several years earlier and to describe the specific treatments applied. The new employee should be able to find the as-built and to describe the specific treatments, the site characteristics, and the project goals.

For quantitative monitoring (which is increasingly being required for project success evaluation), as-builts are a critical foundation of the monitoring process (see Tool 16, Monitoring).

As-Built Template

Project Name (Project ID)	
Location Description	
Project Foreman	
Project Staff	
Start Date	
Completion Date	
Treatment Area (ft^2)	
Soil Loosening Method	
Soil Loosening Depth (in)	
Soil Amendment Type(s) and Source(s)	
Soil Amendment Depth (in)	
Fertilizer Type and Source	
Fertilizer Rate (lbs/acre)	
Seed Mix Name and Source	
Seed Rate (lbs/acre)	
Mulch Type and Source	
Mulch Depth (in)	
Mulch Surface Coverage (%)	
Irrigation Dates, Duration, and Frequency	
Irrigation Wetting Depth (in)	

As-Built Map

As-Built Map Checklist

- ✓ North Arrow
- ✓ Legend
- ✓ Project Name
- ✓ Treatment and Monitoring Areas
- ✓ Photo Point Locations
- ✓ Slope/Fall Line
- ✓ Trails, Roads
- ✓ Utilities – Snowmaking, Hydrants, etc.
- ✓ Significant Landmarks

Site and Problem Description

Include a physical description of the project site and describe problems/issues, unique site characteristics, landmarks, etc. Attach Site Assessment Information Sheet to this report.

Project Goals and Objectives

Test Questions

What are the key questions and variables being tested?

Treatment Description

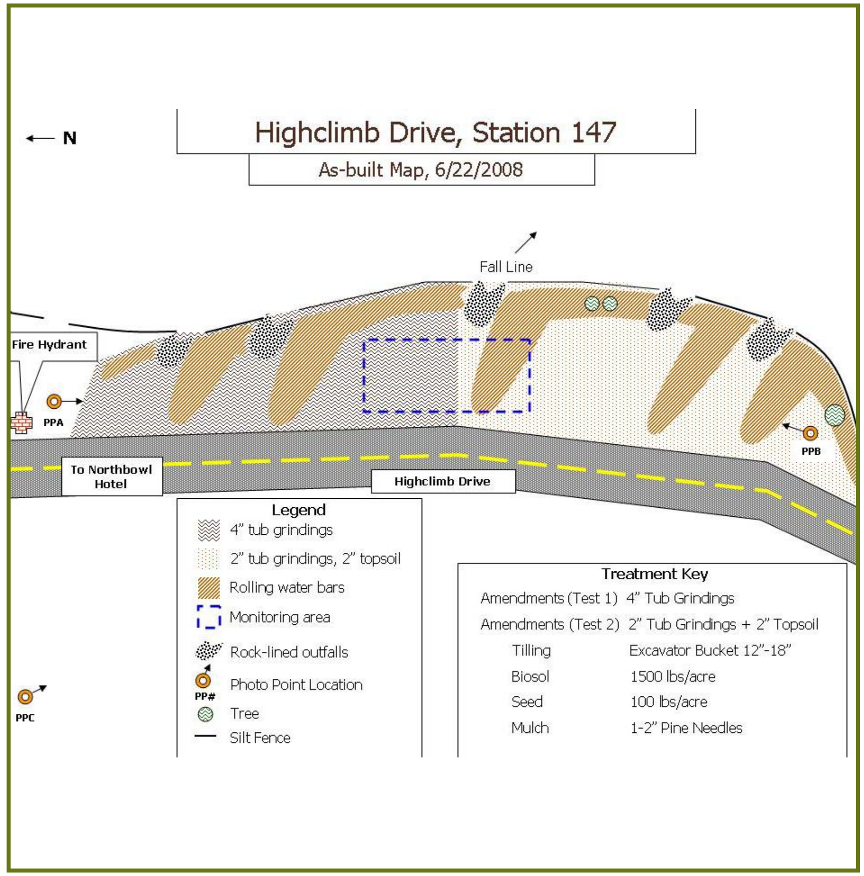
Describe all treatment elements including amendments, tilling, fertilizing, seeding, mulching, and irrigation. Make sure to include treatment specifics in as-built form.

Include before and after Photo Points on another sheet (see page 168 for an example)

As-Built EXAMPLE

Project Name (Project ID)	Highclimb Drive, Station 147
Location Description	Road shoulder at Station 147 on the west side of Highclimb Drive at North Bowl Ski Resort (1.4 miles from Highway 267)
Project Foreman	Lorenzo Mulchman
Project Staff	Dave Wattle, Jeremy Lovestoseed, Kate Kompost, Peter Tillhappy, and Brad LaBiosol.
Start Date	June 10, 2008
Completion Date	June 20, 2008
Treatment Area (ft²)	21,908 ft²
Soil Loosening Method	Tilling with bucket of mini excavator
Soil Loosening Depth (in)	12"–18"
Soil Amendment Type(s) and Source(s)	Topsoil (salvaged from Northbowl Hotel construction site) Tub Grindings (produced on site)
Soil Amendment Depth (in)	Topsoil – 2", Tub grindings – 2"
Fertilizer Type and Source	Biosol organic fertilizer (6-1-3), Pac Coast Seed
Fertilizer Rate (lbs/acre)	1,500 lbs/acre
Seed Mix Name and Source	Upland grass shrub seed mix – Comstock Seed (photo copy of seed tag attached)
Seed Rate (lbs/acre)	100 lbs/acre
Mulch Type and Source	Pine Needles – Incline Village General Improvement District
Mulch Depth (in)	1–2"
Mulch Surface Coverage (%)	98% coverage
Irrigation Dates, Duration, and Frequency	6/22/08 – 4 hrs, 6/30/08 – 6 hrs, 7/3/08 – 6 hrs, 7/10/08 – 4 hrs
Irrigation Wetting Depth (in)	8", 12", 10", 9"

As-Built Map



As-Built Map Checklist

- ✓ North Arrow
- ✓ Legend
- ✓ Project Name
- ✓ Treatment and Monitoring Areas
- ✓ Photo Point Locations
- ✓ Slope/Fall Line
- ✓ Trails, Roads
- ✓ Utilities – Snowmaking, Hydrants, etc.
- ✓ Significant Landmarks

Site and Problem Description

This site consists of a segment of road shoulder alongside Highclimb Drive at Station 147. The site was used as a staging area during the construction of underground utilities for the Northbowl Hotel and Trailside Condos. All vegetation on the site was removed during construction. Topsoil was also removed during grading for road construction. The compacted site was capturing and concentrating runoff from the adjacent paved road surface and upslope parking areas. This concentrated runoff had formed several gullies that ran most of the length of the site, eventually discharging into the adjacent forested area just above Fish Creek. Tub grindings had been spread on the site to help control erosion until full treatment was completed.

Project Goals and Objectives

Goal: To minimize erosion from project area.
Objectives:

1. Reduce runoff AND sediment yield by 75% within one year by stabilizing area and encouraging spreading and infiltration of surface flow
2. Reestablish an appropriate and self-sustaining native plant community from seed
3. Recapitalize soil nutrient and organic matter levels to at or above reference site levels

Test Questions

Soil amendment test: compare 4 inches of tub grindings to a mix of 2 inches tub grindings and 2 inches topsoil.

Will there be a difference in vegetation response and runoff rates between the two different amendment test areas after one year?

Treatment Description

Rolling water bars and rock-lined outlets were installed in the treatment area in order to slow and spread water and provide stable outfall areas during high flow events. Soil amendments (tub grindings and topsoil) were then spread (see treatment map for test areas) and tilled to a depth of 12-18 inches across the entire treatment area. Along the edge of the road, the addition of amendments and tilling raised the soil surface slightly above the road surface. To prevent unnecessary water capture, we re-contoured and lowered the elevation of the treatment area along the edge of pavement to allow even sheet flow from the road onto the treatment area. There was extreme compaction along the road edge from road construction, which limited tilling depth to 6 inches in this area. Fertilizer was hand spread and raked followed by head spreading of seed and raking. The entire treatment areas was mulched by hand with pine needles to a depth of 1-2 inches. After construction was complete, we installed a temporary irrigation system and monitored moisture levels to keep the surface moist during seed germination. Irrigation has occurred one to two times per week thus far, four to six hours per irrigation session. The first seed sprouts were seen two weeks after irrigation began (7/7/08). Irrigation is planned to continue on a weekly basis until nighttime temperatures near freezing.

TOOLKIT

Photo Points

Photo Point A (PPA) — 6/1/08, before treatment

Photo Point B (PPB) — 6/1/08, before treatment

Photo Point C (PPC) — 6/1/08, before treatment

Photo Point A (PPA) — 8/29/08, after treatment

Photo Point B (PPB) — 8/29/08, after treatment

Photo Point C (PPC) — 8/29/08, after treatment

Lessons from the Field

by Michael Hogan — Soil Scientist, Restoration Specialist

"I have implemented many projects and test plots. Since I am an operations-minded person and just want to get a project 'done,' many of the projects I have completed were never adequately recorded. I believed, of course, that I would remember what was installed, when it was installed, what materials were used, etc. However, sadly, I was seldom able to remember what exactly was done, and even when I was, it was impossible to share that information adequately with other practitioners. John Loomis, my friend and co-founder of the California Alpine Resorts Environmental Cooperative (CAREC), and I have had a number of discussions about this. He has said more than once: 'I'm so busy just getting the project done that I don't slow down long enough to even take photographs.' So many projects have been lost to future understanding this way. It's imperative that we slow down long enough to document our work so that we can remember, learn, and improve rather than repeat past mistakes or failed practices."

NOTES

Tool 15 - PROTECTING TREATMENT AREAS

Restoration treatment area disturbed by vehicle and equipment traffic.

Definition

Protecting treatment areas encompasses a range of actions taken to protect treatment areas from disturbance by human-related activities, animals, or natural events.

Purpose

The purpose of protecting treatment areas is to prevent or reduce the risk of re-disturbance following treatment implementation. Disturbance following treatment is a common reason for project failure. Therefore, treatment area protection can be one of the most important measures taken to assure the success of a project if all other treatment measures have been adequate.

Description

There are many methods that can be employed to protect treatment areas from disturbance (see Table 15.1, next page). The method used should be linked to the project's goals and use patterns. Treatment area protection methods range from "hard" methods, such as fences and other physical blockage, to "soft" methods, such as education and signage. The most effective methods acknowledge and work *with* (not against) human behaviors, travel patterns, and user requirements in and around the project area. The best protection strategies often employ a combination of methods (e.g. designated path and signage).

An important component to developing effective protection plans is an understanding and accommodation of the use patterns of the site (past, current, and future). For instance, if a road is to be removed, and that road has become a public access route, a trail should be provided (if possible) through that area or in an adjacent area to allow continued access while discouraging foot traffic in the treatment area. If providing continued access is not a viable option, efforts that are more substantial must be made to exclude traffic and minimize recurring impacts. Even foot or animal traffic can recompact soil that has recently been loosened, rendering the treatment ineffective, or at least less effective.

Treatment areas must also be protected from concentrated surface water that may flow onto the project area. This may require upslope diversion of water flow paths or treatment of runoff source areas upslope prior to implementing the intended project. See Tool 2, Watershed Flow Assessment, and Tool 18, Accommodating Water Flow, for more information on assessing, planning for, and accommodating water flow.

Table 15.1: Treatment Area Protection Alternatives Matrix

Protection Measure	Definition	Advantages	Disadvantages	Photos
Natural Structural Barriers	Use of rocks, logs, high surface relief, or other natural features to exclude traffic from treatment area	• Inexpensive • No import of material required • Blends in with natural aesthetic (i.e. not recognized by public) • Can enhance drainage patterns and reduce erosion	• Natural features may decompose over time • Not always enough to prevent "motivated" users from re-entering site	
Man-Made Structural Barriers	Use of fences, bollards, and other manufactured barriers to exclude traffic from treatment area	• Formalizes exclusion area • Some barriers can be reused many times	• Can be expensive • May encourage vandalism if access is discontinued • Can entail high maintenance costs • May detract from aesthetic value of area • May not be an option in some areas where protection will get damaged by snow or snow removal • May require approvals or permits (potentially lengthy time lapse between approval and protection implementation)	
Signage	Use of informational signage to discourage disturbance and/or educate users about treatments	• PR opportunity (e.g. describe restoration efforts) • Good complement to newly constructed trails	• Does not physically protect against disturbance • Requires advance planning for sign creation • May not remain standing through winter season • Durable signs can be expensive • May need frequent replacement • Sometimes signage actually encourages people to explore an area out of curiosity	
Communication Plan	Communication to all staff about locations and goals of treatment areas and importance of protection	• Can build organizational capacity • Can be integrated into regular and ongoing communication	• Staffing changes • Rapidly changing or unanticipated activities in treatment areas • Communication (e.g. meetings) can be expensive • Requires diligent, ongoing communication • Seasonal changes (e.g. communication during summer may neglect winter concerns)	
Trails	Creation of trails to contain human use patterns in and around a treatment area	• Allows for continued use of area • Education opportunity (signage)	• Poorly constructed trails can be erosion sources • Trails must be well-defined in order to effectively contain foot traffic • Can be ineffective without appropriate signage identifying location and/or purpose of trail	

Appropriate Uses and Applications

- All treatment areas should have some level of protection measures in place to prevent re-disturbance
- Roadside treatment protection is a priority because these areas tend to be the most prone to re-disturbance by vehicle and equipment traffic

Scheduling Considerations

- Treatment area protection should be installed as soon as the project is completed
- In some cases, protection can and should be implemented at the end of each work day before full treatment is complete
- Consider and contact other parties that may have plans in the same area for unrelated work
- Allow adequate lead time to design and produce signage (where appropriate)

Truck parked on roadside revegetation treatment area.

Implementation Guidelines

- Identify areas of your project most susceptible to being re-disturbed
- Consider human behaviors, travel patterns, and user requirements in and around the project area and anticipate likely types of disturbance
    - Recreation – hiking, mountain biking
    - Staging area for materials or equipment (especially for treatments near construction areas)
    - Transportation – trucks, equipment, passenger vehicles
- Identify appropriate treatment area protection methods and materials
- Order materials necessary to protect treatment areas prior to starting treatments
- **Over-communicate** importance of protecting treatment areas to staff and other appropriate parties through trainings, tailgate meetings, and contractor coordination meetings

A well-used trail constructed through a restoration project.

Maintenance and Inspections

Check treatment areas regularly during and after implementation for signs of disturbance and to ensure that treatment area protection measures are still in place and functioning effectively.

Suggested Success Criteria

Treatment areas are not re-disturbed by foot, vehicular, or equipment traffic or concentrated surface flow from outside the treatment area.

Measurement Methods for Success

- Visual observation
- Cone penetrometer (to assess re-compaction)
- Photo points

Management Response to Lack of Success

- Reevaluate methods used to protect against disturbance and consider alternative or additional methods.
- **Over-communicate** importance of protecting treatment areas to the public, staff, and other appropriate parties (such as subcontractors working in area), including those responsible for re-disturbance. Trainings, tailgate meetings, and contractor coordination meetings can be excellent venues for communicating importance of treatment area protection.

Re-disturbance of unprotected roadside treatment areas is a common problem.

Observed or Measured Results

- Re-disturbance of roadside treatment areas is an especially common problem that warrants a great deal of attention.
- Constructing trails through treatment areas has proven to be highly effective in protecting treatments.
- Treatment areas on large construction projects with multiple subcontractors are frequently re-disturbed. Successful treatment area protection in these situations has been achieved through a combination of physical protection and regular discussion of treatment area protection at safety meetings.
- Natural barriers such as rocks, logs, woody debris, and high surface roughness have contributed to the sediment source control effectiveness and aesthetic appeal of many projects.

Lessons from the Field

by Michael Hogan — Soil Scientist, Restoration Specialist

"One of my first large soil tilling operations took place with the US Forest Service in 1991. We had determined that ripping the soil would produce positive results and arranged to use a CAT D-6 tractor with a forest cultivator attached. We ripped, seeded, and mulched. The first part of the following season, the grasses came up, there was no erosion, and things generally looked great. Later that year, we went back to take a look and there was practically no vegetation growing, the mulch was mostly gone, and the soil had been re-compacted. It was obvious that people who had been using the road as a running, hiking, and biking trail had continued to do so, ultimately leading to the demise of our treatments. It was a hard lesson to learn, but one that I have not forgotten. If we had put a trail through the area and made the treatment area impassable, we would likely have achieved success."

TOOLKIT

Tool 16 - MONITORING

Definition

Monitoring has a number of definitions. For the purposes of this Handbook, monitoring is defined as follows: *The process of making observations or measurements over time to detect changes or to determine the current state of the elements being monitored.* There are many types of monitoring. The three primary types of monitoring associated with project construction are **baseline, implementation,** and **performance** monitoring. Within the context of a project, these serve to track project progress and performance. Other types, such as **trend** and **compliance** monitoring, may also be relevant and will be discussed briefly.

Type and Purpose

Each type of monitoring can be used to identify key elements in a project's life cycle.

Baseline monitoring is conducted before treatment to assess existing site conditions. The information gathered in this assessment can be used in the design process and for comparison in determining project success after implementation. Baseline monitoring sites include both the project site and a reference site. A reference site is an area that represents a target for the project and that will be used as a model for the project site restoration. Measurements may include soil and vegetation monitoring and other measurements that reflect site functional conditions.

Implementation monitoring is conducted during and/or immediately following treatment and serves to verify that project specifications are properly implemented or, when field-fitting is necessary, to document actual treatments that are implemented. Data and information collected can provide technical support and feedback to field personnel during the construction process. Implementation monitoring typically includes verification of specified materials and application techniques including: tilling depth, amendment depth, fertilizer and seed amounts and rates, and mulch depth. Implementation monitoring also provides the foundation for "as-built" documents, which describe the details of project implementation. As-built documents can be particularly important for future interpretation of project results. Documentation includes maps and drawings, as-built reports, and photos showing pre-construction conditions and the implementation process. See Tool 14, Documenting Treatments, for an as-built template.

Performance monitoring is conducted during subsequent seasons following construction completion. Performance monitoring is used to assess how well a project is performing. Effective and useful performance monitoring should be linked to success criteria, which can remove a great deal of the subjectivity from the interpretation of project performance.

This type of monitoring is commonly performed one year after project completion and annually thereafter for two to five seasons. Performance monitoring, when linked to success criteria, is also used to determine whether maintenance or follow-up treatments are necessary.

Trend Monitoring is similar to, and is often a subset of, performance monitoring. It is used to determine if changes in particular parameters exhibit a trend over time.

Compliance monitoring is used to compare a project parameter (usually water quality) to a regulatory standard in order to determine whether a project meets that standard. It is assumed that the standards will offer some insight into project performance or effectiveness, but that is not necessarily always the case.

Overview

Monitoring is a critically important component of the restoration process because it provides the information necessary to determine whether goals and success criteria have been met and whether further maintenance or follow-up activities are necessary. Monitoring can include many different types of assessment, from simple visual observation to quantitative analysis. To maximize cost effectiveness, project planners should incorporate specific type(s) of monitoring based upon the specific success criteria that are linked to project goals and objectives. Generally, increasing the comprehensiveness of project monitoring will increase the amount of useful information it provides as well as its defensibility. If used properly, monitoring results can improve the cost-effectiveness and success of future restoration projects.

Arguments are often made that monitoring is too expensive and that all resources are best spent on the project work itself. However, without effective, understandable, and defensible monitoring, it will seldom be possible to know whether the resources spent on a project have had the desired effect and thus whether the project has actually achieved the desired outcome. In order to determine the true cost effectiveness of a project, monitoring is essential.

While it is difficult to overstate the importance of monitoring, it is equally important to understand what monitoring is, what it is not, and what is required to implement defensible monitoring. Poorly planned and/or subjective monitoring can be misleading and result in the misinterpretation of project outcomes.

NOTES

Table 16.1: Monitoring Tools and Techniques

Monitoring Tool/Technique	Definition	Purpose	Advantages	Disadvantages	Photos
Photo Point Documentation	Photo points are the fixed locations of repeat photographs taken over time.	To document visual changes over time	• Simple method, requires little training • Visual representations can be powerful (but also misleading)	• Not quantitative • Soil and hydrologic function is not observable from a photograph	 
Foliar and Surface Cover Point Monitoring	Cover point monitoring is a quantitative method of measuring cover.	To assesses the amount and type of plant and surface cover	• This quantitative method is repeatable and statistically defensible	• Specialized equipment is necessary • More time-consuming than ocular estimation (see below)	 
Foliar and Surface Cover Ocular Estimation	Ocular estimation is a subjective method of assessing cover.	To assess the amount and type of plant and surface cover	• Can be performed quickly • Can provide a very general indication of cover	• Ocular estimates often overestimate plant cover • Estimates vary widely between experienced observers • Not a statistically defensible method	 *Ocular estimate of plant cover is 35%, as determined by an experienced botanist. Plant cover as measured by cover point is 10%.*
Soil Sampling	The collection of soil samples, for subsequent lab analysis to measure specific nutrient and physical parameters.	Soil organic matter and nutrient levels can be used to develop appropriate restoration treatments and assess site sustainability (e.g. ability to support vegetation, infiltrate and store water, etc).	• Can be collected quickly • Lab analysis is relatively inexpensive • Can be used to determine the most cost-effective restoration treatments	• Soil variability may necessitate that many samples be collected • Interpretation of analysis results requires experience and expertise	

Table 16.1: Monitoring Tools and Techniques (continued)

Monitoring Tool/Technique	Definition	Purpose	Advantages	Disadvantages	Photos
Cone Penetrometer Monitoring	The cone penetrometer is used to measure soil's resistance to force, which can be used as a surrogate for soil density.	Cone penetrometer measurements can be used as a surrogate for soil density and an indicator of infiltration	• Minimal training required • Can be performed quickly	• Cannot be used as the sole indicator of hydrologic function	 
Soil Moisture Measurement	Soil moisture is a measure of the water content of the soil.	Soil water content indicates the presence of water for plant and microbial use	• Can be measured very quickly	• Many moisture meters measure water content at a fixed depth • Precise meters can be expensive	
Solar Radiation Measurement	Using a Solar Pathfinder or other solar analysis instrument to measure the solar input potential at a site.	Solar input information can be used to evaluate evaporation potential and develop appropriate vegetation treatments	• Requires little training • Can be performed quickly	• Requires Solar Pathfinder or other solar analysis instrument	
Visual Erosion Assessment	Visual assessment includes observations of erosion indicators such as rills, gullies, and other runoff patterns.	Keen visual observations can help assess problems or determine whether an area needs further monitoring, maintenance, or treatment	• Can be performed quickly • Is a useful first step in site evaluation	• Subject to individual observations, not quantitative • In some areas erosion problems may only be visible directly following a rainstorm or runoff event. Thus, absence of visible erosion does not necessarily indicate that a site is stable.	

Table 16.1: Monitoring Tools and Techniques (continued)

Monitoring Tool/Technique	Definition	Purpose	Advantages	Disadvantages	Photos
Runoff Simulation	Runoff simulation produces sheet flow to measure infiltration, sediment yield, and nutrient content of runoff quantitatively.	Runoff simulation is used to simulate overland flow that occurs during rain-storms and spring snowmelt runoff	• Quantitative measurement • Allows visual observation of erosion patterns	• Requires custom-fabricated equipment • Extensive training required • Small-scale measurements and data may not indicate larger-scale problems	
Rainfall Simulation	Rainfall simulation produces raindrops to measure infiltration, sediment yield, and nutrient content of runoff quantitatively.	Rainfall simulation is used to simulate rainstorms of different intensities	• Quantitative measurement • Allows visual observation of erosion patterns	• Requires custom-fabricated equipment • Extensive training required • Small-scale measurements and data may not indicate larger-scale problems	 

Success Criteria

Success criteria are used to identify specific goals or objectives of a project. Success criteria are the foundation of discussions regarding project completion, effectiveness, and the need for follow-up treatment. They are pre-defined, quantifiable benchmarks that are determined during project planning and design. These criteria will include some of the following specific elements: plant and mulch cover, soil nutrients, soil density (cone penetrometer measurements), visible erosion, and others. See Guiding Principle 3 and Tool 4, Success Criteria, for more information.

Sampling Design

A sampling design determines when and how monitoring data are collected. The design is important to ensure that the selected data collection types and methods will be able to determine whether success criteria are met in an objective manner. Sampling design factors include location, scale, intensity, frequency, and duration of the monitoring, monitoring plot layout, randomization of plots, and statistical methods used. Some monitoring sampling designs can be very simple, such as the location of photo points. Others can be more complex, such as the layout and randomization of cover point transects and the determination of the number of transects needed to achieve a specific level of confidence in the data.

Monitoring Resources

For additional information on monitoring, refer to the following resources:

Elzinga, C.L.; Salzer, D.W.; Willoughby, J.W. 1998. Measuring and monitoring plant populations. Technical Reference. 1730-1. Denver, CO: Bureau of Land Management.

Lee MacDonald et al. Monitoring Guidelines to Evaluate Effects of Forestry Activities on Streams in the Pacific Northwest and Alaska. EPA/910/9-91-001. May 1991.

Monitoring California's Annual Rangeland Vegetation, UC/DANR Leaflet 21486, Dec. 1990.

Hogan, M.P. Cave Rock Revegetation Monitoring Program – Improving Sediment Source Control Projects in the Lake Tahoe Basin, US Forest Service, LTBMU, and Nevada Division of State Lands. July 2005.

A Word About Statistics and Rigorous Monitoring

The term "statistics" usually brings a shudder of either fear or laughter to many people. "Lies, damn lies, and statistics." The fact is that statistical analysis and quantitative monitoring, when done correctly, can be a very powerful approach to understanding what exists and what does not. Since measuring every square inch of a project or treatment area would be difficult, and impractical, proper use of statistics allows us to monitor a representative subset of the project and use that data to make statements about the entire project area (or "area of interest"). The rigor of the monitoring (see Sampling Design) determines how statistically "confident" we are that the data collected in the measured area are representative of the larger project area. The higher the "confidence" in the data, the more defensible that data is to scrutiny. Of course, measurements need to be taken in a certain way and data must be analyzed in a particular way, but none of this needs to be extremely complicated or expensive. While actual research-level analysis requires a greater amount of time, experience, and often funding, collection of robust and defensible data is well within the reach of most project implementers and, if used properly, can lead to cost savings on future projects.

Tool 17 - SKI RUN CONSTRUCTION TECHNIQUES

The run on the left was graded, the run on the right was cleared.

Definition

Ski run construction techniques refers to a wide range of methods used to create, expand, or improve ski runs by removing or reconfiguring vegetation, rocks, and large woody debris and, in some cases, reshaping slopes.

Purpose

The purpose of this tool is to describe a range of techniques that can be used to create new ski runs or expand existing runs, and to explain the key factors that must be considered to minimize the impacts of ski run construction on watershed functions. These techniques are considered within the context of maximizing watershed function and providing maximum protection against erosion.

Overview

Not all ski runs are created equal. A properly constructed ski run can be a valuable asset, while a poorly constructed ski run can create an unnecessary and long-term erosion liability. There are a variety of strategies and tools available for creating new ski runs, and the decision to pursue one strategy over another can determine whether a new ski run will continue to provide valuable watershed services or create a long-term source of erosion problems.

Planning Considerations

What is the current condition of the planned run alignment?

If a new ski run is being constructed in an area that is relatively undisturbed, construction plans should include measures to protect existing resources to the greatest extent possible (such as topsoil salvage and reuse—see Tool 7). Refer to the Tool 2, Watershed Flow Assessment and Tool 3, Site Condition Assessment, for guidance on assessing current conditions and developing appropriate treatments.

Can the existing grade be maintained or is grading required?

If the current grade is adequate for the desired ski run, low-impact clearing and grading techniques can be used to minimize impacts and protect soil and vegetation resources. Grading typically results in impacts to soil and vegetation that are very difficult and expensive to repair after the run has been constructed. Grading also typically results in reshaping of slopes, which can alter hydrology and drainage patterns and can lead to large-scale erosion issues unless water flow is planned for and accommodated. If grading is required, plans should include (at a minimum) topsoil salvage and reuse to ensure that soil nutrient and organic matter levels are adequate to establish and sustain a robust plant community following construction (see Tool 7, Topsoil Salvage and Reuse).

Does the run alignment cross any streams or water flow areas?

Careful consideration must be given to existing water flow areas and eliminating ski run impacts on them and vice versa. Runoff from ski runs must be carefully accommodated so that no additional erosion is created. This planning consideration is perhaps the most critical and potentially problematic.

Will run construction result in concentrated water flows?

Terrain alteration usually results in disrupted surface flow, either from drainage interception or through the development of a compacted surface or subsurface. These flows will need to be anticipated and then monitored to ensure that they are adequately accommodated in a stable flow path.

Will run construction intercept, disrupt, or affect other area uses, such as roads or trails?

Ski run construction is sometimes done in areas that contain roads or trails. Run construction should be planned to minimize the impacts of the ski run on those features and to minimize the impacts of those features on the ski run. For instance, if a high-use road exists that will cross the ski run, consideration must be given to the potential for that road surface to carry water that can become an erosion source if it is allowed to exit onto the ski run during runoff periods.

Can run construction be done in such a way as to improve wildlife habitat?

The construction of a ski run does not always create a negative impact on wildlife. For instance, many ski resorts have overstocked forests on their property that preclude many mammals and birds from inhabiting them. Carefully planned and considered ski runs, especially when linked to other management activities such as forest health and fuels reduction treatments, can improve wildlife habitat. Wildlife specialists can offer input into which species will benefit from which types of treatments. Further, ski runs themselves can become surrogates for natural forest openings and can be used by wildlife for grazing purposes if the appropriate plants are established. Plants including a range of native grasses, berry- and seed-producing species, and shelter species can provide a range of benefits to wildlife. Careful planning can thus create a benefit and help to build common ground with environmentally active citizens and groups.

Ski Run Construction Tools and Techniques

Table 17.1 on the following page provides an overview of alternative ski run construction techniques.

Table 17.1: Ski Run Construction Alternatives Matrix

Methods	Definition	Advantages	Disadvantages	Photos
SMOOTH GRADING	Trees cut and removed; large rocks removed; stumps buried or removed; slopes reshaped to create desired terrain.	• Requires common equipment and minimal training • Relatively fast to implement	• Alters hydrology and drainage patterns • Typically displaces topsoil • Likely to increase erosion • Requires high level of treatment effort to mitigate impacts	
CLEARING	Trees cut and removed; stumps flush-cut; rocks left in place wherever possible; minimal disturbance to soil and vegetation.	• Maintains existing slope contours, drainage patterns, and soil profile • Preserves existing understory vegetation and root structure • Little or no follow-up treatment required	• May require specialized equipment such as masticator or tracked chipper	
GLADING	Similar to clearing but only *selected* trees are cut and removed in order to improve skiing conditions in densely forested areas.	• Same as clearing but preserves additional trees and canopy cover	• May require specialized equipment such as masticator or tracked chipper	

Understanding and Mitigating Impacts

Every construction project results in impacts to soil and vegetation. However, the important questions to consider are: *What are the potential impacts of a particular action? How can I minimize or eliminate some of those impacts? How do those impacts relate to project goals and success criteria? What tools are available to mitigate those impacts?* Table 17.2 provides a framework for considering the operational and functional impacts of different run construction methods and related treatment tools.

Methods	Operational Impacts	Functional Impacts	Relatated Treatment Tools
Smooth Grading	Topsoil displacement	Reduced soil nutrients and organic matter	Tool 7, Topsoil Salvage and Reuse Tool 9, Soil Amendments
	Slope shaping	Altered hydrology/drainage patterns	Tool 2, Watershed Flow Assessment
	Soil compaction	Decreased soil hydrologic function (infiltration, water storage); increased surface runoff	Tool 8, Soil Physical Treatment
	Vegetation removal	Reduced nutrient cycling	Tool 11, Vegetative Treatments
	Mulch removal	Decreased hydrologic function; increased sediment yield	Tool 12, Mulches
Clearing/ Grading	Tree removal	Increased solar exposure; increased shrub growth	Regular mowing or brush cutting
	Soil compaction	Decreased soil hydrologic function (infiltration, water storage); increased surface runoff	Tool 8, Soil Physical Treatment

Table 17.2: Potential Impacts of Ski Run Construction Impacts and Asscociated Treatment Tools

Vegetation Clearing and Maintenance

A wide range of tools exist for clearing and managing vegetation on large scales (such as ski runs). New and innovative types of mechanized equipment are being developed and becoming available at a fast rate, largely driven by the need to reduce fuel loading in overstocked forests to reduce the risk of catastrophic wildfires. Table 17.3 describes several methods that are already being employed by ski areas to remove and manage vegetation and their associated costs and efficiencies.

Methods	Description	Cost per Acre	Acres per Day
Mowing	Mowing with an all-terrain tractor and flail mower	$180-$220	4-6
Mastication	Masticating with an excavator and flail masticating head on the excavator	$1,500 -$2,500	0.5-2
"Pluck and Chuck"	Excavator with thumb smoothing and removing obstacles, some revegetation	$1,000 -$2,000	1-3
Chipping	Hand crew of 4-5 people, self-propelled chipper, and chainsaw	$1,000 -$2,000	1-2
Brush Cutting	Hand crew of 4-5 people, brush saws and rock bars	$200-$800	1-5

Table 17.3: Vegetation Clearing and Management Tools

TOOLKIT

Tool 18 - ACCOMMODATING WATER FLOW

Water flow.

Definition

Accommodating water flow refers to the construction and maintenance of features that are designed to capture, convey, detain, infiltrate, or treat surface water flow.

Purpose

The purpose of water flow features is to accommodate and manage surface water flows in a manner that does not cause erosion. Water flow features can be designed to serve a variety of purposes, ranging from drainage of a project area to treatment of contaminated surface water.

Overview

The intuitive method of dealing with water flow is to concentrate it and get it "off site" as soon as possible. However, simply diverting water off a project area and into an adjacent flow path without adequate consideration of downstream impacts can create more problems that it solves. To accommodate water flow successfully, one must fully understand the watershed context—where the water is coming from, where it is going, and the seasonal variability of that flow regime. This information is gathered as part of an assessment of the overall watershed or drainage area (see Tool 2, Watershed Flow Assessment).

It is imperative that concentrated water be considered through its entire surface residence life cycle. That is, water must be accommodated until it either infiltrates or enters an established water body such as a stream, lake, or river. Once water is concentrated, its flow path must be protected and regularly maintained to remove accumulated sediment (see photo below). One must also carefully consider what type of water flow feature is most appropriate for the site, the flow regime, and the project goals. If water enters or exits a site and is allowed to flow freely, it is likely to concentrate, down-cut, and cause additional erosion down slope. This Tool summarizes several types of water flow features that can be used to accommodate water flow in a manner that does not cause or exacerbate erosion.

Deposited sediment in unmaintained rock-lined ditch.

Tools for Accommodating Water Flow

Water bar.

Water Bars

Water bars are earthen ditches, usually with an associated berm, that are designed to capture and divert water from steep slopes when surface runoff occurs. Water bars can be useful where surface flows are expected. Alternatively, soil and vegetation restoration treatments can be used to maximize infiltration, thus reducing or eliminating surface flows. Water bars have three major problems associated with them:

1) As water bars capture and divert surface runoff, the change of direction, grade, and velocity usually results in sediment deposition. This deposited sediment can create a dam, eventually diverting concentrated water over the water bar and onto the slope below, usually resulting in a rill or gully. Concentrated water can also down-cut into water bars, resulting in additional erosion from the water bar and from the newly concentrated flows. Many ski runs become eroded in this manner.

2) Water concentrated by water bars must exit somewhere and must be accommodated once that water leaves the water bar. This outflow water must be infiltrated, spread, or conveyed effectively in order to avoid additional off-site erosion.

3) Water bars and their associated outflow areas require frequent maintenance to be effective. Most water bars observed in western ski resorts are not maintained adequately, if at all. A single water bar, for instance, may require one to two hours or more to maintain during the summer season. Cumulatively, water bar maintenance often requires a significant capital investment.

Settling Basins

Settling basins are depressions constructed to allow coarse and medium sediment to settle out from the water column. Settling basins can also be used to slow flow velocities. Settling basins have lost popularity in recent years because they are generally ineffective at capturing finer sediment. Fine sediment particles, such as silts and clays, pose a greater threat to water quality than more coarse sediment particles, due to their larger surface area and propensity to accumulate nutrients (especially phosphorus) on their surface. Fine sediment can remain suspended in water for long periods of time—from several hours to several days. Most settling basins are designed to have a volumetric capacity and residence time much less than that required to settle out silts and clays, rendering them a relatively ineffective tool for removing fine sediments. Furthermore, captured sediment must be removed from settling basins regularly or it can be remobilized in future storm events quite easily.

Settling basin near capacity during an early winter storm.

Infiltration Areas

Infiltration areas include a range of features that are designed to infiltrate large volumes of water in order to reduce surface flow. Depending on design goals and site constraints, infiltration areas can be constructed in many forms, ranging from broad and shallow meandering swales to narrow and constrained channels. In some cases, infiltration areas can be designed as landscape features, adding to the amenity or aesthetic value of a project. The primary design parameter for infiltration areas is that they infiltrate the maximum amount of water possible and continue to do so over time. Design and implementation of infiltration areas must take into account the following considerations:

- Infiltration areas should have soils rich in organic matter. Organic matter drives infiltration through soil aggregation. Active soil aggregation helps maintain high infiltration rates over time by reducing the potential for clogging of soil pores by fine sediment. Coarse organic materials such as coarse compost blends or wood chips can be incorporated into soil that is low in organic matter to drive aggregation and help sustain high infiltration rates over time. See Tool 9, Soil Amendments.
- Excessive deposition of fine sediment into infiltration areas will reduce infiltration over time. Forebays or settling areas are recommended for areas where high sediment transport is expected.
- Infiltration areas should be designed to accommodate expected maximum water velocities. Vegetation is an important element of this design. Additional design features may include partially buried rocks within the flow path to dissipate flow velocities, gravel or partly graveled surfaces, thick mulch stabilized with rocks, and other flow dissipation and surface protection elements to minimize additional erosion.
- Vegetation for infiltration areas should be designed for dry-season soil moisture conditions. That is, infiltration areas may not be wet all through the year and thus may not support wet-site plants. In fact, wet sites seldom infiltrate well due to the saturation or near saturation soil conditions of those types of sites. A mesic to dry vegetation community should be used if the site is not wet during the summer months.

Infiltration areas off Highlands View Drive at Northstar-at-Tahoe. Full soil-vegetation treatment was implemented to maximize infiltration over the entire roadside. In addition, berms were constructed every 50 feet to direct high flows to stable, rock-armored outfall areas.

Vegetated swale

Rock-lined swale

Spreading structure

Vegetated Swales

Vegetated swales are broad, shallow features with well-established and dense vegetation that are designed to infiltrate and convey water during low to moderate flows. Vegetated swales are not commonly used where high flow velocities are expected because of water's tendency to down-cut through vegetation and cause erosion. Vegetation for swales should be selected based on the driest part of the season. Sod can be used, but requires the same soil conditions and prep that a seeded or planted area needs. Many sodded swales return to bare soil within three seasons if soil conditions are not adequate to support plants. The design parameters listed for infiltration areas (see previous page) are also key considerations in achieving success with vegetated swales.

Rock-lined Ditches/Swales

Rock-lined ditches and swales are similar to vegetated swales but are designed to accommodate higher flow velocities. The standard design for rock-lined ditches has been a compacted ditch that is covered with a protective fabric and one or two layers of cobble or other size rock. Recent work in the Lake Tahoe region (Upper Cutthroat Environmental Improvement Project in Placer County) has tested an improved version of this treatment. A new rock-lined swale design was developed, consisting of a swale with tub-ground wood chips tilled into the soil beneath the ditch to a depth of eighteen inches. The finished ditch was then seeded and covered with coir (coconut) fabric and one layer of rock. In both runoff tests and storm events, this swale infiltrated large volumes of water, thus reducing flows to downstream infrastructure.

Spreading Structures

Spreading structures are designed to intercept concentrated water and redistribute it in a dispersed manner. Spreading structures are commonly used to accommodate outflows from settling basins, evenly distributing water over a broad, flat outlet rather than channeling it through a narrow one. One primary consideration of spreading structures is that the surface of the outflow/spreading structure must be well protected, usually with a combination of vegetation and rocks. Further, spreading structures/areas must have high infiltration rates if water is expected not to re-concentrate.

TOOLKIT

Lessons from the Field

A local ski area expanded in the early 1990s. A steep slope was cleared of trees and graded smooth, then water bars were added to shunt water off the run. The area was hydroseeded and mulched with straw. Subsequently, runoff began to cut a drainage path down the side of the run, eventually cutting a four-foot-deep gully that exposed snowmaking lines, causing them to eventually rupture and create additional erosion. The first fix entailed repairing the snowmaking line and backfilling the gully. Four years later, the area became severely eroded and exposed the snowmaking line again. An engineer was called in who drew up another series of water bars and some drainage repairs. However, the sources of the problem—a series of springs upslope, highly compacted soil, and lack of a well-established drainage path through the site—were not considered. Then, in 2005, a disrupted drainage caused a landslide in an undisturbed area, which cut a deep gully through the ski run in the same location. The planning team for the fix was made up of an experienced ski manager and an erosion specialist, who decided to use the new gully as the basis for a protected flow path. They reasoned that because the flow kept returning to this area, they would accommodate it and create a rock-lined channel for it to travel through. Adjacent areas were also restored with full soil-vegetation treatment, thus improving infiltration and reducing surface runoff. Ever since the latest fix was completed, the flow path has remained stable and no further down-cutting or erosion has occurred. Previous approaches proved to be expensive, both in direct maintenance/lost revenue costs and in drawing up plans that ultimately failed to solve the problem. The current plan acknowledges that water will always flow down this ski run from the top of the mountain and is designed to accommodate it in a stable channel that protects the site from further erosion.

NOTES

"We are part of the earth and it is part of us ...
What befalls the earth
befalls all the sons of the earth."

- Chief Seattle, 1852