Sediment Source Control Handbook

An Adaptive Approach to Restoration of Disturbed Areas

A Sierra Business Council Publication

Produced in collaboration with the Lahontan Regional Water Quality Control Board and the California Alpine Resort Environmental Cooperative

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January 2009

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This Project has received support through a grant from the California State Water Resources Control Board with funding from the U.S. Environmental Protection Agency under the Federal Nonpoint Source Pollution Control Program (Clean Water Act Section 319).

For more information
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Sierra Business Council

Pioneering innovative approaches and solutions to foster community vitality, environmental quality, economic prosperity, and social fairness in the Sierra Nevada

About the Sierra Business Council

The Sierra Business Council is a nonprofit association of more than 750 businesses, agencies, and individual members committed to promoting a new perspective on regional wealth while emphasizing collaboration in planning and policy making. The Sierra Business Council is the only business organization serving the entire Sierra Nevada region. Founded in 1994, the Sierra Business Council does not believe that Sierra communities must choose between economic, social, or environmental health. We demonstrate, through innovative projects, that social fairness, environmental quality, and economic prosperity are the critical elements of long-term sustainability in the Sierra region.

The Sierra Business Council is a resource for business leaders, government officials, and other decision makers seeking solutions to local and regional challenges. Our work includes research, policy analysis, public education, leadership development, and collaborative initiatives with local and regional partners. We are involved with numerous collaborations between private, nonprofit, and governmental organizations. We educate and inform a network of community leaders and have assisted more than 200 Sierra towns in the creation of more vibrant, prosperous, and sustainable communities. Through on-the-ground programs, the Sierra Business Council demonstrates a style of collaborative leadership that turns complex challenges into elegant solutions.

ACKNOWLEDGMENTS

This document is the product of the vision and commitment of a great number of people and organizations, many of whom were originally thought to be unlikely partners in an effort such as this. Regulators and those whom they regulate, consultants, scientists, practitioners, and a range of interested individuals have all come together and in a number of ways have helped put this document together and see it through to fruition. The hardest part is often the finish line. This document would not have been finished without the persistence and hard work of Kevin Drake at Integrated Environmental Restoration Services (IERS), many weeks of field monitoring by Rachel Arst (IERS), and the able input and review of Krissy Gilbert at the Sierra Business Council (SBC) and Brian Moss (IERS).

The original vision and energy for this document came from Martin Goldberg, then of Lahontan Regional Water Quality Control Board (Lahontan), and John Loomis at Northstar-at-Tahoe. We were supported and encouraged by Scott Ferguson and Harold Singer of Lahontan and Cadie Olsen, also with Lahontan when this project was getting started. As we moved forward, we were encouraged and supported by Clifford Mann with Mammoth Mountain, Tim Silva with Northstar-at-Tahoe, and Larry Heywood, then with Alpine Meadows and now a ski safety consultant.

The Sierra Business Council managed the collaborative process of this project. Integrated Environmental Restoration Services managed the on-the-ground and scientific work of this project including drafting the Sediment Source Control Handbook, designing test plots, overseeing and assisting with test plot implementation, and monitoring results. IERS maintained partnerships with various research faculty at the University of California, Davis, including Dr. Mark Grismer and Dr. Vic Claassen, who provided valuable technical input on treatment approaches and monitoring throughout the project.

A number of other individuals have been absolutely critical in this effort – investing time in meetings and document reviews, helping in the field, and offering inspiration and encouragement in the face of unknown outcomes.

Thanks to Walt Pachuki and Naomi Garcia, TEAM Engineering, for your generous contribution of time and irreplaceable encouragement and critical eyes to the output; Mike Schlaafman, Erin Lutrick, Todd Ellsworth, and others at Inyo National Forest for too many things to mention and for being solid and insightful and working hard to keep us going; Jason Drew for a critical eye and invaluable input; and Jerry Owens for your insight, your reviewing skills, and your time when you had plenty of other battles to fight.

We feel fortunate to have been able to partner with the Sierra Business Council. Their overall perspective and commitment to the notion that business, community, and environment are not mutually exclusive but can create a true synergy that benefits us all is a powerful and abiding vision for the future. Thanks to Jim Sayer, Paquita Bath, Amy Horne, and Dave Polivy, all formerly with the Sierra Business Council, who all played critical roles in shepherding, reviewing, and pushing this process and this document; also to Anna Toso, Steve Frisch, Krissy Gilbert, and Susan Carpenter: you have all been inspirational influences and have helped point the way to where we might go. We hope this document reflects some of that inspiration.

We would also like to point out that Harold Singer, Executive Officer of the Lahontan

Regional Water Quality Control Board, recognized in this program a process that could supplement or in some cases replace the top-down approach to achieving water quality objectives, and saw that by working cooperatively and as peers, regulators, and regulatees, we could achieve a more effective and positive outcome if a flexible, proactive, and accountable process were available. This document and the process it presents are not intended to replace exising water quality regulations. Rather, they offer a logical approach and set of tools to improve the effectiveness of all efforts directed at reducing erosion and protecting water quality. We hope that this document and the process that created it can be the models they are intended to be.

We are grateful for the opportunity to work with this collaborative and serve as editor for this Handbook. We look forward to continued cooperation and effort on behalf of the Sierra Nevada and watersheds throughout the West.

Michael Hogan

Michael Hogan
Soil Scientist, Restoration Practitioner

The California Alpine Resort Environmental Cooperative (CAREC) emerged as a collaborative partnership that includes representatives from six ski resorts, the Lahontan Regional Water Quality Control Board, the US Forest Service, the Tahoe Regional Planning Agency, TEAM Engineering and Management, Integrated Environmental Restoration Services, and the Sierra Business Council. Time, resources, and technical input were all provided by the core members plus outside experts such as the Natural Resource Conservation Service (NRCS), the Nevada Tahoe Conservation District, and the University of California, Davis. Without this broad support, this document and process would not have been possible.

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INTRODUCTION TO THE SEDIMENT SOURCE CONTROL HANDBOOK

What Is the Problem?

The health of a nation is reflected in the health of its soil. We depend on the soil to grow our food, support our forests, provide clean water, and process our waste. Soil health is deeply interconnected with some of the most pressing environmental issues of our time including global climate change, drinking water supply, air supply, and increasing rates of species extinction. Throughout the West, soil erosion has become a major problem, polluting waterways, depleting fisheries, lowering productivity in forests and fields, and creating myriad other environmental and infrastructure problems. When soil resources are depleted and the soil erodes into a waterway or into the air, it is difficult or impossible to replace it within any reasonable time period. Ski areas, as well as highways, building development, and agriculture, can all take a major toll on soil if those activities do not care for or manage the soil properly. We have created a legacy of carelessness, leaving bare or poorly vegetated soil in the wake of much of our human development.

Awareness of and concern for the soil do seem to be growing, partly as a result of a growing understanding that soil is "more than dirt" and partly as a result of increasing regulations that protect water and air quality. Once soil particles begin to move (erode) they are extremely difficult to capture and are responsible for water and air quality pollution and degradation. Thus this work focuses on sediment source control that keeps particles attached and at their source. Ultimately, we have realized that the protection of water quality starts with protection of soil resources.

What Is This Handbook?

The Sediment Source Control Handbook presents a set of principles and practices for sediment source control on disturbed sites in the West. It has been developed to help people better understand the fundamental concepts of soil protection and restoration, and also to offer specific guidance for those desiring or required to protect or rebuild disturbed soil. Ostensibly, this is a guidebook for reducing erosion on disturbed lands. It is also a methodology guidebook for planning, implementing, and assessing projects of all kinds. In essence, this Handbook is intended to guide the user through a process of restoring function to the soil and the plant community that depends on that soil. If the soil and plant community are robust, healthy, and stable, erosion will usually be limited. And if you, as the user of this manual, can glean additional understanding of process, practice, and progress of restoration projects, we will all benefit. As the responsibility for soil and ecosystem protection becomes more obvious to us as a society and to us as land managers, we will need more and better tools to help us protect and enhance soil resources. We will need to be clearer about our intentions, clearer about our responsibilities, and clearer about how to maximize our efforts to protect soil and vegetation, even as we develop more land. We may soon find that, instead of looking for new areas to develop, we will need to return to areas that have already been developed and repair what we can. We hope that this Handbook serves as an important resource and road map to assist you in your efforts to plan, implement, monitor, and most of all understand ecosystem protection and restoration efforts, whatever kind or size of project you undertake.

A New Approach

The California Alpine Resort Environmental Cooperative (CAREC) was organized in 2003 in order to develop and demonstrate a new approach to planning, implementing, and measuring erosion control projects and to test (and improve) various approaches to site restoration, sediment source control, erosion reduction, and water quality protection. CAREC has employed the philosophy that a collaborative approach between land managers, field practitioners, regulators, and scientists is the most effective way in which to develop an effective, functional, and workable program that is both adaptable and embraced by all partners. This effort is based on the belief that increased knowledge and information sharing will result in better project outcomes, especially if that knowledge is combined with a sense of responsibility and accountability for the outcome.

The Sediment Source Control Handbook has been developed over a six-year period in order to fill the need for a systematic, field-tested approach—including specific goals, treatment tools, documentation procedures, and effective monitoring—to enhance restoration and erosion control practices in ski resorts and disturbed sites throughout the West. Prior to CAREC, projects were undertaken in a trial-and-error fashion, with application information and recommendations coming from industry "experts" and/or sales personnel. Some products and materials have been demonstrated to be effective and others have not. In either case, the projects often have produced less than optimal results, especially on drastically disturbed sites. Furthermore, while a broad range of knowledge and experience exists across resorts, information sharing has been limited. One practitioner's success or lessons learned have seldom been shared, thus minimizing progress throughout an entire industry. CAREC has acknowledged this limitation and now provides a much needed forum for information sharing between resorts. A forum for information sharing is available on the CAREC blog on the Sierra Business Council web site (www.sbcouncil.org). As you utilize this handbook, we encourage you to share your successes and challenges.

How to Use This Handbook

The Handbook is comprised of three main parts:

Part One: Guiding Principles for Sediment Source Control

Describes an adaptive management approach to planning, implementing, and measuring sediment source control and restoration projects

Part Two: Sediment Source Control Toolkit

Describes specific techniques that can be used individually or in combination to implement effective erosion control projects and to measure the effectiveness of those projects

Part Three: Literature Review

Presents and summarizes research information and journal articles that support and provide background for successful, systematic, and ecosystem-based sediment source control projects

Who Should Use This Handbook

Users of this Handbook will include field staff, professional restoration practitioners, planners, regulatory and other agency staff, and members of the public. The Handbook is intended to provide thoughtful solutions to a range of issues. We assume that the reader is interested in learning more about these issues and is willing to invest some time in considering a range of alternatives. Further, this Handbook is built around the concept of accountability rather than simply following directions. Erosion and environmental issues are complex and do not lend themselves to simplistic answers or approaches. This Handbook reflects the opportunities and challenges embedded in that concept. If you are a **project implementer,** you will find much to consider and use in these pages. If you are an **agency staff member,** you will be able to use this Handbook and its tools to consider the validity and amount of thought and planning put into a project that you are reviewing. You can also offer additional alternatives to those who have submitted project plans and help develop appropriate success criteria with which to measure the outcome of a project. If you are a **planner,** you can use this Handbook to develop a complete project and one that has a high likelihood of success. In fact, this Handbook can help you define success criteria that are based on project goals. This Handbook can be employed by a range of other users including **homeowners, teachers,** and **nonprofits,** such as **watershed groups** and **land trusts,** to help develop complete project plans, grant applications, and project review for constituent members. Whatever your need, this Handbook is designed to educate, offer alternatives, provide specific tools, and encourage creativity in approaching sediment source control projects. We hope that through this process, you will be able to play a part in restoring, conserving, and revitalizing soil and plant communities, thus assisting in the long-term sustainability of our natural resources.

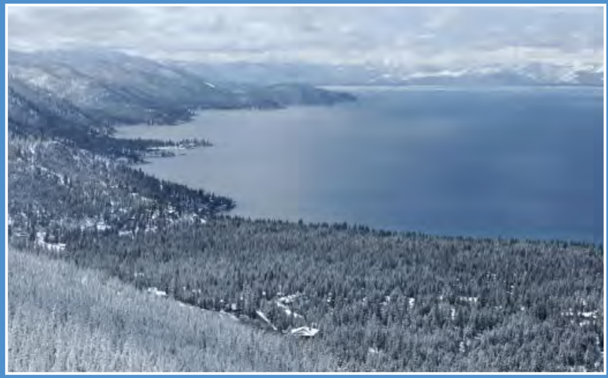
While the focus of this Handbook is on disturbed sites in ski resorts, it is clear that the same issues are being faced in other disturbed areas throughout the West and that the principles and practices described here can be applied to a wider range of project types and areas such as roadside revegetation, forest and range restoration, and home landscaping. In fact, some of the data and information contained in this Handbook have been derived from projects outside of ski areas.

This Handbook is designed to be used as an active field document…so go ahead and get started!

"The soil is the great connector of our lives, the source and destination of all."

— Wendell Berry

part one
GUIDING PRINCIPLES



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INTRODUCTION TO THE GUIDING PRINCIPLES

These Guiding Principles are intended to serve as the framework from which to plan, implement, assess, and improve erosion/sediment control and environmental restoration projects in ski resorts and beyond. They are not guidelines or standards per se, but are instead a set of principles that, taken together, represent an applied adaptive management process. They are intended to assist and GUIDE, rather than prescribe. Success is seldom attained by a first-time practitioner but instead tends to evolve over many years of experience, education, and information sharing. These guiding principles are not intended to be a substitute for actual field experience. Successful environmental projects usually require an adequate understanding of the setting within which one works. However, these guiding principles will help first-time as well as experienced project planners and implementers ask appropriate questions and design a project that has a higher probability of success. In environmental projects such as restoration and erosion control, there are no guarantees of success because of the extremely large number of variables that exist in the project. Some, such as extremes of weather and other natural phenomena, cannot be controlled or designed for. However, when all elements of the project are addressed as completely as possible, the project is much more likely to achieve the desired outcome.

The Guiding Principles are divided into three main sections: 1) Planning, 2) Implementation, and 3) Performance Monitoring and Follow up. These guiding principles describe an applied adaptive management approach to project planning, implementation, monitoring, and ongoing improvement that encourages a stepwise, direct approach. In this way, projects with complex variables become easier to understand and plan.

Guiding Principle

"A statement that articulates shared organizational values, underlies strategic vision and mission, and serves as a basis for integrated decision making. Principles constitute the rules, constraints, overriding criteria, and behaviors by which an organization abides in its daily activities in the long term."

http://www.ichnet.org/glossary.htm

NOTES

Each Guiding Principle follows a general format for consistency and accessibility and contains the following headings:

Goal

Describes the purpose of the Guiding Principle.

Description

Describes the Guiding Principle in greater detail.

Example

One or more examples of the Guiding Principle. In some cases the example also contains a solution or positive example of an application that supports the Guiding Principle. In other cases, the example describes a less than optimal situation that a particular Guiding Principle is meant to address. These examples were included in order to offer concrete examples of each principle.

Solution or Outcome

In cases where the example describes a sub-optimal situation, the solution section describes an ideal application of that Guiding Principle. Where the example describes an action, the outcome section describes the result of the action as it relates to the Guiding Principle.

Additional Suggestions

Describes any additional information or suggestions related to each Guiding Principle.

For references cited, please see the Reference List on page 224.

Toolkit

Most Guiding Principles also include a reference to the related Tools (Part Two) that describe specific treatment tools and strategies for implementing that Guiding Principle.

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FRAMING THE PRINCIPLES: The Adaptive Management Model

The Guiding Principles describe an operational adaptive management process. The concept of adaptive management has been applied for centuries under a number of different names. Physical engineers have used this approach since the first structure or bridge was constructed to continually learn from failures and successes to improve designs. In the realm of applied restoration sciences including erosion control, adaptive management has not been widely practiced and thus, unlike the engineering profession, we have not been able to clearly identify many of our failure modes. For instance, when we attempt to establish vegetation on a disturbed site and it does not establish as expected, we may not know why. Without this type of knowledge, we are likely to repeat past mistakes. The adaptive management process holds a great deal of potential for addressing many of the failure modes and thus can provide clear direction to improvement.

Adaptive management has a number of definitions. As used here, we assume the following: Adaptive management has a dual nature.

First, adaptive management is a philosophical approach toward resource management that acknowledges that we do not completely understand the system within which we are working. It acknowledges that we will proceed with a project or program using existing information while we gather the knowledge that we lack.

Second, adaptive management is a structured decision-making process that includes the following components, usually in stepwise and cyclical fashion:

- Articulate project goals, outcomes, and success criteria (future desired conditions)
- Collect existing knowledge and practices relative to achieving the goals
- Identify information gaps and related research needs
- Develop a strategy and apply knowledge and relevant practices toward achieving the clear project goals
- Develop a clearly defined and defensible monitoring program to determine whether the goals are being achieved
- Identify pre-defined potential management responses if the goals are not met
- Use monitoring data to determine whether success criteria have been met and whether a management response is necessary
- Reassess and improve practices and reconsider the goals or outcomes

While there are a number of manifestations of the adaptive management process, the CAREC partnership chose to use an adaptive management model as adapted from The Nature Conservancy and as outlined in Elzinga et al. (1998) and others (Ringold, Alegria, et al. 1996; Chiras 1990). Figure 1 represents the adaptive management model graphically. It is used throughout the document to illustrate where a particular step or practice falls within this model.

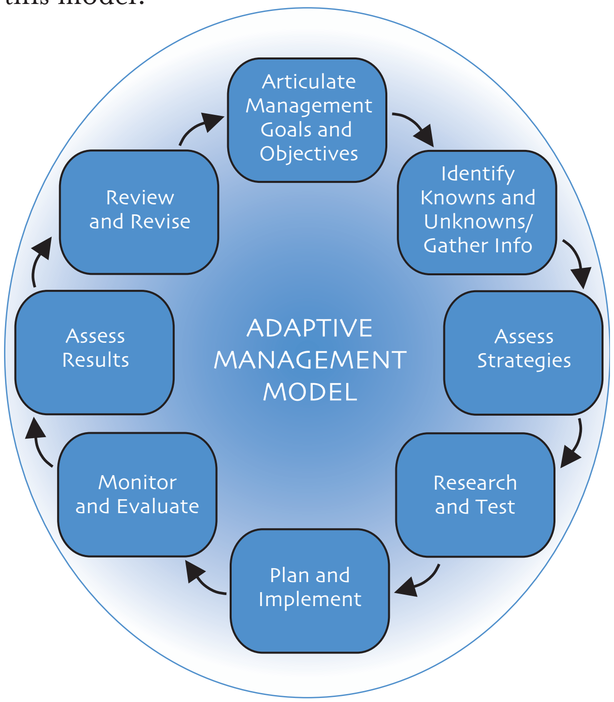


Figure 1: The Adaptive Management Model

SECTION 1: Planning

The Guiding Principles are divided into three sections. The first section deals with planning the project. Planning goes beyond just the project plans themselves and includes other less tangible issues such as clearly defining the project goals, the intended project outcome, including the appropriate individuals on a project team, and defining what success is expected to look like.

Guiding Principle 1: Identify the Need for Action and/or the Problem

Goal

To clearly understand both the need, or trigger, for taking action and the specific problem(s) being addressed.

Description

The steps are to 1) decide or understand why action is being taken and then 2) identify what the problem is or problems are. The need for action may often seem straightforward. Identifying the nature and cause of the problem is often more difficult. Action is sometimes taken without understanding the true nature or scale of the problem and thus may result in solutions that address the symptom, but do not directly resolve the source of the problem.

- Action may be triggered by identification of a water quality/erosion problem, such as rilling of a ski run or a mass failure (landslide). It may be triggered by new site development or disturbance such as the clearing of a new ski run or new road. It may also be triggered by regulatory agency request or any number of other circumstances.
- When the need for action is understood, it is critically important to understand the nature of the problem as completely as possible.
- It may take time to fully understand the nature of the problem. Time spent defining and understanding the problem(s) early in the planning process usually pays off because there is a much higher probability of focusing resources (people, equipment, and money) on the causes of the problem, rather than the symptoms. The contributing factors of the problem may become more apparent during the process of **site assessment** and **limiting factors assessment** (see Tool 3, Site Condition Assessment).

Example

A ski run is heavily rilled. Both resort management and the local USFS representative identify the rilling as a problem and source of sediment loading to a nearby creek. The area is re-seeded, mulched, and irrigated. Vegetation is established. However, after a summer thundershower, rilling is again noted.

Solution

Rilling was merely one manifestation of the real problem. A breached set of five water bars above the area of concern indicated a more complex problem. In this case, the lack of water infiltration in the soil across the entire ski run resulted in the surface runoff. The runoff was not stopped by either the vegetative cover or the water bars. This area will need soil physical treatment so that infiltration rates are increased and surface runoff is decreased (see Tool 8, Soil Physical Treatment). It may also need additional organic matter/soil amendments to maintain loose soil after soil physical treatment (see Tool 3, Site Condition Assessment).

Additional Suggestions

The erosion model below may provide a good starting point or checklist to help identify which elements of the erosion control process may be failing.

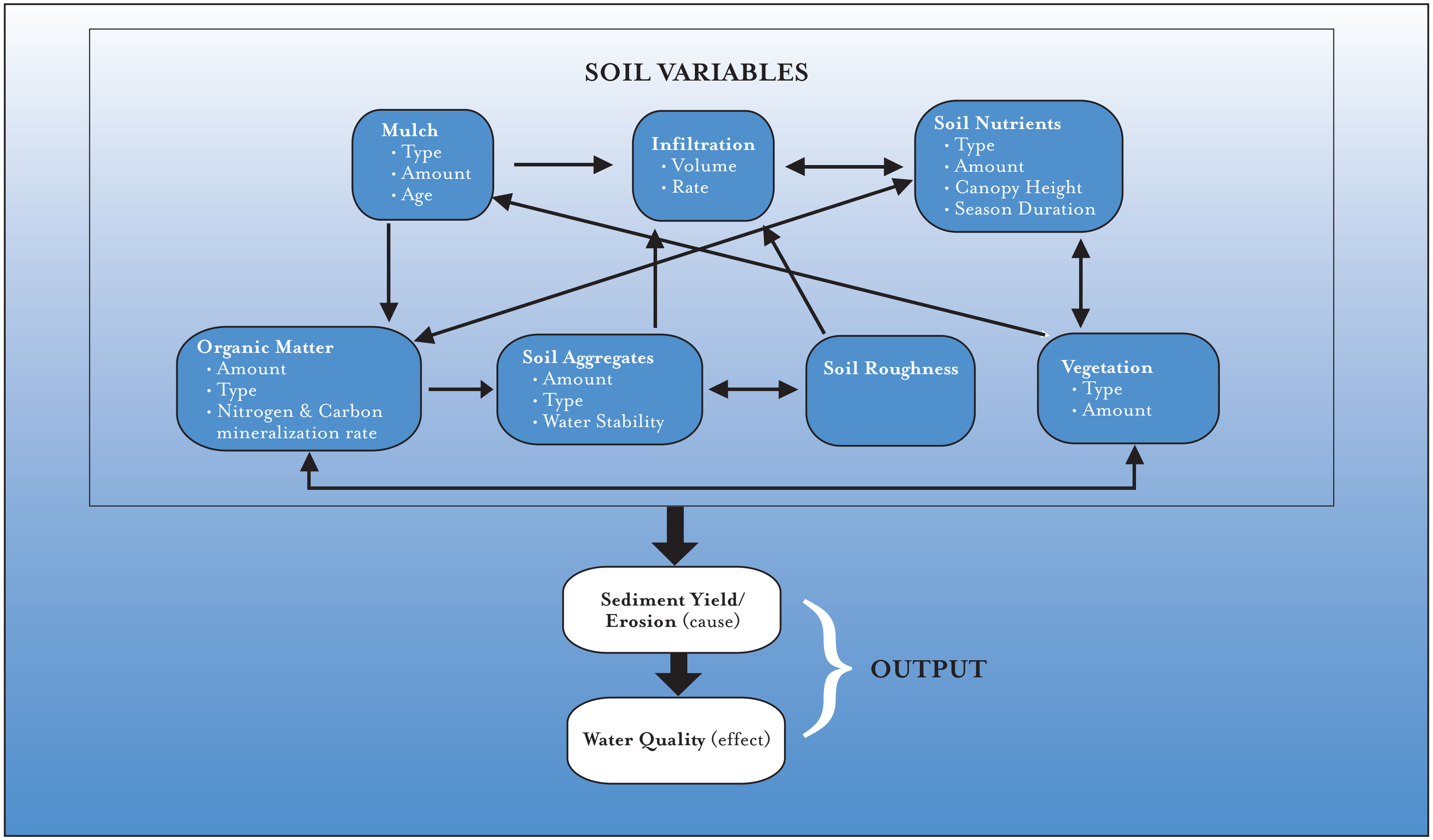


Figure 2: The diagram above represents a conceptual model of the variables that influence erosion processes. These variables are interconnected and must be considered as a system in order to fully understand an erosion problem and develop appropriate treatments.

Guiding Principle 2: State Project Goals and Objectives

Goal

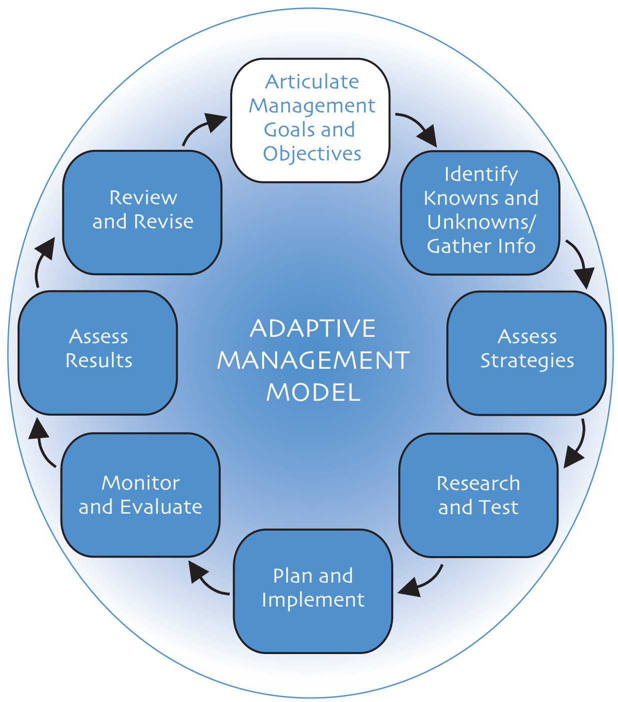
To define the desired project outcome(s).

Description

Developing and defining project goals and objectives allows the project planner(s) to define and perhaps iterate the intended outcomes. Further, where project participants differ in their point of view or individual mandates, the development of clearly articulated goals and objectives becomes the cornerstone for common understanding. The goals and objectives become the basis for "key agreements" which can be revisited during the project for clarity whenever necessary. Where regulatory staff and land managers interact on a project, the more clearly articulated the goals and objectives are, the easier it will be to determine whether those goals have been met. Thus, spending time early in the project to identify and agree on those goals and objectives can save a great deal of time, frustration, and money down the road.

Project goals and objectives should be reference points that define and guide the rest of the project. Ideally, these goals and objectives will be directly linked to **addressing the problem(s)/needs for action** that were identified in Guiding Principle 1. They should also be the foundation for monitoring and success criteria, which are described later in this document.

The words *goals* and *objectives* refer to similar concepts but differ in detail. As used here, goals are broad, general, and non-specific statements such as "controlling erosion on the ski run." Objectives are more specific and often measurable. Statements such as "reducing erosion on the ski run by 50% within two seasons through the use of mulch and revegetation treatment" would qualify as an objective.[1]



The terms *goals* and *objectives* can be confusing. For the purpose of this document, we use terminology that has been adapted from *Ecological Restoration and Watershed Stewardship Planning Terminology* (Stanley 2004).

Goals should be:

- Clearly stated and direct
- General and non-specific
- Inclusive (sediment control AND wildlife habitat maximization)
- Flexible enough to persist over time

Objectives should be:

- Specific
- Measurable
- Realistic and attainable (physically and economically)
- Directly related to the problem
- Time specific (state when and how long)

Success criteria are specific measurable elements directly tied to project goals and objectives (see GP 3).

Example

While goals are relatively non-specific, they can be problematic if not clearly related to the source of the problem. For instance, a goal such as "revegetate the ski run" is vague and may not be the appropriate solution for sediment source control in that area. The statement is based on the idea that vegetation will reduce or stop erosion. However, vegetation alone may not actually reduce erosion to the appropriate level. Poorly framed goals and objectives are difficult or impossible to measure, and thus do not contribute to improved sediment source control.

Solution

Identify Goals: To control erosion (on an eroding ski run) through full soil restoration treatment and native vegetation community establishment.

Identify Objectives: To establish an infiltration rate on the ski slope to levels similar to (within 10% of) a native forested area of similar slope and aspect in the vicinity, and to establish a native plant community with a cover level of 25% vegetative cover within three years.

Additional Suggestions

The process of defining goals and objectives can be simple and involve only a couple of individuals. With larger projects, it may involve a larger number of stakeholders. Generally, involving as many interested and/or affected parties as possible, and as early as possible in the planning process, minimizes unforeseen roadblocks later in the process. Further, when these goals and objectives are the result of regulatory requirements and/or public interest (and scrutiny), it is especially important to involve agency staff and/or members of the public as much as possible. That involvement may be to share the goals and objectives openly and does not necessarily mean that others will help develop them. However, in some cases, review and iteration of goals by a broader range of stakeholders can produce better, more inclusive and robust goals and objectives. Also, inclusion in the developmental stage often results in greater buy-in by all involved parties.

NOTES

Guiding Principle 3: Define Success

Goal

To define success in quantitative terms wherever possible so that the project outcome (at a specific point or points in time) can be clearly measured and understood.

Description

In order to measure the achievement of goals, goals must be translated into specific criteria. Success is defined by quantitative or at least clearly identifiable specific criteria. Success criteria must be achievable and practical. These criteria will generally include a number of elements, all of which taken together support the project goals and objectives. For instance, the percent plant and mulch cover, soil nutrient levels, soil density (cone penetrometer measurement), and visible soil movement are success criteria categories, all of which support the goal of sustainable site restoration. The most effective success criteria reflect the variety of elements needed to support the goals and reflect an integrated process.

Example

A project is being planned whose goals include both erosion control and aesthetic or visual impact improvements. Success criteria may include plant cover, mulch cover, adequate soil nutrients, no signs of visible erosion, low soil density, native flowering shrubs and forbs, and no bare areas.

Solution

Each of these elements will be assigned a quantifiable *"success" value* based on actual verified field plots and research. Based on the differing objectives, each project will probably have different site- and project-specific success criteria.

Additional Suggestions

Success criteria often represent indirect measurements of performance. For instance, soil nutrients do not measure plant growth but rather suggest the nutrients available for plant growth. Claassen and Hogan (2002) and others have studied and shown the relationship between soil nutrients and plant cover on disturbed sites. Cummings (2003) and others have suggested that success should be linked to functional elements such as hydrologic function (infiltration, water storage, etc.), nutrient cycling (soil nutrients, plant potential for cycling, etc.), and energy capture (plant and microbial biomass production and carbon processing, water storage in the soil), rather than just measuring or assessing the above-ground plant community (how the site looks). This change in emphasis may be much more effective in indicating long-term project success and can help in developing measurable success criteria. For instance, soil infiltration may be difficult to measure on each project, but a cone penetrometer can be used to determine soil density indirectly. Thus, if a lower amount of force is required to push the penetrometer into the soil, that soil is likely to be less dense and thus infiltrate more water than a compacted soil.

Toolkit

See Tool 4, Success Criteria, for additional information on developing success criteria.

Management Response *(See Guiding Principle 14)*

A pre-defined management response is an essential element of success criteria on projects that have a specific outcome or level of outcome in mind. Management response describes actions that are to be taken when success criteria are not met that will move the project toward achieving the success criteria. (See Table 4.2, page 79 for an example.) For instance, if vegetation success is defined as 20% total vegetative cover and that criterion is not met, management responses may include reassessing soil nutrients and soil density, and re-seeding the site. This process places the responsibility for action in the hands of the land manager. It defines when a management response is triggered and typically does not require regulatory agency oversight or input. A proactive and agreed-upon set of management responses prior to project initiation can maximize the efficiency of both agency and land managers, making interactions more straightforward and positive since follow-up is agreed upon in advance and not suddenly enforced through crisis regulations.

A Word About Time

The element of time is a critical consideration for developing effective success criteria. In order for a disturbed site to become self-sustaining, key functions must be restored. And function is a process over time rather than a specific point in time. However, in order to be effective, success criteria and project plans must define success at a particular point in time. The best success criteria will define more than one point in time and at each point, progress will be implied. For instance, if vegetation cover is declining over time, that may be an indicator that the site is not sustainable.

NOTES

Guiding Principle 4: Assemble the Project Team and Engage Project Partners

Goals

1) To identify and assemble appropriate planning, implementation, and monitoring personnel that will assure the best project outcome.

2) To include, to the extent appropriate, other interested/invested individuals.

Description

An effective plan and project requires appropriate team members. Project personnel should include those with an understanding of a) the nature of the problem, b) how to fix the problem, c) how to effectively carry out the plan in the field, and d) how to effectively monitor and assess the outcome of the project. Project team make-up and size vary greatly from project to project and from area to area. Simple projects can be managed with a small team or even by individuals, while larger, more complex projects may require a broad range of expertise. An effective team will include, at a minimum, a team leader/project coordinator and a person or persons with expertise directly relevant to the problem areas. A list of potential team members is included in the sidebar at the end of this Guiding Principle section. One common reason for project failure can be traced to planning and implementation by inexperienced individuals.

Another element of this Guiding Principle is the process of engaging other interested parties or partners in the project. This action will be relevant to each type of project. For instance, for a simple culvert replacement, there may not be any other interested parties. However, for larger, more complex and/or controversial projects such as clearing a new ski trail, there are likely to be individuals or groups that, by entitlement or inference, have a stake in the process. Increasingly, the adage is developing: "Ignore at your own peril." Interested parties may include those that have information on the project or project area that can help make the project more successful, or those that have a complaint or do not support the project. Early engagement of any of the aforementioned individuals or groups is likely to produce a better long-term outcome if they are engaged with a common, positive outcome in mind. Many "interested individuals" may surface at the eleventh hour in a project and demand any number of things. If that individual had been engaged earlier in the process, it may have been possible to clarify their perceptions and thus reduce their concerns. Last-minute resistance has stopped or seriously slowed down many projects.

The following sections describe the step-by-step process of developing a team and engaging other parties:

4.1 Select a Team Leader/ Project Coordinator

The most basic element of a team structure is the team leader, project coordinator, and/or contact person. In a simple project, this person may also have the expertise to plan and implement the project. In more complex projects, this person will be responsible for assembling and coordinating the team and should be the central contact point for both the team and the stakeholders.

4.2 Assemble a Team with Appropriate Expertise

Appropriate expertise is critical. A civil engineer will not usually have the expertise to address sediment source control issues and a botanist will not usually be able to design a retaining wall. The nature of the problem or project will determine the expertise needed.

4.3 Identify and Engage Interested Parties

Other individuals or groups outside of the project team may have valuable input or legitimate concerns about the project. If information is available from beyond the team, such as from a person who has historical information about the project site, those persons holding such knowledge should be contacted and engaged. Their information may add a great amount of value to the project in terms of reduced design costs or considerations of critical path elements that are not visible, such as old flow paths or abandoned roads.

Others may have legitimate concerns about the project. Where those concerns are discussed, either the project can respond to them if they were not originally considered or they can be discussed and often can be resolved through a better common understanding of the issue. Indeed, there are times when individuals or groups may not have legitimate concerns but may simply oppose the project for their own personal, but unstated, reasons. Often these individuals or groups will take a defensive or offensive stand. It still may be productive to engage them or at least listen to their concerns to the extent possible. If they are not willing to discuss and negotiate and their concerns do not seem legitimate or transparent, the only recourse may be to continue with the project without their input.

Example 1 – Small-Scale

A ski run has been identified as not meeting specific success criteria. It shows evidence of rilling, a large bare area, and two failed water bars. The mountain manager and the Regional Water Board representative discover these conditions during a routine walk-through. They agree that the mountain manager will provide the Regional Board with a plan to repair the problems and then, upon review, implement the plan.

The mountain manager contacts the erosion control manager on staff who has 15 years' practical experience and several courses in erosion, botany, soil processes, etc., and asks her to develop a plan. This plan is developed, submitted to the Regional Water Board, and approved. The erosion control manager then gives direction to the 3-person crew to carry out the plan as written.

Functionally, this project team is made up of five people: the project leader/coordinator (mountain manager), the planner/implementation director (erosion control manager) and the implementation team (3-person crew).

Example 2 – Large-Scale

A new ski run was defined in the Ski Area Master Plan of 1985. Funding has been acquired to construct this run, which skirts a wetland. Management has begun

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planning this year's construction schedule. In this case, the ski area planning director is responsible for project coordination. This project will be large and complex. The planning director engages planning, permitting, wetland identification and protection, civil engineering, botany, soil assessment, and revegetation/erosion control expertise. Planning will be challenging to coordinate. Further, a second level of the project team, who are kept in the loop through two-way communication, may include those in the community or interest group members who have general or specific concerns—such as intrusion into potential wetland habitat—that could present roadblocks later in the project if not addressed up front. The project coordinator will choose some or all of the expertise from the sidebar list, as appropriate.

Additional Suggestions

Assembling and coordinating an effective team is time-consuming and challenging. However, a great deal of project experience shows that when done properly, this process is likely to ultimately lead to a more effective and efficient project on the ground and can minimize challenges and/or roadblocks to project implementation. On the other hand, many projects have failed or had to be redesigned—at great expense—because the project proponent tried to save money by working beyond the true expertise of the team. During the planning process, additional opportunities may arise where information gaps can be identified within the team setting. That was the case for a Lake Tahoe west shore ski resort. Quantitative data relating to treatment and sediment reduction had been lacking. This resort, along with the project consultant, assembled a team that included the Regional Water Board and the local Resource Conservation District and applied for a grant to address this information gap. In 2008, the resort and partners received the grant and began doing work to address this gap. This is an example of a collaborative partnership that has brought significant additional funding to restoration efforts.

Potential Expertise / Team Members

PLANNING
Ski area managers
Project manager(s)/coordinator
Planners
Wetland specialist
Ski run construction specialist
Ski area implementation personnel
Monitoring specialists

TECHNICAL
Erosion control specialist
Revegetation specialist
Botanist
Geomorphologist
Watershed specialist, watershed hydrologist
Restoration specialist
Engineer

REGULATORY
USFS
EPA
Water Board staff
County staff (engineering and/or permitting)

COMMUNITY
Stakeholders
Environmental advocates

Note: A team may include some or all of the above listed members. Some 'members' may have a limited role. For instance, county staff may simply advise what permits will be needed and will then review the plans to make sure they adhere to county ordinances. Environmental advocates may offer input and review but may not actually develop plans unless they can offer positive input from a technical standpoint. Implementation personnel should review plans to ensure they are feasible. Engineers and erosion control specialists may be involved throughout the process. Recognize that individuals may have two or more areas of expertise; for instance erosion control, revegetation, and watershed hydrology.

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Guiding Principle 5: Assess Strategies for a Site-Specific Implementation Plan

Goal

To develop a sediment source control implementation plan that is based on specific site conditions and that targets clearly identified outcomes.

Introduction

This is perhaps the most complex Guiding Principle and actually includes a number of sub-principles. Care must be taken to understand and address each sub-principle.

Description

There are two main elements of this principle: 1) develop a plan that is based on and incorporates existing site conditions, including hydrology (water flow), soil, and vegetation, and 2) define a process for meeting the desired project goals, objectives, and success criteria. The following list details steps and considerations for developing that plan.

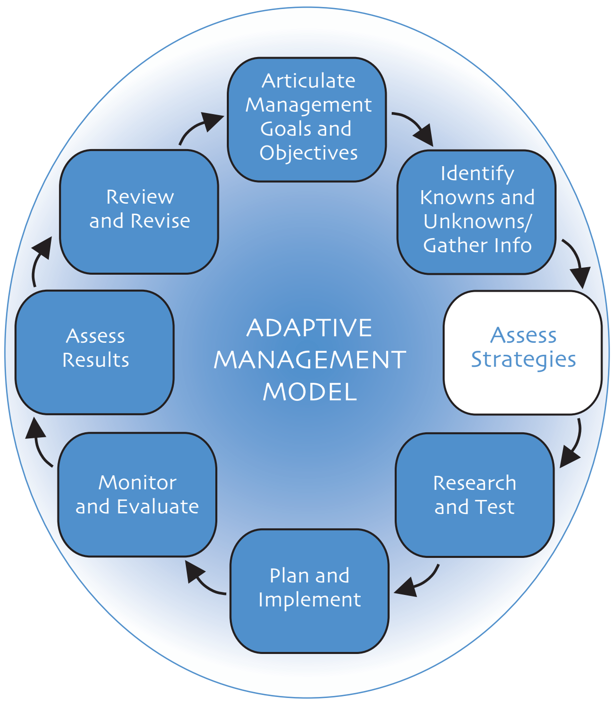
5.1 Assess Site Conditions

Document and understand existing site conditions in order to determine the nature of the problem, the causes of the problem, and the functional condition of the site (soil, hydrology, vegetation, and other elements).

A number of critical tools are described in the Toolkit (Part Two). The first step will be to understand and map water flow onto and from the site. This step is also used to determine site **Limiting Factors** (see Tool 3, Site Condition Assessment), which will be the foundation of developing a treatment plan, materials, and methods.

Example

Careful site assessment indicates that a rill or shallow gully has formed through the center of the project site and has, in fact, caused degradation and erosion throughout the site. By following the rill upslope, the team erosion control specialist discovered that an old road on the upper mountain has captured drainage and diverted it onto the project site, which is more than a quarter-mile away. In order for the project site to be protected and treated, the off-site road must be addressed or water will continue to run across the site, thus compromising the project. To address this relatively simple issue, a drainage and maintenance plan is developed.



5.2 Choose a Reference Site

Identify and assess a suitable reference site that represents a target condition, or reference, to aim for. Assessment measurements should include soil density, soil nutrients, vegetation type and amount, soil type, and a range of other elements. Choosing a suitable reference site serves two purposes: 1) a "good" or self-sustaining site typically defines success by the fact that it is sustainable, and 2) a reference site adds credibility to the goals and success criteria in that it can remove much of the subjectivity from the definition of success or desired future conditions.

Example

Soil nutrient analysis of a nearby reference site that supports adequate native vegetation suggests the appropriate level of nutrients needed in the treatment area. Vegetation analysis of a reference site suggests what vegetation community can actually be supported in this environment. By defining these two elements, success criteria are prepared and easily agreed upon by project partners. A reference site may be a native site or a previously treated site that is performing according to success criteria.

Note: it is important to understand the seral stage of a reference site and adapt the success criteria accordingly. For instance, a mature forest would seldom be chosen as a reference site since it would be impossible to achieve that condition in a meaningful time period. On the other hand, a mature shrub and grass community often is chosen as a reference site. However, success criteria in three years (or whatever time frame is chosen) may list a shrub density (rather than total cover), with the understanding that the treatment site is on the way toward becoming a mature shrub community.

5.3 Develop a Plan Based on the Two Previous Steps

The project plan is based on site conditions and information found in nearby reference sites. By comparing these two, a plan can be developed that is site-specific and achievable. "Stock" plans seldom address site-specific issues that must be understood and addressed in order to achieve success.

Example

A project site is analyzed for both soil density and soil nutrients. The project site has a soil density maximum of 500 psi (pounds per square inch) to a depth of 6 inches, at which point the penetrometer stops (reaches refusal). Total soil organic matter is 0.7% and total nitrogen (N) is 350 lbs/acre. The reference site, a previously revegetated site nearby with a high level of plant cover, has penetrometer readings of 225 psi to a depth of 16 inches. Soil nutrient analysis indicates 3.75% organic matter and 1,800 lbs/ac of total N. This baseline clearly indicates that the treatment site is deficient in soil nutrients and has a compacted soil, thus suggesting that soil tilling and organic matter amendments will be required as part of the treatment.

5.4 Maintain Natural Conditions to the Greatest Extent Possible

It is important to maintain natural hydrologic, nutrient cycling, topographic, and other physical conditions to the greatest extent possible on and around the project site.

Example

During construction, drainages will ideally be left unaltered. Topsoil will be left in place or salvaged and replaced. When one or more of these natural conditions is altered, the plan should re-create the natural conditions to the greatest extent possible. For example, if a drainage is intercepted and/or altered during the construction of a ski run, a new drainage should be constructed that mimics the pre-disturbance drainage as much as possible and/or routes the drainage through the project in a stable channel or conveyance. A road constructed across a hillside interrupts the dispersed surface runoff (site hydrology). The road should be "outsloped" and drainage should go across the road to encourage ongoing dispersion. Capturing the hillside runoff, by contrast, would concentrate water and build up erosive energy.

5.5 Consider Potential Alternative Treatments

More than one potential treatment should be considered. Treatment alternatives can be developed using the tools and techniques described in the Toolkit section of this document (Part Two) or using other appropriate, field-tested tools. Input and ideas should be provided by all members of the team. Time, intensity of the problem, and available resources will define which tools will be most appropriate.

Example 1

A steep slope is eroding and depositing sediment near a stream. Alternative treatments may include silt fencing, straw bales, full soil-restoration treatment, or mulching. The project team reviews the alternatives from different perspectives. Given the proximity to the stream and the temporary duration of some of the potential alternatives, the full soil-restoration treatment is likely to be the most effective though initially the most expensive of the alternatives. However, when long-term maintenance/replacement costs are considered, this most-effective alternative could prove to be the *least* expensive option available.

Example 2

A nearly flat area erodes during high intensity rainfall events. This area is 500 yards from the nearest creek, and runoff must travel through a great deal of duff and vegetation to reach the creek bank. Alternatives include full soil-restoration treatment, mulching, tilling of wood chips, straw bale barriers, or a silt fence. Given the distance to water, the flatness of the slope, the easy availability of wood chips, and the fact that budget constraints exist (it's a ski area), the project manager chooses to till wood chips into the soil to increase infiltration and mulch the soil surface with no further treatment. If this treatment meets the success criteria (no measurable erosion off site and high rates of infiltration), this would be an effective and cost-saving alternative, though it may need re-treatment in the future as the mulch breaks down.

5.6 Incorporate Tests Where Information Gaps Exist

There are more questions than answers relative to sediment source and erosion control. When choosing treatments, planners will encounter information gaps with regard to materials, treatments, time frames, etc. Wherever possible, treatments should be overlaid with tests to help answer those questions and fill information gaps. In this way, each project adds to our collective knowledge base and potentially enhances future project outcomes and costs.

Example

A recent erosion control conference presentation showed that a specific fabric significantly reduced erosion during year one of a large project in South Carolina. A steep road cut near Mogul Lift has been eroding and management has decided to address the problem. The budget is too small to apply fabric to the entire area. Management is also not sure how the fabric will respond to snow over the long term and wants to test it in local conditions. They are able to afford 500 ft^2 of the fabric, which is applied to one portion of the project. In the following three seasons (the time portion of the success criteria) the entire site is monitored, comparing the fabric area to the standard treatment, looking for signs of erosion and measuring plant growth for differences. This test was relatively inexpensive and provided valuable information regarding whether the fabric contributed to achieving the success criteria and its general usefulness for controlling erosion in high alpine areas.

5.7 Choose Appropriate Treatments

The treatment alternatives that are chosen should be adequate to meet project goals and objectives, should be based on site assessment so that they will fit the site, should be field tested if possible, and should be aligned within project budget parameters.

Example

In the first two of the previous three examples, if a silt fence had been chosen, it is unlikely that effective project outcome would be achieved. Silt fences are temporary structures, tend to be compromised by snow, and fail to address root problems. CAREC is committed to avoid these "do something, even if it doesn't work" treatments by rigorously testing alternative approaches. Therefore, treatments that improve soil conditions such as addition of organic amendments and soil loosening, combined with a locally-derived or adapted seed mix and a robust cover of mulch, will support increasing function over time and, if the right type and amount of organic amendment is used, will support project sustainability.

5.8 Identify and Address Potential Threats to Project Success

Impacts on treated sites such as post-project vehicle or foot traffic, skier or Sno-Cat impacts in areas with low snow, lift tower access, recreational trails, or potential ATV traffic need to be considered and addressed. If these impacts cannot be eliminated, protections must be put into place if overall project goals are to be met.

Example

A ski run is smoothly graded. Topsoil is replaced and the site is tilled, seeded, and mulched. After a fall rain, grass begins to germinate. While preparing the snowmaking system, mountain staff decides to drive quads straight up the slope in order to access snowmaking hydrants at the top of the run (in this case, there was a longer access road available to the top of the run). Other staff, seeing the tracks, also begin to use the shortcut. During a late season rainstorm that produces 2 inches of rain in less than an hour, the tracks from the quad become water flow paths and transport sediment to a nearby creek, resulting in a violation from the Regional Water Board. Before the area can be repaired, snow falls. During spring runoff, those tracks continue to transport sediment into the creek, resulting in additional violations. (In California, the Regional Water Board can fine a discharger up to $10/gallon for sediment-laden water delivered to a creek.)

Toolkit

See Tool 3, Site Condition Assessment, for more information.

Simple Fixes

Beware of fixes that seem too simple or like the proverbial "silver bullet." We would all like to find these types of solutions, but they have typically not been shown to be effective in the long term because ecosystems are complex and always changing. However, learning can be one of the most rewarding aspects of a project and can lead to great cost savings and/or more successful projects in the future.

SECTION 2: Implementation

This section describes processes that will assure maximum success when applying sediment control treatments in the field. The Guiding Principles in this section assume that a carefully constructed plan has already been developed.

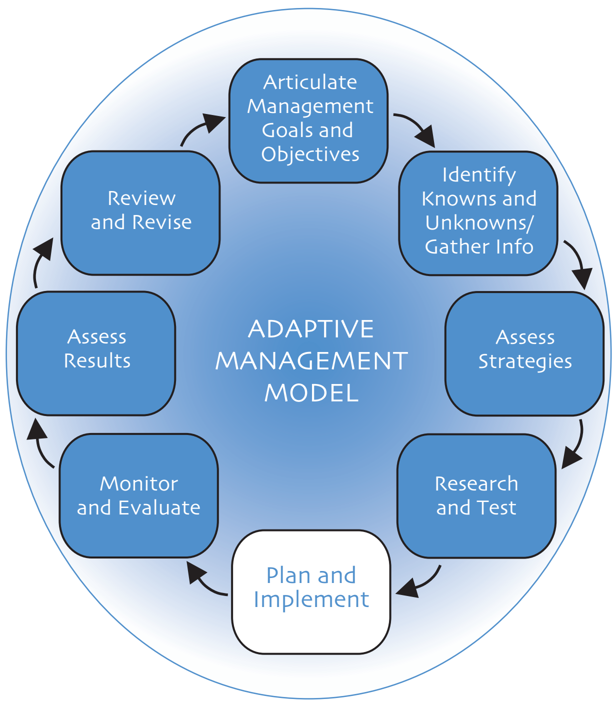
Guiding Principle 6: Train Staff and Associated Personnel

Goal

To increase the level of awareness and understanding of the sediment source control program and build competence in all staff involved in project treatment activities as well as those who are not. This Guiding Principle is for internal resort protocols and practices.

Description

Training is critical to develop competence in and raise awareness of sediment source control, as well as to ensure that no post-treatment disturbances disrupt the project. Implementation staff must be fully versed in project goals, implementation strategies, materials, and techniques. Clear articulation of these elements can make the difference between success due to correct installation and failure due to incomplete or incorrect installation. General resort personnel must understand travel restrictions and ways to avoid inadvertently affecting treated areas. Strategies need to be developed and shared to minimize impacts to treatment areas, such as by mountain bikes, ATVs, etc. (see Tool 15, Protecting Treatment Areas). With full staff support and understanding, treatment areas will be better managed. Further, when personnel understand erosion processes and goals, they can help spot, and possibly repair, small problems such as water bar breaks or clogged culverts. This process, if done effectively, also develops ownership of the outcome of the project or process.



Example 1

A small ski area maintenance crew is spreading compost on the Downhill Run so that it can be tilled in and revegetated. They haul the compost to the run and push it over the side, covering the run as told to do. Unfortunately, the compost is 1 inch deep at the top of the run and 9 inches deep farther down. Remedying this mistake costs an additional four hours for three people. If the mistake were not remedied, the uphill portion of the project would not produce adequate vegetation and thus not meet success criteria, and the downhill portion of the project would pose a water quality threat due to excess compost being washed from the project site into a nearby creek.

Solution 1

A 15-minute training session that explains the soil restoration process and why compost needs to be spread evenly for tilling, and then **demonstrates** that process, would help ensure that the crew distributes the compost effectively and efficiently the first time.

Example 2

The Lower Concourse area near lift 500 has just been recontoured and restored along an old, seldom-used lift access road. To access a new area designed for summer concert activities, Joe Liftoma, a long-time lift mechanic, drives straight across the treated area in the approximate location of the old road. This ruins the treatment and requires soil tilling to get rid of the 4-wheel-drive ruts, plus the added expense and time needed to recontour and replant.

Solution 2

A memo sent to all personnel, communication with department heads, and a directive from the Operations Manager indicates that all treatment areas are to be protected and are strictly off limits to foot, vehicle, and equipment traffic. The memo details the accepted driving routes. An on-site meeting with all affected staff reinforces this directive. A system of personal accountability will help achieve these goals.

Additional Suggestions

This proactive step, while requiring more up-front time, is essential for managing treatment sites. A structured communication process from sediment source control personnel to the rest of the staff can help to meet goals and gain widespread support for the program when staff understand the purpose and strategies being implemented on the treatment sites. This communication may need to be repeated annually, or even seasonally, as personnel change.

Toolkit

See Tool 15, Protecting Treatment Areas, for additional information.

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Guiding Principle 7: Oversee and Document Activities

Goals

1) To oversee implementation of erosion control activities in order to ensure proper implementation of planned treatments.

2) To document implementation of treatments in the form of as-builts, reports, and/or other implementation monitoring documentation. Precise documentation provides information that allows for useful future interpretation of project results, supports ongoing monitoring efforts, and may help satisfy regulatory requirements.

3) For contracted projects, to provide assurance that the contractor is doing the best job possible, thus providing high value to the owner.

Description

Implementation oversight, sometimes called implementation monitoring, assures that treatments are implemented as defined in project plans and specifications. This step is also used to make adjustments to specifications in the field where plans are not feasible as written or where some other method may simply work better.

During implementation oversight, notes, drawings, and photographs that explain what was done, how it was done and when, who was involved, any changes to the original plans, and ideas for alterations or method improvement should be documented. The erosion control manager must ensure that implementation is tracked and then check for accuracy and a consistent tracking format across all projects. Communication of these elements in a timely manner to the appropriate team members is critical. Thus, an effective communication and accountability system needs to be in place in order to ensure the success of this process.

Example - Oversight

A manager instructs his crew to seed the Uphill Down ski run after a snowmaking line is installed. The manager is not able to supervise the project, which requires coordination between the snowmaking installers and the revegetation crew. The snowmaking line is installed and backfilled and the revegetation crew hydroseeds the area. The following day, planned snowmaking equipment movement tears up the hydroseeded area.

Solution - Oversight

Effective coordination or direct oversight of this project would have allowed the revegetation crew to know that the snowmaking crew would need to re-access the area within the week. This would have resulted in only part of the area being revegetated initially. The crew was unaware that lateral lines were being installed, requiring additional entry. Better coordination would have saved five hours of labor and $700 worth of seed and fertilizer.

Example - Documentation

Erosion control treatment is installed along the length of a full ski run, with two cost-effectiveness test areas along one side, where compost is being compared to aged wood chips. The project manager does not record or photograph the process, nor indicate the location of the test plots on a map. She is sure she will remember this simple layout and will record it before winter begins. However, she forgets to record the layout because of the onset of an early winter. During the winter, she takes a beach break and disappears over the Bermuda Triangle, never to return to work. The following season, one plot has much higher plant growth than the other, but nobody knows which treatment was installed where or how much compost or wood chips were applied.

Solution - Documentation

The project manager used the as-built template (see Tool 14, Documenting Treatments) and provided additional information about the treatment. She also put stake chasers at each corner and marked the corners with small rock cairns. She then mapped the site using GPS and created a site map with the coordinates. The following season, her replacement knew exactly what was done, where it was done, how deep the soil was tilled, the exact seed mix, and who worked on the project in case of questions. He also had photos of the treatment process so he could better understand how the treatments were implemented.

Additional Suggestions

Project oversight can make the difference between success and failure. While plans may be carefully prepared, there is no guarantee that they will be properly implemented. There are many incentives to install treatments at a substandard level, including cost, time, and personnel. Adequate project oversight by knowledgeable, empowered individuals can prevent substandard treatments and will often pay for itself in the end. Project documentation and tracking can make the difference between knowing why a project treatment worked and having no idea why it succeeded or failed. Both elements take extra time initially but significantly reduce wasted resources and frustration, and can lead to more cost-effective projects in the future. In addition, cooperative and proactive oversight can often lead to more cost-effective and innovative techniques being developed by the contractor and incorporated into future project plans.

Toolkit

See Tool 14, Documenting Treatments, for additional information and an example of an as-built report.

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Guiding Principle 8: Protect or Optimize Hydrologic Function

Goal

To maintain or create site conditions where hydrologic function, especially surface hydrology, is accommodated and does not degrade the site or the watershed.

Description

Surface hydrology (flow patterns) typically has a major influence on watersheds and on specific projects. When disturbance occurs, some of these flow patterns can be disrupted. Site and watershed hydrology, especially surface flow patterns, must be well understood and accommodated in the site assessment and planning process. Planning for and accommodating natural surface flow is critical whenever new developments disturb the soil. The most effective approach is to leave existing flow patterns undisturbed and design around them. Where that is not possible, a high level of practical planning is needed to address and accommodate existing and potential water flows.

Example 1

A ski run was built that intersected an existing drainage. However, the project engineers who designed the project had little understanding of intermittent surface hydrology. The old flow patterns were not accommodated in the design, and in three subsequent runoff events, major erosion damaged the ski run. Each time this occurred, a great deal of time and effort was required to fill in the gullies and in two cases, to fix the snowmaking lines that were exposed.

Solution 1

Finally, the mountain manager and an erosion/hydrology specialist collaborated and decided to identify and rock-armor and seed the primary flow paths. This resulted in a stable, vegetated site that is capable of carrying seasonal and pulse runoff without eroding.

Example 2

A new ski run was cut down a steep north-facing slope that holds snow late into the spring. This slope was logged more than 40 years ago, and remnants of four legacy logging roads that transected the slope were still present. The ski run was cut and successfully revegetated. Five years later, large, 3-foot-deep headcuts and trenches could be seen from across the valley during the summer. Large amounts of sediment from those trenches (gullies) were deposited into the nearby creek, reducing summer flows and essentially ruining the little remaining fish habitat.

Solution 2

Two elements of this situation contributed to the problem. The most obvious is the capture of flows from the four roads by the ski run. This contributed to high volumes of concentrated surface flows. In this solution, the legacy roads were eliminated (full re-contour restoration), surfaces restored, and the road capture of runoff water eliminated. A related and more subtle issue is that the construction of ski runs tends to result in a great deal of compaction, particularly in high-clay soils. Compaction results in very low infiltration rates and greatly increases sheet flow runoff, which also contributes to sediment movement throughout the entire ski run. This type of erosion is difficult or impossible to see until rills and gullies begin to form. The solution was to add organic matter to the soil surface and till the run in strips across the run face to maximize infiltration. This process effectively reduced surface flow by 600%, thus reducing, and in many cases eliminating, erosion.

Additional Suggestions

Designing for effective hydrologic function related to roads, ski runs, and other disturbance areas needs a great deal of further investigation. Standard Best Management Practices (BMPs) do not tend to deal with this issue in a systemic manner. In developing the project team, an experienced erosion specialist with a background in hydrology should be consulted. Some ski resorts may have experienced staff who, through years of experience and observation, may already have these skills.

Toolkit

For more specific information on maintaining and restoring hydrologic function, see:

- Tool 2, Watershed Flow Assessment
- Tool 3, Site Condition Assessment
- Tool 18, Accommodating Water Flow

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Guiding Principle 9: Protect or Optimize Soil Function

Goal

To create soil physical and biological conditions that optimize water infiltration and have robust and stable nutrient cycling and sustainable plant and soil microbial communities.

Description

Soil is the foundation of terrestrial ecosystems. Soil functions include nutrient cycling, water storage, water infiltration, plant support, microbial activity, and erosion resistance. Soil physical and biological conditions are the primary determinates of how erosion-resistant a site is. Maximizing soil function on disturbed sites is done through:

- Soil assessment to determine soil density, soil nutrient content, and nutrient cycling potential;
- Soil amendment (organic matter) addition where suggested by soil samples; and
- Soil loosening where density is high and/or where organic matter is to be incorporated into the soil profile.

Where soil function is compromised, project success is highly unlikely. Maximizing soil function may be the most difficult to achieve by using intuition since soil function potential can be largely invisible and tends to require interpretation by an experienced soil specialist.

Example 1 – Large-Scale

Two adjacent ski runs were constructed. The planning team just attended a seminar where it was suggested that tilling and organic matter amendments are important elements of disturbed site restoration. On one run, a standard smooth grading technique was used, employing a bulldozer to smooth the entire run, burying rocks, stumps, and topsoil. Following grading, 2 inches of compost, native grass seed, and pine needle mulch were applied, with the compost tilled in. The other run was constructed using a non-intrusive "pluck and chuck" technique whereby trees were cut (over the snow) and large rocks were removed by an excavator, which made one pass down the run.

Outcome 1

The first, smooth-graded run was extremely expensive to construct but due to requirements by the US Forest Service, robust growth was required, and thus soil amendments were used to replace the buried topsoil. The year following treatment, vegetation growth was moderate. Two inches of compost was not enough organic matter to replace the buried topsoil. However, no erosion was observed, despite minimal plant growth. The second, non-graded run required no further treatment, and since all topsoil was left in place, there was no evidence of erosion. That run required more snow to open than the first run but retained a much more natural aesthetic and offered a more pleasing view from the nearby popular summer hiking trails.

Example 2 – Large-Scale

A hotel was built as part of a ski resort expansion. During the construction of the new main feeder road into the resort, a soil and erosion specialist suggested that all topsoil be removed prior to construction and re-spread after cut and fill slope construction was complete. This was done, and additionally, all of the small trees and root balls were put through a tub grinder and the wood shreds were stockpiled on site. After topsoil placement and tilling, seed was applied and the wood shreds from the tub-ound trees were used as a surface mulch. Since the slopes were relatively steep, water truck irrigation was used in order to germinate the grasses so that their roots could develop the required soil strength. Since the soil was well loosened, water from the water trucks, when applied properly, infiltrated into the soil. This project approach saved the developer a great deal of money since no compost or other soil amendment was used and no permanent irrigation system was installed. Three years later, a robust native grass and shrub plant community was well established and no additional irrigation was required.

Outcome 2

This project was considered successful when measured against the project success criteria. Self-sustaining native vegetation and no visible erosion were the primary success criteria for this project.

Lessons Learned:

1) Early in this project cycle, loose topsoil was placed on a relatively smooth road cut surface. During the first winter after treatment of some of the slopes, more than 27 inches of rain fell in one month, saturating the soils and causing some mass failures, largely due to lack of root establishment. In the second season, water truck irrigation was used, as described above. The project planners learned that water truck irrigation could be quite effective if done properly and on an appropriate schedule since loosened soil allowed water to infiltrate rather than run off, as is usually the case with water truck irrigation.

2) The second lesson learned was that smooth surfaces beneath topsoil can lead to mass failures in very wet conditions. Therefore, the contractor was directed in the future to "scallop" the subsurface region in order to help anchor the applied topsoil and increase the subsurface coefficient of roughness (see Tool 8, Soil Physical Treatment).

Example 3 – Small-Scale

A highway was constructed in Central Oregon. Road cuts were comprised of extremely fine, powdery volcanic soil, very much like soils in many Sierra ski resorts. Soil specialists were called in to assess the potential for that site to erode. It was determined that the soils, after being cut into, were very low in organic matter and were unlikely to support plant growth or to establish the microbial community required to help aggregate the soil. In a small, 40-foot by 70-foot section, compost was applied and tilled into the soil, in order to ascertain whether adding some amount of organic matter would support establishment of vegetation and would help control erosion.

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Outcome 3

Four years following this small test application, a robust, non-irrigated, self-sustaining native grass community had been established, in contrast to the sparse vegetation on the adjacent, non-amended portion of the site. While this application of organic matter was not used on the entire site, and is unlikely to be used on a large scale due to the relatively high cost of compost, the small comparison site will allow planners to understand that this type of application can help them achieve the type of vegetation community desired and to consider the cost-benefit of a wider range of treatment alternatives.

Additional Suggestions

Our understanding of soil processes and soil amendments for steep wildland areas is still in its infancy. Information gaps related to soil function present a range of opportunities for testing.

Toolkit

The Toolkit section (Part Two) of this document describes several tools and techniques for maximizing soil function, including:

- Tool 3, Site Condition Assessment
- Tool 7, Topsoil Salvage and Reuse
- Tool 8, Soil Physical Treatment
- Tool 9, Soil Amendments
- Tool 16, Monitoring

Saving and Reusing Topsoil

One of the most effective methods to maximize soil function is to save and reuse topsoil wherever possible on a new project. Topsoil contains stable organic matter, millions of microbes, and thousands of seeds in every cubic foot. Saving topsoil or not disturbing it in the first place are valuable tactics that cannot be easily replaced by subsequent treatment. Compost and other organic amendments are poor substitutes for topsoil. Every effort should be made to save topsoil.

Guiding Principle 10: Protect or Optimize Mulch and Surface Protection

Goals

1) To provide surface cover and protection as the first line of defense against erosive forces.

2) To provide long-term nutrient input to the treatment area (not applicable for all projects).

Description

Surface cover, or mulch, is a critical and potentially the most cost-effective sediment source control treatment. Mulches vary widely in both form and function and include wood fiber mulch, straw, wood chips/tub grindings, pine needles, gravel, erosion control blankets, and others. Mulch should be applied heavily enough to control surface erosion, and long-lasting materials should be used for permanent applications. Temporary surface covers, such as erosion mats and blankets, can also be used, but these materials do not typically provide adequate long-term (>2 years) protection.

Mulches are known to provide some or all of the following benefits:

- Interception of raindrop energy
- Reduction of surface water flow velocities, reducing erosive (shear) forces, and increasing runoff residence time and infiltration
- Filtration of sediment entrained in surface water flows
- Long-term, slow-release nutrient source
- Infiltration by increasing soil biologic activity/soil aggregation
- Attenuation of soil temperatures
- Reduction of evaporation from soil
- Weed suppression
- Aesthetic benefits

Mulches vary widely in appearance, durability, and cost. Wood chips or tub grindings are a popular choice in the Sierra Nevada. Pine needles have recently gained wide acceptance as an effective mulch that results in a natural-looking surface after application. Erosion control blankets are often used on very steep slopes. However, a great deal of recent monitoring work in the Sierra Nevada has shown that many erosion control blanket applications allow erosion to occur beneath the blanket without being observed. Blanket-type methods of surface protection vary widely in effectiveness and longevity.

Example 1

A planner identified bonded fiber matrix (BFM) as the mulch of choice on a new ski area road cut. This was intended to be a permanent installation. A wood fiber BFM was mixed with seed and fertilizer, then applied (with no other soil treatment). After two seasons, very little plant growth had occurred and the road cut was becoming heavily rilled due to surface runoff.

Solution 1

Mulch selection and application should be linked to project goals and the service life of the mulch. If a short-term, temporary mulch such as bonded fiber matrix is used (1-2 year service life), a follow-up application is necessary. Unfortunately, in this case, short-term cost savings overrode long-term project goals, and therefore the site was not tilled, amended, seeded, or mulched properly. In retrospect, some or all of those treatments should have been applied. In a nearby project with identical conditions, the fully treated site has maintained a high level of plant cover and erosion resistance over many years. Conversely, the site treated with BFM was inspected by the county inspector and since it was delivering a large amount of sediment to a nearby creek, was required to be re-treated, resulting in additional, unplanned costs.

A note on BFM: While this mulch choice may not be cost-effective, it does contain synthetic materials. There is mounting evidence that polymers have a negative impact on ecosystems. Use of natural materials is preferable.

Example 2 – Large-Scale

During an erosion assessment, a ski resort operations manager discovered that a long, narrow ski run had developed a number of rills and a moderate-sized gully, all of which led to a nearby creek. Access to the run was difficult and his budget was slim, but he recognized that something had to be done to address the issue. Coincidentally, this resort had undertaken a fuels reduction program, which produced a large volume of wood chips that were being hauled off site. He decided to use some of the excess wood chips to mulch the run. However, he was still worried about the potentially high cost of spreading the wood chips on the run, which would likely have to be done by hand, given the steep slope and difficult access.

Solution 2

The snowmaking supervisor, who also worked on the summer maintenance crew, noted that they would be making snow in a few weeks and suggested that it would likely be more efficient to spread the wood chips over the snow using the food service Sno-Cat, which was equipped with a large bed. One month later, wood chips were spread over the entire run in two days using the blade on the Sno-Cat to spread the wood chips down the slope. The operations manager estimated that spreading wood chips over the snow saved $3,000 in labor costs for this run compared to hand spreading. The following summer, the crew returned with an excavator to finish the restoration treatment. They used the teeth on the bucket to loosen the dense soil and poke in the wood chips, then spread seed and raked out the remaining wood chips to cover the seed. The operations manager has continued to use wood chips both as a mulch and a soil amendment to treat erosion problem areas that are near fuels reduction projects. This approach has improved the effectiveness of the resort's erosion control projects and saved money by reducing the need to import soil amendments and haul away wood chips.

Example 3 – Large-Scale

A 20-acre, smooth-graded ski run was severely eroding due to surface runoff. The resort operator priced the application of surface mulch to the entire ski run and found that the cost was prohibitive.

Solution 3

Working with the local Water Quality Control Board and an innovative local contractor, a plan was devised to create 6-inch-deep, 4-foot-wide mulch strips using tub grindings across the run. These mulch strips intercepted and filtered sediment from surface flows. By linking this treatment to the project goal of reducing erosion, and by monitoring the outcome, it was shown that this application was nearly as effective at reducing erosion as mulching the entire ski run but was implemented at a fraction (about 35%) of the originally projected cost.

Additional Suggestions

Mulch use has changed a great deal in the past ten years, with more emphasis being placed on long-lasting, durable mulches. During certain times of the year, a large portion of the garbage/waste stream in a ski community consists of materials that can be used as mulch (such as pine needles). As forest fuels reduction work continues, wood chips and other long-lasting, inexpensive mulches may become more readily available.

Toolkit

See Tool 12, Mulches, for additional information and case studies.

Guiding Principle 11: Protect or Optimize Appropriate Vegetation Community

Goal

To apply the appropriate plant materials to achieve project goals.

Description

Vegetation is an extremely important component of any integrated treatment approach to controlling erosion on disturbed sites. The appropriate type, amount, growth form, and condition of vegetation used will affect both the soil succession and the overall project outcome. Vegetation choice should be linked to soil treatment type, site condition, project goals, and desired outcomes.

Vegetation considerations are complex, and knowledge of native plant species and communities is somewhat limited. Considerations for choosing plant material will include some or all of the following:

- Is the plant species easy to establish?
- Does the chosen species germinate easily and grow quickly from seed?
- Is the plant species appropriate for the site?
- If planted from seedlings, what is the expected (and observed) survival rate?
- Does the plant mixture require additional irrigation, and if so, has that irrigation been planned for?
- Does the species regenerate itself?
- Is it an *indigenous* native species?
- Is there risk of a non-native species becoming invasive?
- Is the plant material of choice locally available and in sufficient quantities?
- Does the chosen plant material fit budget realities?
- Can the species survive in a ski run situation (i.e. regular grooming), especially with low snowpack?
- Does the species fit with the desired aesthetic?
- Does the species stabilize the soil?

Example

A steep-cut slope consisted of high-density soil. This site was revegetated with expensive native shrub plantings that were placed in standard planting holes. Planting was difficult and required additional irrigation that actually created erosion during application. Within two months of installation, a late summer rainstorm delivered 1.25 inches of precipitation in less than 45 minutes. Following the thundershower, rills covered the entire slope and approximately 1/3 of the plantings had washed away.

Solution

Habitat or aesthetic goals were confused with soil stabilization goals. In this case, a full mixing of soil and organic matter, combined with the seeding of a grass mixture and low-flow irrigation during the initial establishment period, would have provided the soil with surface protection and soil strength through root structure. Native seedlings are often less effective than grasses for soil stabilization in the first few months after treatment and have shown a propensity for increasing erosion in the short term. A good seeding of grasses and a robust mulch cover (assuming adequate infiltration) would have provided early protection for this area. In subsequent years, seedlings could have been planted to provide a long-term plant community for slope stabilization and deeper root penetration.

Additional Suggestions

Little is known about many native species in terms of direct seeding, transplant viability, propagation, etc. (see **Native Plants Journal** http://nativeplants.for.uidaho.edu/), though this type of research is already under way throughout the West. Planting and tracking survival rates of different native species on each project can provide valuable information to inform future treatments and improve understanding of different plant materials.

Toolkit

See Tool 11, Vegetative Treatments, for additional information on application and effectiveness of different plant materials.

Guiding Principle 12:
Protect Project Area from Further Disturbance

Goal

To reduce or eliminate post-project disturbance in order to maximize treatment benefits.

Description

Once an area has been treated, additional disturbance is likely to re-compact or otherwise disturb the soil, reduce infiltration, and destroy vegetation. Protection against post-treatment disturbance is critically important for project success. In many cases, protection against post-treatment disturbance should be built into the project plan. For example, in some areas where foot traffic is known to occur, an erosion-resistant trail should be designed into the project to keep people off the treatment area. Or, if a quad road is needed, the project planner can incorporate it into the design to provide site access and still reduce erosion.

Example 1

Construction of Bubba's Run had just been completed and subsequently treated. Vegetation was just beginning to sprout when Bubba himself, a much-loved and now retired staff member, decided to take a quad trip to see what his run looked like in the summer. He took the summer road to the top of the run and, in a fit of pride and exuberance, headed straight down the run on his quad. The irrigation technician (also a snowmaker) had just completed watering the run, so Bubba's trip down was a bit slippery and required some skidding. The next spring, two large tire tracks/rills were visible from the top to the bottom of the new run. During that summer, a large thundershower turned those rills into gullies and transported sediment into a nearby creek.

Solution 1

Guiding Principle 6 discusses the importance of staff training. However, not all staff, and certainly not the general public, know to avoid treated areas. In dealing with both staff and visitors, physical blockades, signage, and warnings help enforce the message. Blocking previous access points with boulders, logs, ribbon, and possibly signs would have eliminated a large and growing sediment delivery problem on Bubba's Run. Clearly defining access trails and roads can contain traffic and prevent treatment areas from being re-disturbed.

Example 2

A large disturbed area has been treated/ revegetated next to a mountain bike trail. The Cross Country Mountain Biking World Cup is to be held at the resort in a week, and a large number of participants are in town early to practice. The bike department staff checks the course and requests that the maintenance crew fence off the treated area. However, the crew becomes sidetracked on another project and believes they still have five days until the race. When the lifts open for practice runs, the bikers, seeing an open area with a pine needle cover, use that area for warm-ups and as a shortcut to the lift. By the time the fencing is installed, the entire area is destroyed, requiring extensive and expensive re-treatment. The cost of the re-treatment is not even covered by the profit from the bike event.

Solution 2

When the soil-vegetation treatment was completed, fencing should have been installed immediately, eliminating any potential confusion and protecting the recently completed treatment area. Furthermore, signs should be put in place along the edge of the project explaining that it is an environmentally sensitive area and travel is prohibited.

Additional Suggestions

Where all other restoration elements are in place, post-treatment disturbance is often the one factor that causes project failure. Early planning to protect treatment areas and avoid disturbance pays off.

Toolkit

See Tool 15, ProtectingTreatment Areas, for additional information.

NOTES

SECTION 3: Performance Monitoring and Follow-up

This section describes practices that monitor or assess the effectiveness of site treatments. Monitoring or assessment informs the project proponents, regulators, and other stakeholders how the project is performing relative to success criteria. Monitoring can also suggest where additional treatment may be required before small problems become large. This information can directly help improve the design of future projects.

Guiding Principle 13: Performance Monitoring

Goal

To assess project performance in a quantifiable manner against project success criteria and to gather information for a number of subsequent uses, as described in Guiding Principles 14, 15, and 16.

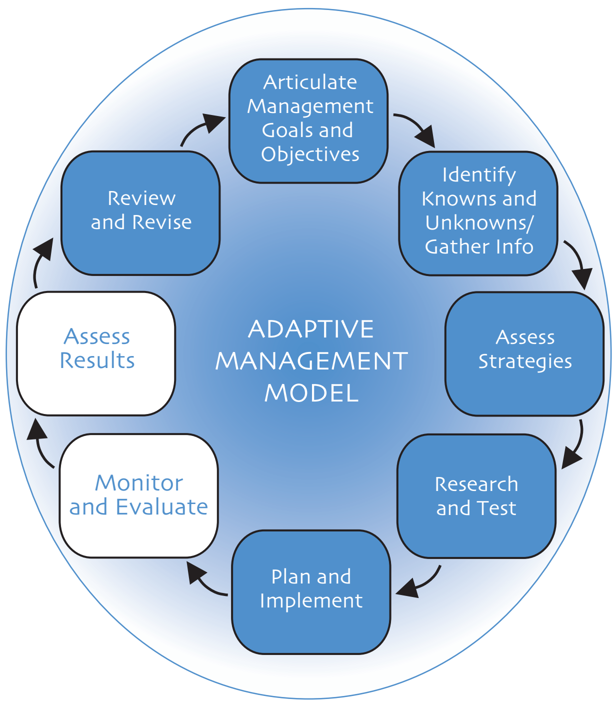
Description

There are three main types of monitoring:

- Compliance monitoring (meeting regulatory, especially water quality standards)
- Implementation monitoring (was the project implemented as planned? This type of monitoring is discussed in GP 7)
- Performance monitoring (how the project is functioning or performing)

It is this third type of monitoring that we are discussing here.

Performance monitoring should gather useful information relative to how well the project is functioning and whether it is meeting the project success criteria. Information or data should be quantifiable to the greatest extent possible. When quantified, information or data is less prone to subjective interpretation and thus argument. Visual interpretation is generally not very reliable. Well-prepared monitoring data and interpretation help the reviewer understand not only if success criteria are met, but also how the treatment area(s) are functioning.



Monitoring may include assessment of any or all of the following methods and parameters, depending on project goals and success criteria:

- Soil nutrients analysis
- Soil density (penetrometer measurement)
- Plant and mulch cover (cover point)
- Visible erosion
- Plant composition (e.g. native vs. weedy species)
- Bare areas
- Drainage and/or hillslope hydrology functions
- **Time**

Performance monitoring will determine whether success criteria are met and trigger management responses (see GP 3) when they are not met. Performance monitoring should also include a time element. A single point in time is rarely as useful as multiple assessments over time.

Example

A run-smoothing project is constructed on the Lower Left Out run of Inner Mongolia. Success criteria list, among other things, a requirement that no bare areas of greater than 15 square yards shall exist in the treatment area and that of the 300 shrub seedlings planted, a survival rate of 50% would be expected. Upon inspection, a large bare area was noticed as a result of a small surface slump. Further, in the nearby area planted with seedlings, only 40% had survived, some of which had been in the surface slump area. The erosion control manager, who had been tasked with inspection and success assurance, noted the problems in his monitoring assessment and report.

Solution

The success criteria included management responses to both of these issues. The bare area management response was to re-mulch and re-treat the area if indicated. Since only a slight amount of movement occurred, most of the soil amendment remained in place. Soil was moved back into place by hand some re-seeding was done, followed by mulching and irrigation. Since only 120 seedlings survived the winter and a plant census showed that two particular species had the best survival rates (85 and 70%), 75 individuals of those two species were planted and irrigated. When the USFS staff inspection took place three weeks later, the area was already showing a robust cover of young green shoots in the re-treatment area and the newly planted seedlings were showing good growth and new buds as well.

The results of this process eliminated the need for the USFS inspection staff to take any sort of action since the responsibility and initiative for action had been taken by ski area staff. Note also that the inspection showed that no sediment had moved below the temporary BMPs. The inspection was positive and non-confrontational.

Additional Suggestions

Latitude exists to develop and suggest monitoring protocols and procedures that may be less expensive and/or more accurate in determining project function for disturbed site treatment. For instance, cone penetrometer readings may provide more information about site erosion potential than cover-point monitoring. Work to determine which monitoring methods are most useful and cost-effective is being conducted by a number of entities.

Toolkit

See Tool 16, Monitoring, for information on specific monitoring tools and techniques.

Guiding Principle 14: Follow-up Treatment and Management Response

Goals

1) To address problem areas that fail to meet success criteria so that they can be brought up to acceptable levels (as defined by success criteria).

2) To apply additional resources (water, seed, fertilizer, etc.) that may be needed in subsequent seasons to assure the success of certain treatments.

Description

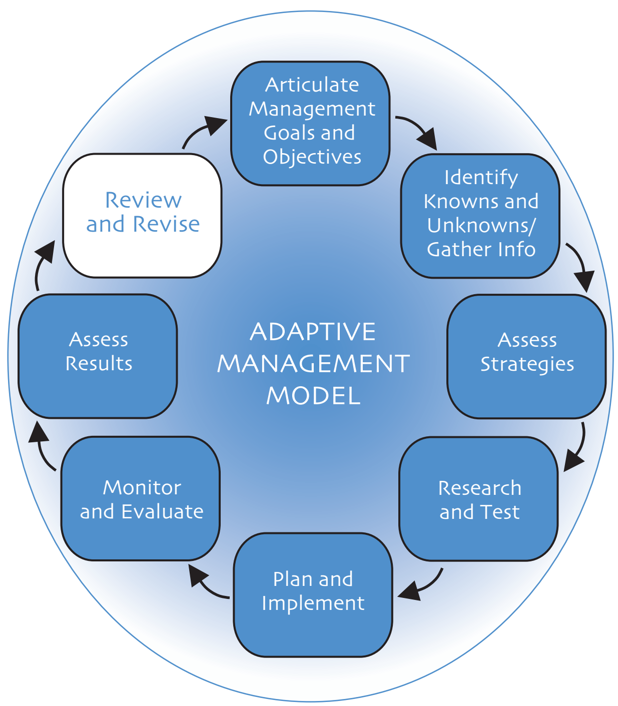
Follow-up treatments can reverse problem trends quickly and cost-effectively and can help a project reach the required level of function if the initial treatment doesn't accomplish the intended outcome. If left alone, small problems can become large and expensive problems to repair and/or result in ongoing watershed, water quality, and environmental degradation.

Example 1

A run-cutting project area is inspected the season following treatment. A small rill has formed and has carried water from above the run and at one point has resulted in a small rotational failure (mini-landslide). The inspector follows the rill upslope and finds that a water bar has filled with sediment and breached. The water bar has a slight level spot, which accumulated sediment, thus causing the breach. The water bar was re-shaped, the rill was hand tilled and re-seeded, and the rotational failure was rebuilt and re-seeded. All were irrigated.

Solution 1

The solution described in Example 1, while somewhat time-consuming, dealt with a relatively small problem. Left untreated, this trend would have resulted in a large gully forming which would also have run across a key service road, requiring re-engineering of the road as well as partial rebuilding of the run. A relatively small amount of work precluded a great deal of work later.



Example 2

A small road improvement project was completed and the road cut received an integrated soil-vegetation treatment. However, due to disturbance during the winter, a small area had no vegetation. The erosion control manager immediately re-treated the area and added irrigation.

Solution 2

The solution is contained in the treatment. If the manager had not paid attention to this area, it is likely that it would have begun to erode and ultimately become a problem requiring a high level of effort to repair, which would have been costly and may have resulted in additional road maintenance work as well.

Additional Suggestions

Follow-up treatment includes standard post-project treatments such as re-seeding, re-tilling, supplemental irrigation, and fertilization. Most projects are more cost-effective when follow-up treatments such as these are minimized and/or employed for as short a time as possible. If an area needs ongoing irrigation or fertilization to maintain success, once expensive follow-up treatments are ended, the site is likely to revert back to low plant cover and high runoff potential.

NOTES

> "If you can't explain it simply,
> you don't understand it well enough."
> – Albert Einstein

Guiding Principle 15: Future Project Improvement

Goal

To use information and data from existing and past projects to improve future projects.

Description

When gathering information from existing projects (see GPs 7 & 13), that information, if assessed and processed properly, can be used to improve the effectiveness and success of future projects. This is especially true if experimental or test elements have been included. With good documentation (i.e. as-builts), successful treatments can be replicated and modified. Treatments that haven't worked as expected can be eliminated or adjusted for future projects. In fact, many projects that don't meet success criteria hold great potential for improving practices as project managers adjust, alter, and change those practices.

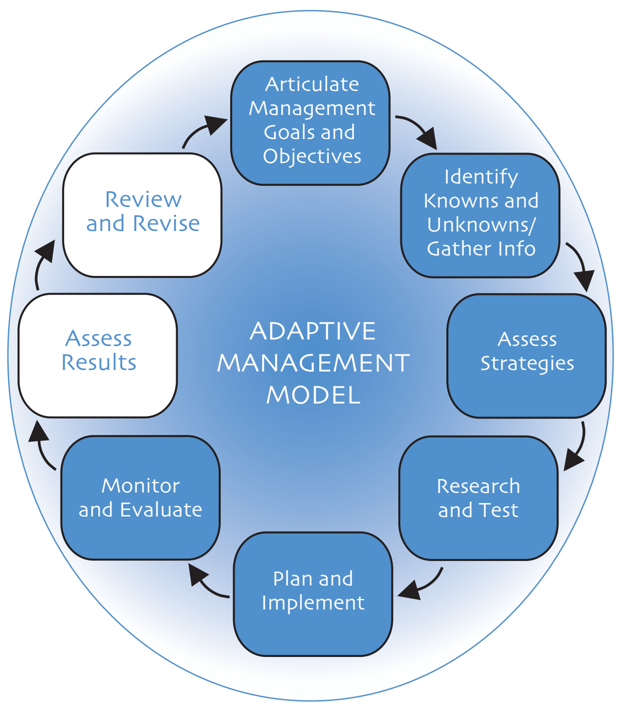
Example

Hydroseeding and fertilization with ammonium phosphate or ammonium nitrate (16-20-0) has been used in ski resorts and other treatment areas for more than twenty years. No goals, success criteria, or monitoring have been applied on most of those projects.

Current monitoring is showing that most hydroseeding projects and other types of surface treatments on drastically disturbed slopes have not reduced erosion to acceptable levels.

Solution

Clearly stated goals and monitoring linked to appropriate success criteria would have allowed project inspectors to recognize that many of those surface treatments were not producing desired plant cover or effective sediment source control. Appropriate monitoring and feedback could have provided information for project improvement. The guiding principles described in this handbook are designed to fill that critical gap.



Additional Suggestions

Collecting data and information on projects should go beyond simple data collection. Information and data are put to their highest use when they are used to improve existing and future projects.

Guiding Principle 16: Information Sharing

Goal

To share useful project information so that other project planners, implementers, and assessment personnel can improve their practices.

Description

Where information can be shared effectively, the information benefits the environment and others doing similar work. It can result in significant cost savings through improved project performance, reduction in "reinventing the wheel," and the increased synergy that is generated from creative interaction between practitioners. This commitment to share information brought the CAREC team together and has driven the production of this document. This step assumes that environmental improvements are likely to be universally beneficial and not limited by proprietary processes.

Information distribution can take many forms such as web-based distribution, professional societies or group meetings, trainings, newsletters, and so on. If tracked efficiently, information sharing improves the state of the art in sediment source control, thus benefiting all participants environmentally and economically.

Example

A ski area employee has just been appointed head of erosion control. Reading a trade publication, she begins to assume that hydroseeding is the most powerful and effective erosion control treatment on the planet. A magazine article shows two people and a car that had all been hydroseeded and were completely covered in grass. She contracts with a local hydroseed specialist to seed an eroding run for the sum of $2,000/acre, a relatively reasonable price. The following season, no vegetation is established and the new manager must defend her job. Photos from the magazine article are no longer convincing!

Solution

The manager goes onto the web to a newly developed CAREC website that lists local results of a number of erosion control field tests. She sees that in high alpine situations on her soils, hydroseeding produced inconsistent and typically poor long-term results. However, a more expensive "integrated soil treatment" had been shown to completely eliminate runoff and thus eliminate erosion in rainstorms up to 5 inches per hour for the three monitoring seasons to date. She quickly calculates how many times she would have to hydroseed to equal the cost of the soil treatment. She reasons that four hydroseed treatments would roughly equal one integrated soil treatment. She implements this treatment and achieves success and, since the results are verified the following season, solidifies her job as well.

Additional Suggestions

Information sharing is challenging since most practitioners are extremely busy getting their normal work accomplished. However, when information sharing is efficient, work will be more effective since practitioners will not have to treat the same site multiple times. Information sharing systems require time, funding, commitment, intention, and participation. Through the CAREC process, we have clearly identified the need for such an ongoing process or processes.

Visit the Sierra Business Council web site (www.sbcouncil.org) for information-sharing opportunities.

"Land, then, is not merely soil;
it is a fountain of energy flowing through a circuit of soils, plants, and animals." – Aldo Leopold

part two
TOOLKIT

TABLE OF CONTENTS - Sediment Source Control Toolkit

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

TOOLKIT

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.

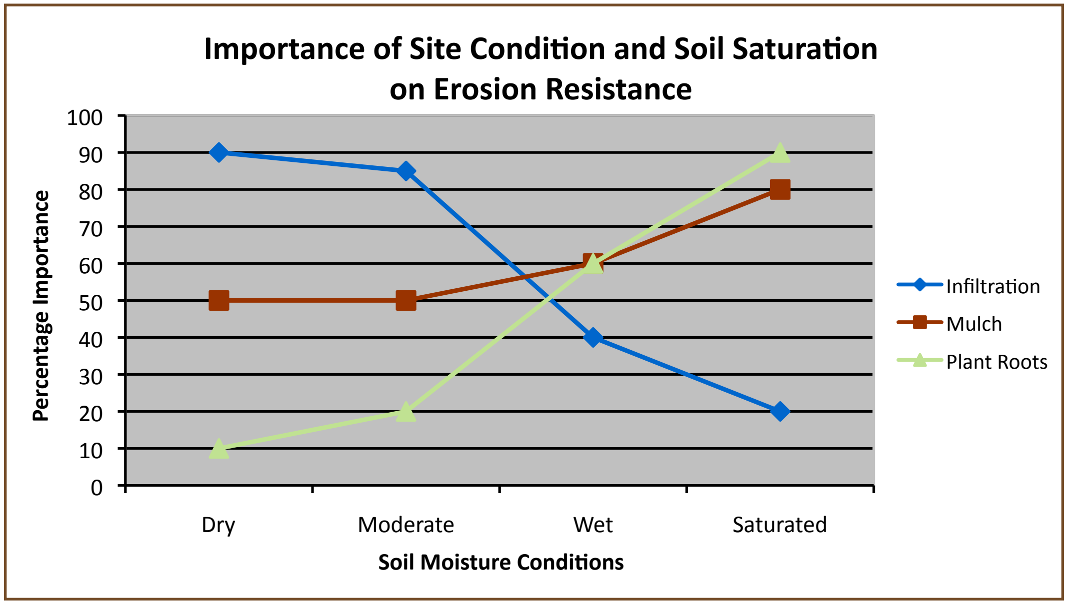


Figure 1: A graphical model of soil moisture levels: The influence of specific site conditions on erosion over a range of soil moisture conditions by approximate percentage of importance. For instance, when soil is dry, infiltration is the dominant process that minimizes erosion. However, when the soil 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.

TOOLKIT

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.

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.

"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:

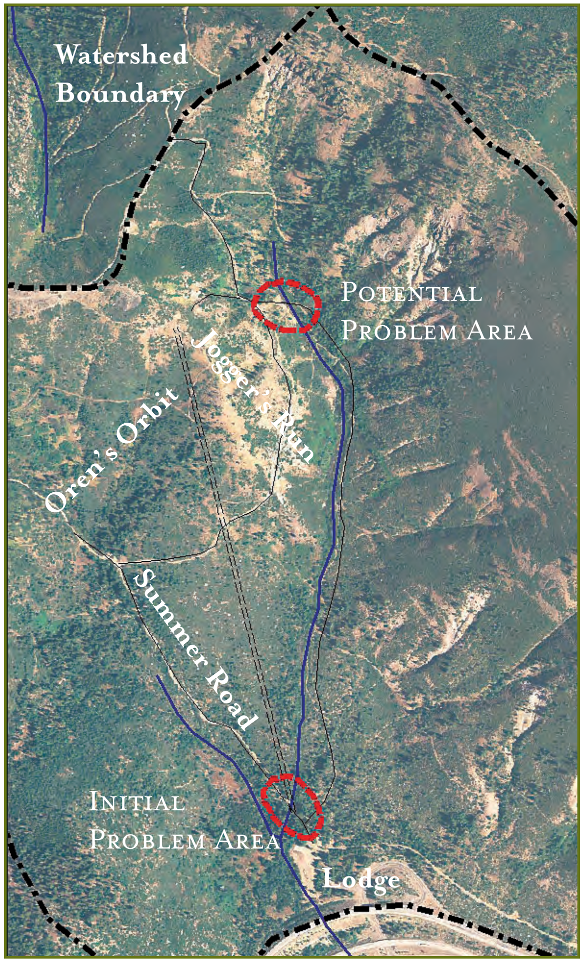


Figure 2.1, Map 1: Example base map with key water flow features, known and potential problem areas.

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 (see Step 3). It is important that Step 2 is led by an erosion specialist with an understanding of erosion processes and water flow patterns during large runoff events in the watershed of interest.

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

Step 3. Conduct field assessment

Take the map and GPS unit into the field to verify and further describe erosion problem areas and key features. Typically, 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

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Erosion on dirt road.

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 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

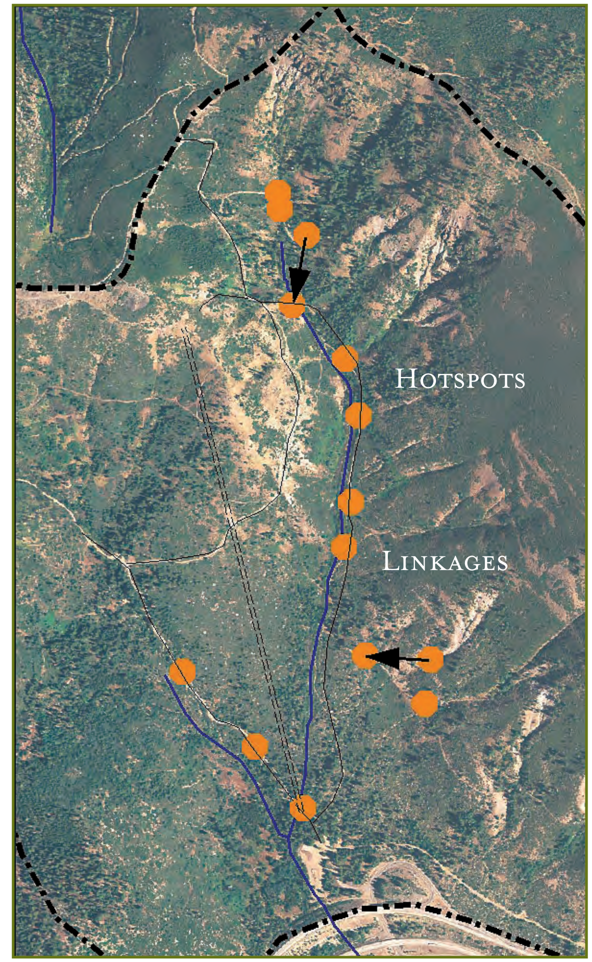


Figure 2.2, Map 2: Example map of problem areas (hot spots) and interconnections.

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.

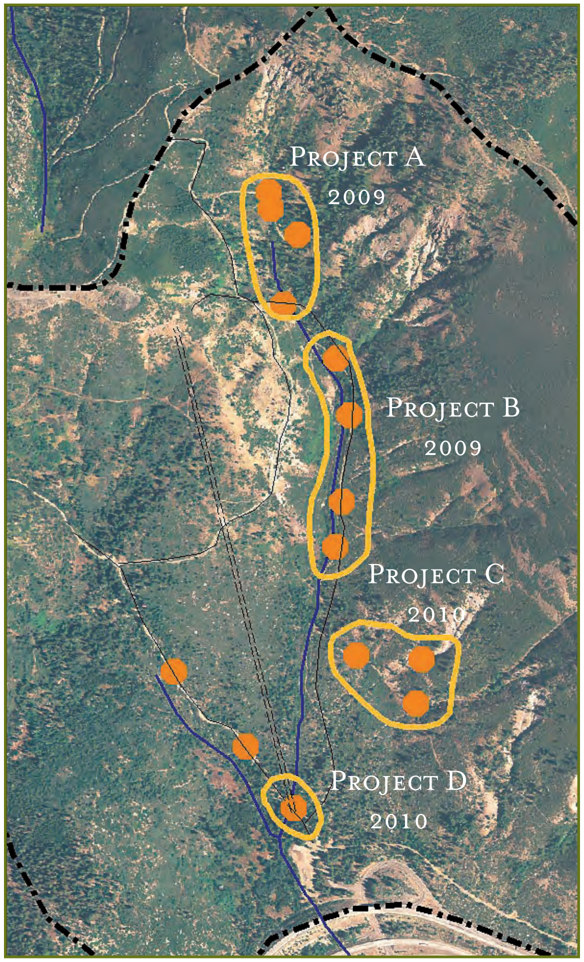


Figure 2.3, Map 3: Example map of problem areas prioritized for treatment.

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 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.

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.

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.

NOTES

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.

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)

NOTES

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)

NOTES

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

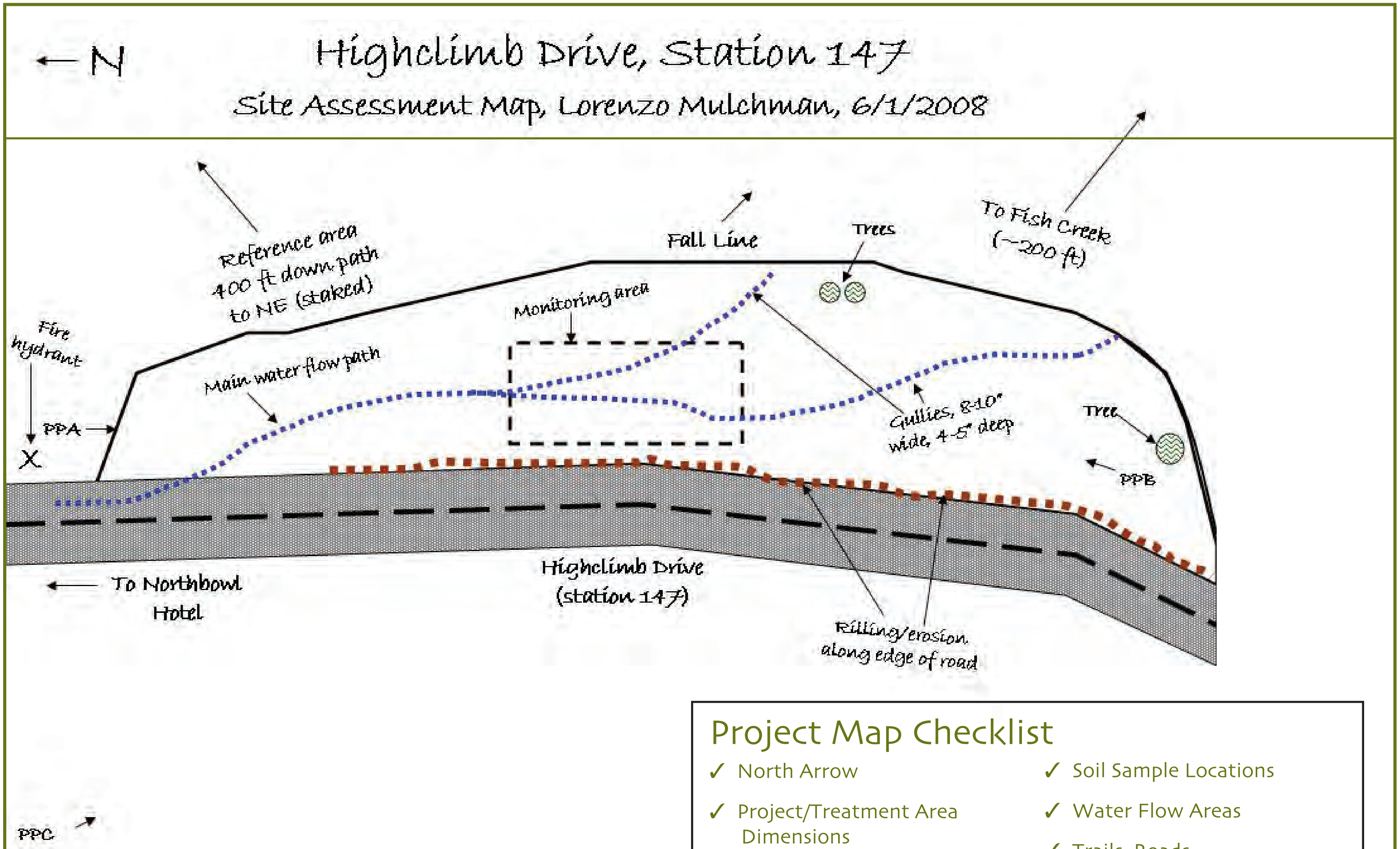
- ✓ North Arrow
- ✓ Project/Treatment Area Dimensions
- ✓ Monitoring Plot Locations (including Reference Site)
- ✓ Photo Point Locations
- ✓ Soil Sample Locations
- ✓ Water Flow Areas
- ✓ Trails, Roads
- ✓ Snowmaking, Other Utilities
- ✓ Landmarks (e.g. Signs)

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) — yes circled	Evidence of Rodent Activity?	(yes/no) — no circled
Solar Input *(% direct sunlight in August)*	82%	Tree Canopy Cover (%)	0-5%
Hydrologic Condition Assessment Complete?	(yes/no) — yes circled	Soil Condition Assessment Complete?	(yes/no) — yes circled
Vegetation Condition Assessment Complete?	(yes/no) — yes circled	Reference Site Condition Assessment Complete?	(yes/no) — yes circled

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.

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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

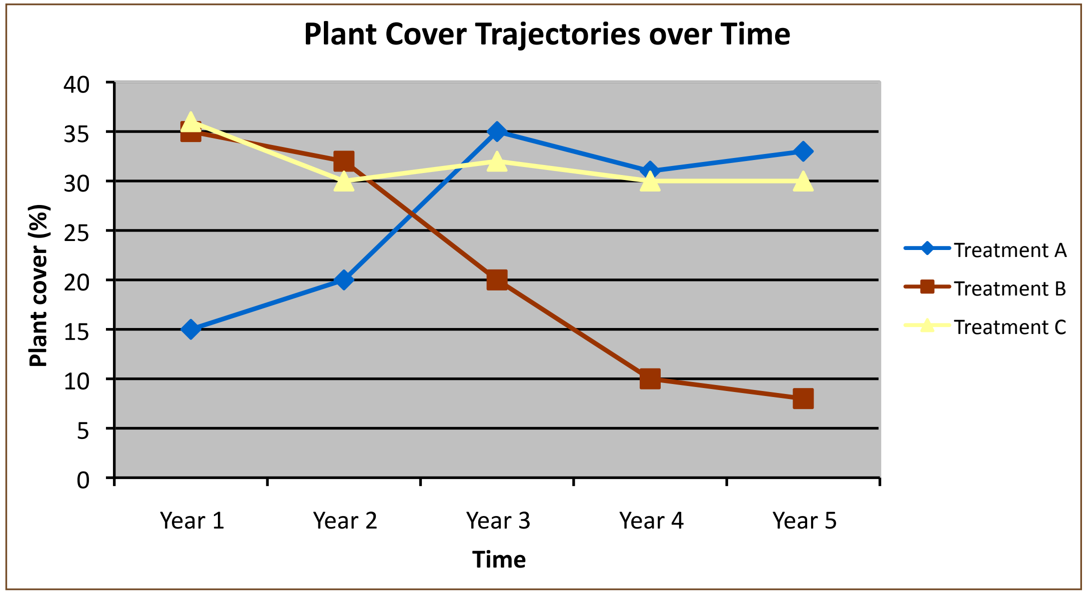


Figure 4.1: The conceptual graph illustrates different plant cover trajectories over time following three different treatments. Trajectories must be considered when attempting to define or determine the success of any ecosystem-based restoration or erosion control project. In this example, if success 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%+

TOOLKIT

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

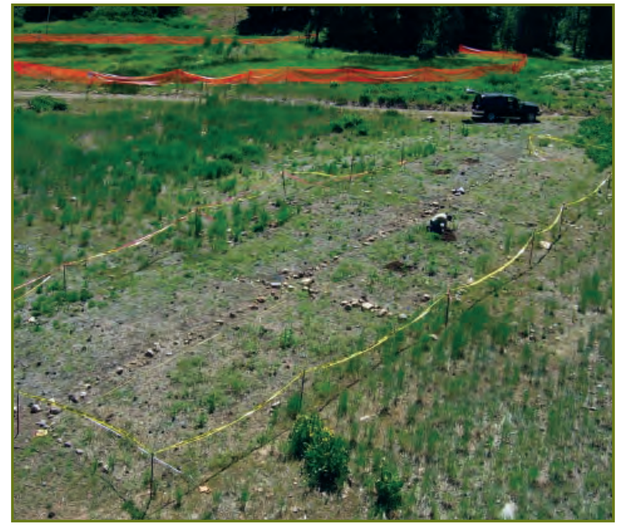
This example illustrates the importance of anticipating the range of potential failure modes during project planning and pre-defining how management will respond. If these management responses had been included in the restoration plan, the fixes could have been implemented more efficiently and management 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

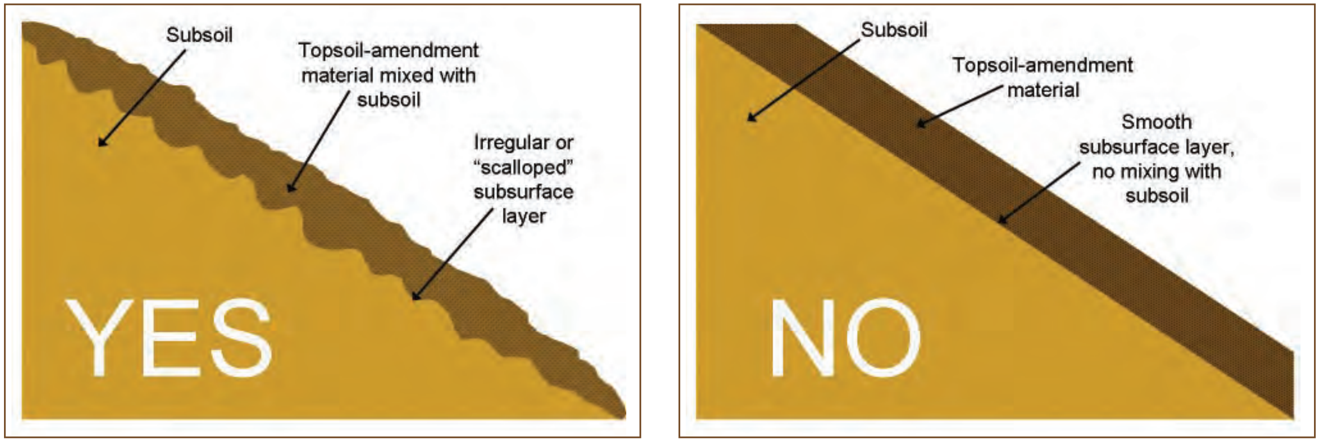

Figure 7.1: Topsoil amendment applied and mixed with subsoil, creating a "scalloped" subsurface layer (left). Typical topsoil-amendment application without mixing with subsoil (right).

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.

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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.

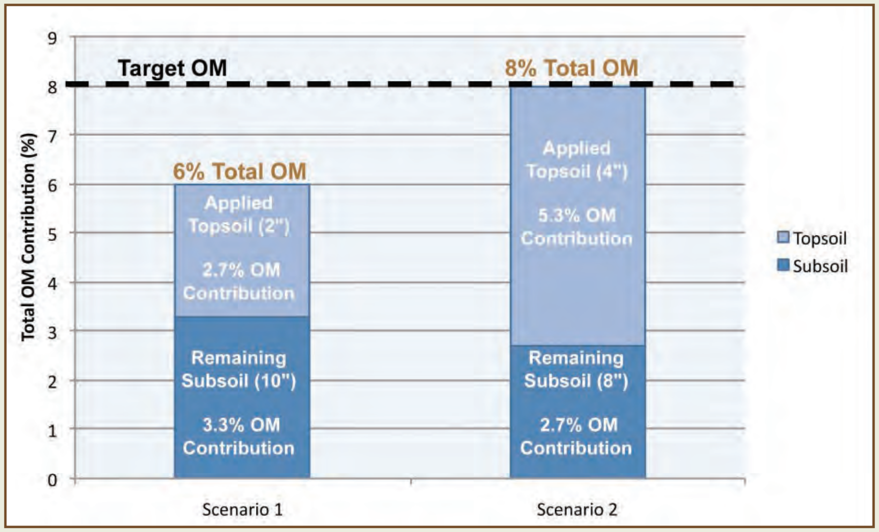


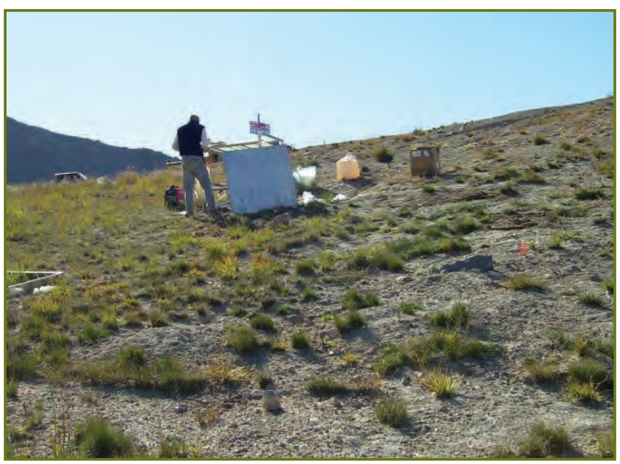
Figure 7.2: Graph showing OM contributions of different amounts of topsoil and resulting in total soil OM compared to target soil OM.

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.

TOOLKIT

"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.

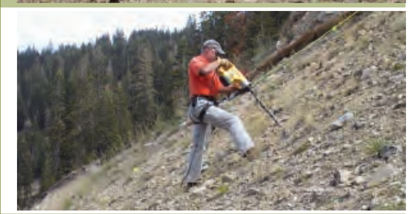
Purpose

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	

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.

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.

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		

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)

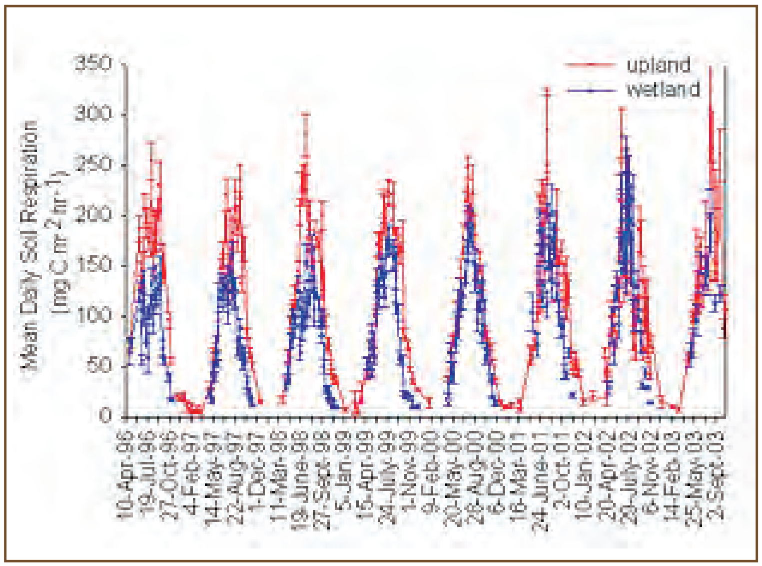


Figure 8.1: This soil respiration graph from Howland Forest shows how soil actually "breathes." The graph shows CO2/respiration measurements over eight years. The peaks are summer maximums. Of special interest is the fact that uplands respire at a higher rate than wetlands, indicating the importance 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.

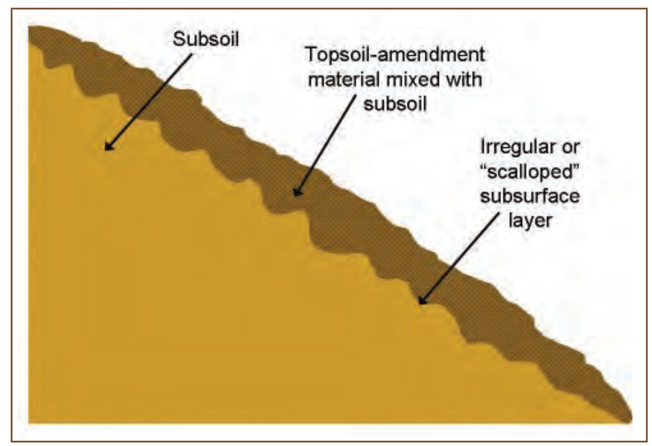


Figure 8.2: Topsoil-amendment material applied and mixed with subsoil during tilling, creating a roughened or "scalloped" subsurface layer.

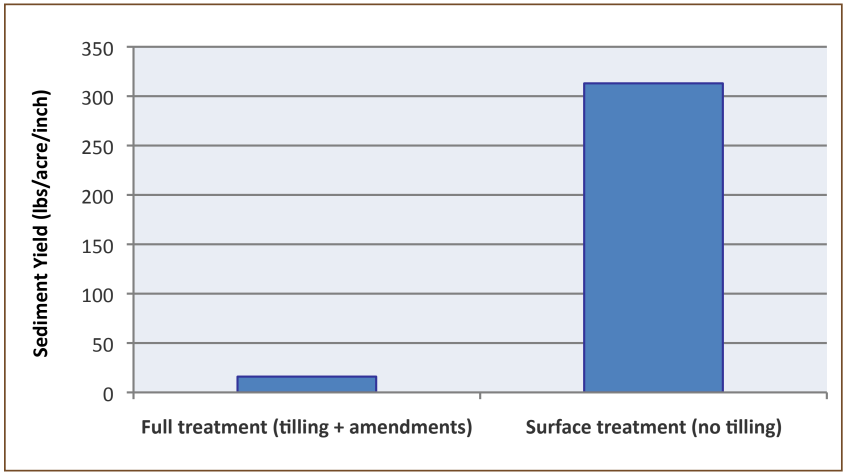


Figure 8.3: Heavenly Gunbarrel test plots. Sediment yield was 20 times higher at the "surface treatment" plot (313 lbs/acre/in) than at a "full treatment" plot (16 lbs/acre/in). "Full treatment" included 4 inches of wood chips tilled to a depth of 18 inches, 2,000 lbs/acre Biosol fertilizer, upland seed 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.

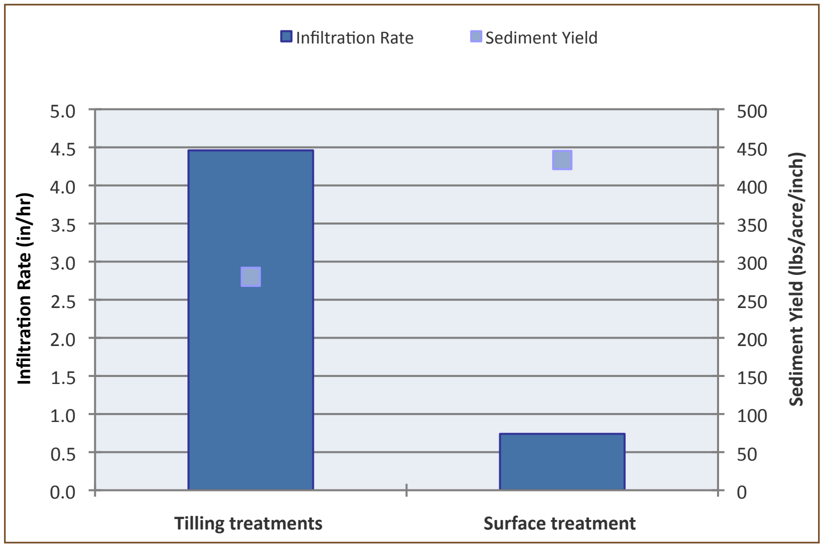


Figure 8.4: Mammoth Mountain Stump Alley test plots. Tilling treatments with incorporated amendments exhibited infiltration rates more than 5 times greater than the adjacent surface treatment. On average, sediment yield from the tilled test plots was 1.4 times lower than the surface treatment plots—280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

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

TOOLKIT

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.

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

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).

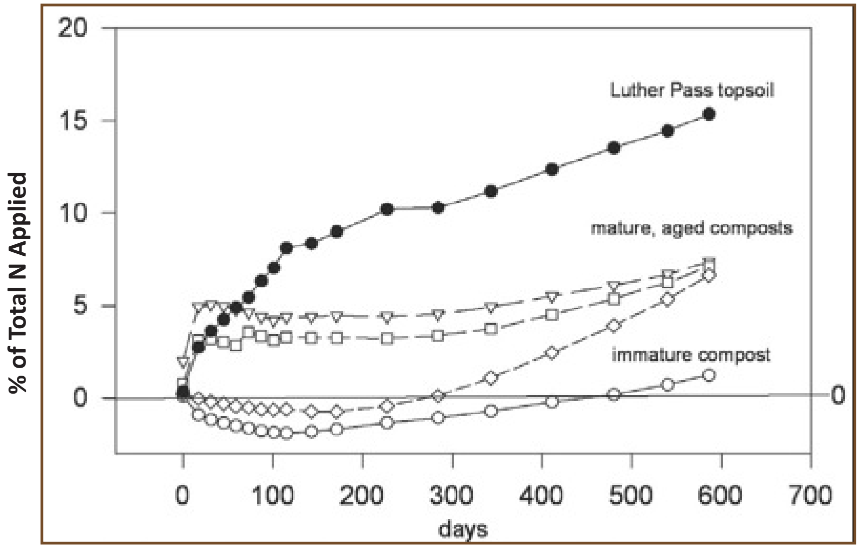


Figure 9.1: shows the differences in compost nitrogen (N) release over time. This chart indicates the importance of matching the appropriate compost or soil amendment to a specific site condition. For instance, immature compost actually removed or "locked up" nitrogen, and thus would tend to reduce or 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.

TOOLKIT

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.

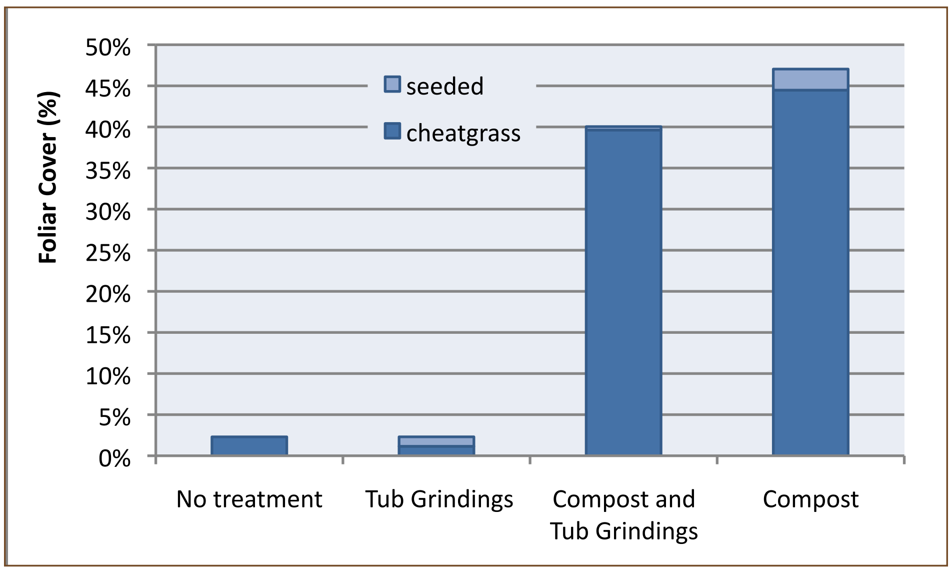


Figure 9.2: Compost is known to encourage the establishment of weedy and undesirable plant species, especially where weed seed is present in the seed bank. At Brockway Summit, cheatgrass outcompeted the native (seeded) species on all plots where a fine-textured compost blend was used as a soil amendment.

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

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

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.

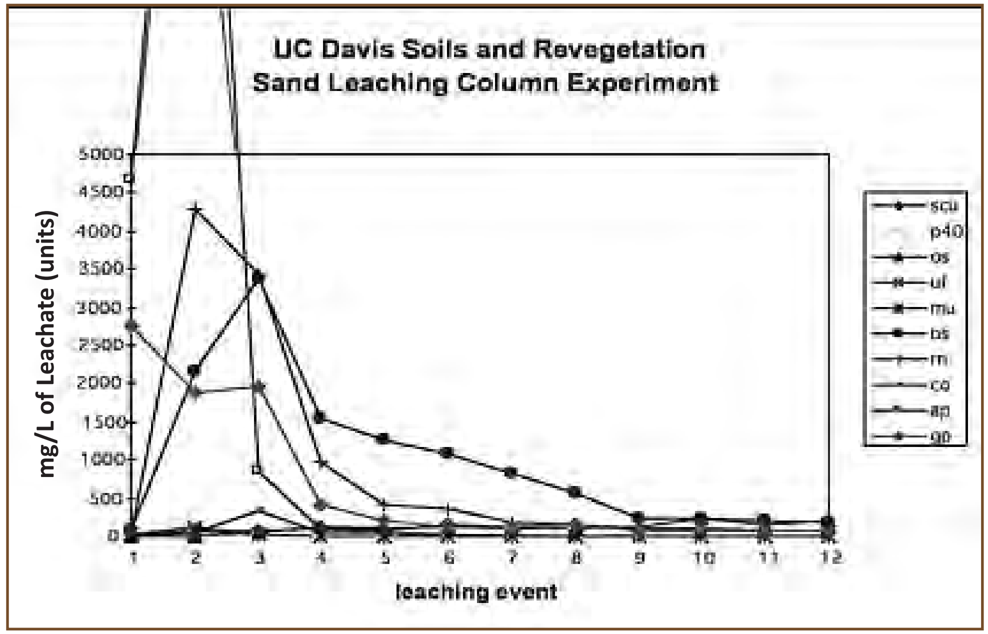


Figure 10.1: Leaching data for a number of mineral and organic fertilizers. The horizontal (X) axis represents leaching events (water leached through a sand column containing one form of fertilizer or soil amendment). The vertical (Y) axis represents the amount of nitrogen (N) leached from the sand column. 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.

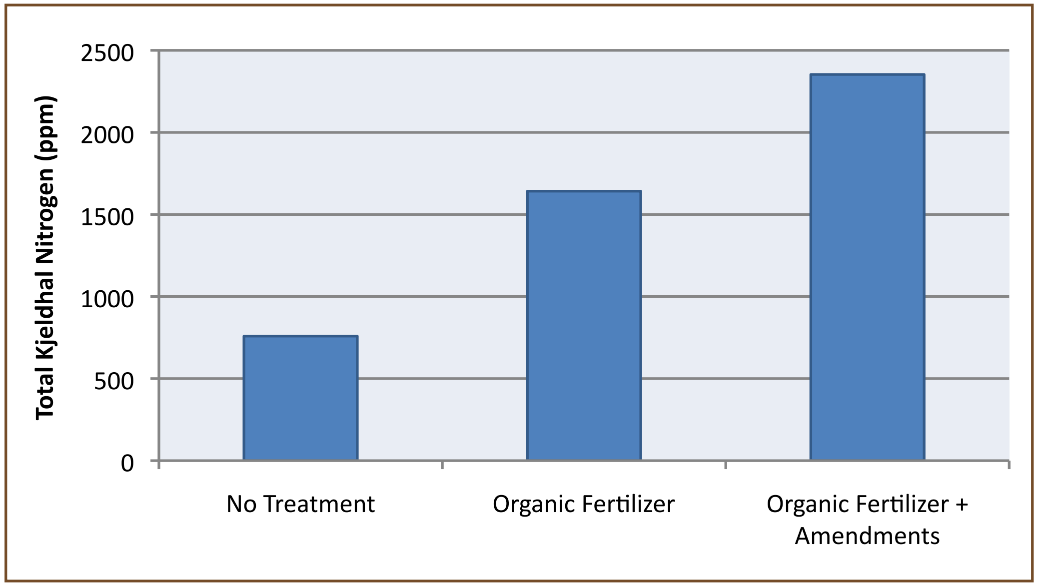


Figure 10.2: The graph shows soil total Kjeldhal nitrogen (TKN) levels for a treatment test area at Northstar-at-Tahoe. Three years after treatment, soil TKN levels were highest where a combination of organic fertilizer and amendments were used, as compared to application of fertilizer alone and an untreated 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.

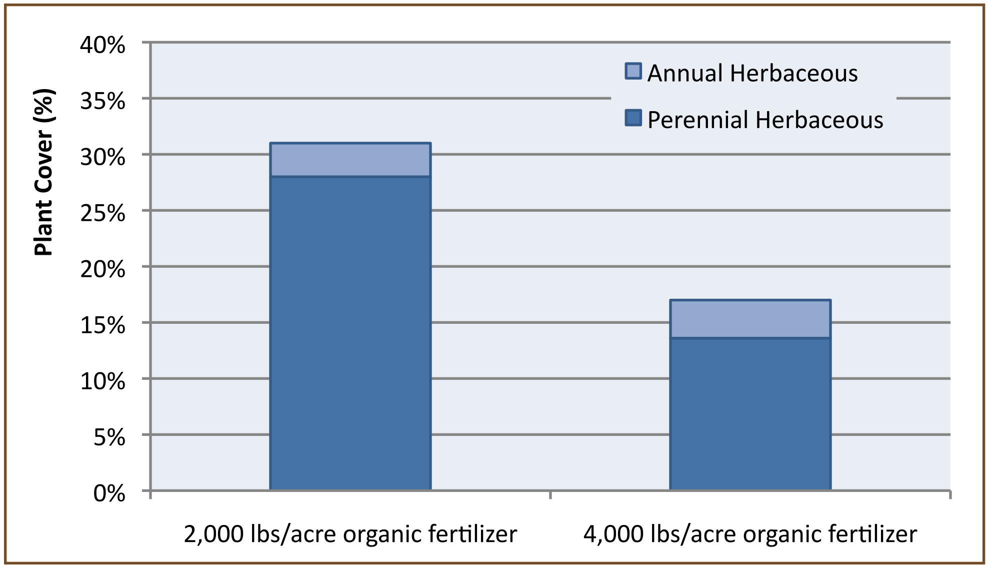


Figure 10.3: Truckee Bypass test plots. On average, plots treated with the lower fertilizer rate (2,000 lbs/acre) exhibited higher cover by seeded, perennial species than those plots treated with the higher fertilizer rate (4,000 lbs/acre).

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*

NOTES

TOOLKIT

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

Table 11.1: Vegetative Treatment Alternatives Matrix

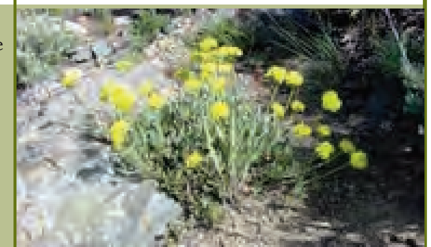
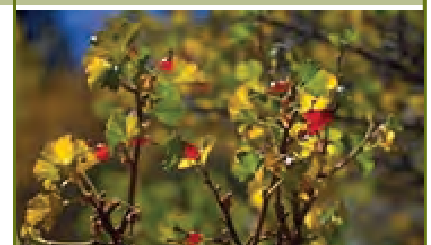
Seed/Planting Type	Definition	Advantages	Disadvantages	Photos
Native Perennial Grasses	Any perennial grass that is native to the local area	• Native plants are an essential component of the local ecosystem • Most native perennial grasses are deeply rooted and add strength to the soil • Native grasses 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

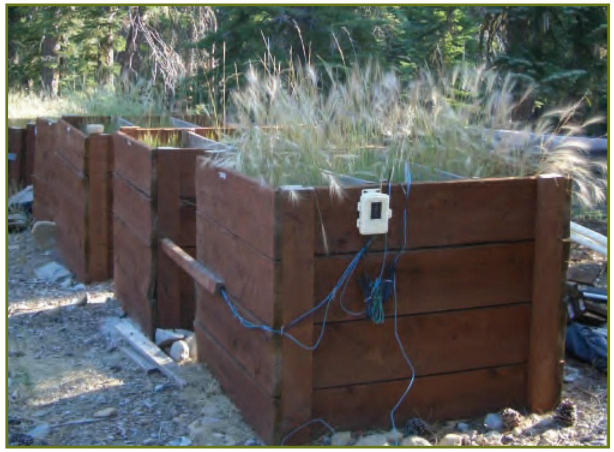
In general:

- 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.

- 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.

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.

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).

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

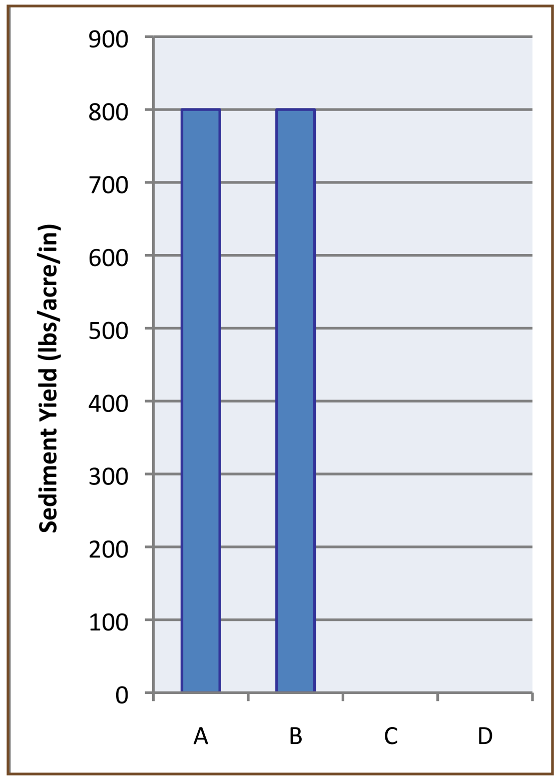
- In several seed rate tests, different seed rates produced similar plant cover and species composition. Instead, plant cover and species composition appear to be more closely linked to local site conditions such as solar exposure, aspect, and soil physical and nutrient conditions.
- Selecting vegetation 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.

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.

"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.

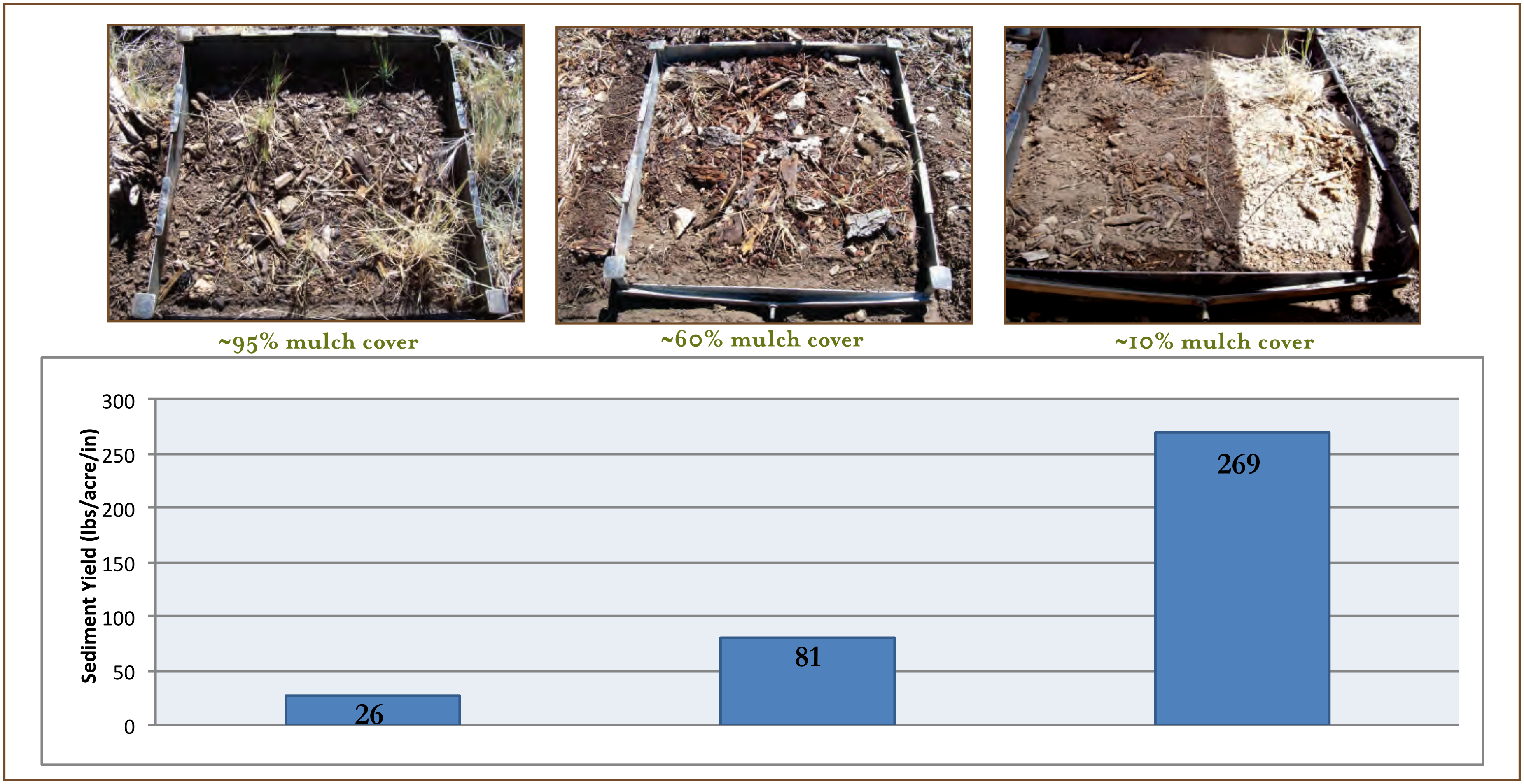


Figure 12.1: Mulch cover and sediment yield. Sediment in runoff increased as mulch cover decreased, as measured using rainfall simulation at an erosion control project at North Lake Tahoe, CA.

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.

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.

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

TOOLKIT

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

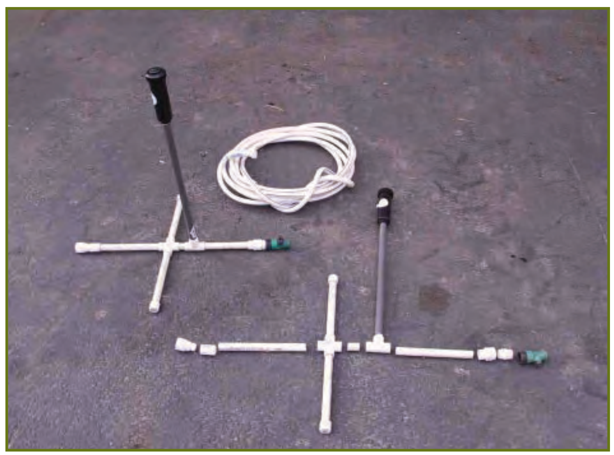
Type	Definition	Advantages	Disadvantages	Photos
Low-flow Overhead Irrigation	Sprinkler types that produce a low precipitation rate, typically less than 2.5 gallons per minute	• Low potential to cause erosion or displace mulch • Potential for deep penetration of water into soil, thus encouraging deep 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 efficienct 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").
- 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).

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.

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

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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

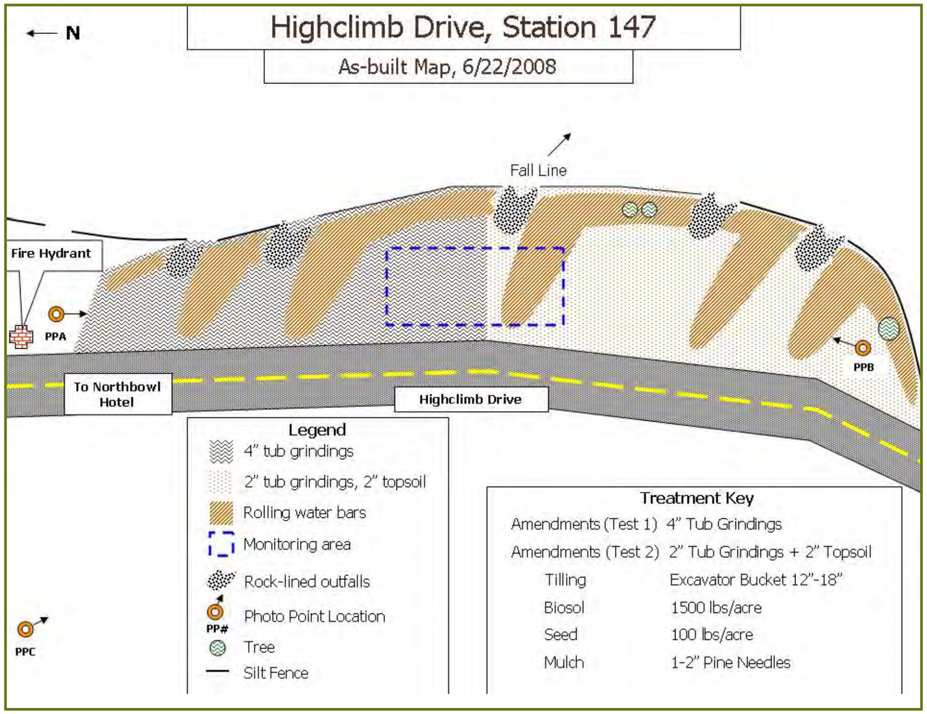
A full soil and vegetation restoration treatment with temporary, first-year irrigation was applied to this road cut slope. Three years later, the treated slope was supporting high native plant cover and had no signs of erosion.

Highway 267 slope, three years after treatment.

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

- Franklin Delano Roosevelt

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

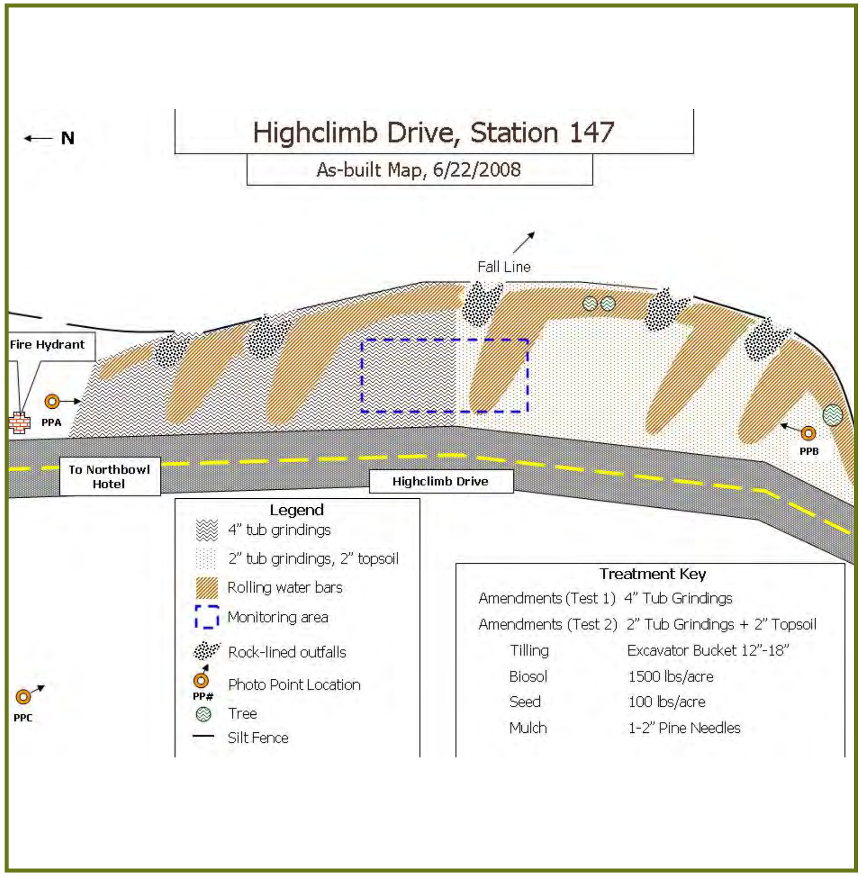
Describe all treatment elements including amendments, tilling, fertilizing, seeding, mulching, and irrigation. Make sure to include treatment specifics in as-built form.

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."

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

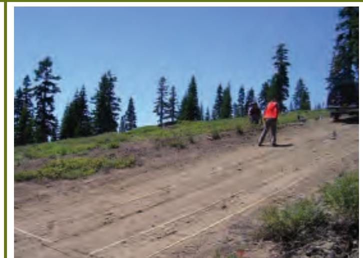
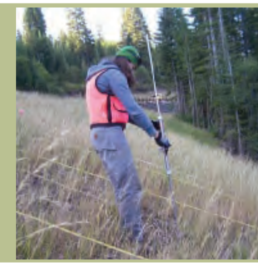
Monitoring Tool/Technique	Definition	Purpose	Advantages	Disadvantages	Photos
Photo Point Documentation	Photo points are the fixed locations of repeat photographs taken over time.	To document visual changes over time	• Simple method, requires little training • Visual representations can be powerful (but 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)

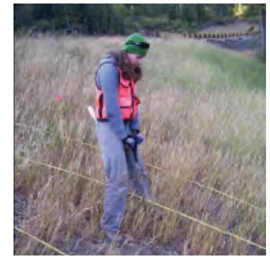
Monitoring Tool/Technique	Definition	Purpose	Advantages	Disadvantages	Photos
Cone Penetrometer Monitoring	The cone penetrometer is used to measure soil's resistance to force, which can be used as a surrogate for soil density.	Cone penetrometer measurements can be used as a surrogate for soil density 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

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

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 swale

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 structure

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.

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"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

TOOLKIT

"We cannot solve problems
by using the same kind of thinking
we used when we created them."
– Albert Einstein

part three
LITERATURE REVIEW

TABLE OF CONTENTS - Literature Review

INTRODUCTION TO THE LITERATURE REVIEW

The California Alpine Resort Environmental Cooperative (CAREC) came together in 2003 to develop a process for planning and implementing erosion control projects and to experiment, through field plots, with various approaches to control sediment on site. In addressing an issue as large and complex as erosion control, CAREC wanted to determine what we know, what we do not know, and what we need to learn. This is an essential element of the adaptive management cycle discussed in Part I: Guiding Principles. As part of this *Sediment Source Control Handbook,* CAREC requested a Literature Review that references appropriate information for planners, practitioners, monitoring personnel, and scientists involved in upland sediment source control projects.

The ability to return disturbed sites such as ski slopes to a high level of effective soil-plant function requires knowledge and understanding of ecological, physical, and operational processes. Too often, this information is not readily available during the planning and implementation of erosion control projects. Actual field-level or field-relevant research or other literature tends to be difficult to find or simply non existent in the case of high alpine areas. Much of the information available is produced by manufacturers and suppliers and often includes a significant bias.

This review attempts to collect as much relevant scientific information on erosion and restoration-related subjects as possible. It is intended to be a working document that will be added to over time as additional research becomes available. Information is cited on erosion control and restoration in the following sections:

Section One: Erosion – Key Concepts

Establishes a common understanding of what is meant by "erosion"

Section Two: Variables That Influence Erosion Rates

Describes types of erosion and particular variables that affect erosion rates

Section Three: Treatments for Sediment Source Control

Suggests issues to consider when applying different types of treatments to achieve sediment source control objectives

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FRAMING THE ISSUE

Definition(s) of Erosion

The entire process commonly referred to as "erosion" actually consists of two closely related processes: 1) erosion, or the detachment or breaking away of soil particles from a land surface by some erosive agent, most commonly water or wind, and 2) sedimentation, or "subsequent transportation of the detached particles to another location" (Flanagan 2002). It is important to understand the nature of these two processes, since addressing them requires quite different techniques and approaches.

Typically, controlling erosion requires keeping soil particles attached to one another and to the soil matrix. Native soils usually do this through the aggregation process (Kay and Angers 2002). Soil aggregates are combinations of soil particles that are bound together. Typically, this process is the result of physical and biological, especially microbial, processes (Horn and Baumgartl 2002). When soil is disturbed, aggregates tend to separate and are more prone to erosion. Once soil particles begin to move, it is extremely difficult to capture fine silt and clay particles, which are typically responsible for a great deal of water quality pollution and degradation. Thus, the CAREC work and this literature review focus on *sediment source control* — keeping soil particles attached and at their source.

An Introduction to Erosion

Erosion and sedimentation pose a serious problem throughout the world. Any land "improvement" or development is usually associated with the potential for accelerated erosion and associated water pollution. This is especially true in mountainous regions where steep slopes and relatively young and/or poorly developed soils create ideal conditions for accelerated erosion after an area has been disturbed.

Topsoil is an irreplaceable resource that is high in organic matter, supports healthy vegetation, and resists the erosive forces of wind and water. It also offers the most optimal seedbed for germinating and establishing vegetation, increases the water-holding capacity of the soil, contains the primary source of nutrients for plants and soil microbes, and contains seeds and beneficial soil microorganisms. Removal or burial of topsoil—a common result of development—tends to accelerate the detachment and transport of sediment. Particles of eroded sediment cause turbidity in water bodies and harm fish by clogging their gills, smothering spawning gravels, burying submerged plants, and transporting other pollutants adsorbed to the sediment (Horne and Goldman 1994). In order to take meaningful action to reduce or control erosion to acceptable levels, and thus protect water quality and topsoil resources, it is useful to develop an integrated, comprehensive understanding of what erosion is and what we currently know about controlling it.

Erosion is generally a "systemic" or functional issue rather than a two-dimensional surface issue; that is, it is the product of an entire system of environmental interactions rather than simply a function of the amount of plant cover on a site. When a system is "healthy" or operating at a high level of functionality, soil particles will stay connected to each other on site and erosion levels will generally be low. When one or more components of the system have been disturbed, erosion (the disaggregation of soil particles) coupled with sedimentation (the movement of those particles) is likely to increase.

Background or "natural" erosion tends to take place in an equilibrium with other watershed elements such as infiltration, stream flow, stream bank stability, and changes in the vegetative community. When disturbance takes place, this equilibrium is disrupted, resulting not only in increased sediment movement, but also in an increase in surface water flow, an increase in stream water volume and velocity during runoff events, a decrease in stream bank stability, and a decrease in watershed water storage (Selby 1993; Dudley and Stolton 2003). On a watershed basis, accelerated erosion and sedimentation results in removal of watershed "capital," or the carbon-rich soil organic matter that drives so many important processes within a watershed. Carbon provides energy that in turn drives ecosystem processes. Once this "capital" is diminished, the ecosystem tends to function at a lower level.

While diminished functionality may be barely noticed on small scales, when large areas such as roads or ski runs are developed, watershed function can be severely disrupted. When this happens, input and output erosion variables are no longer in balance and often result in a downward spiral of ecosystem damage or negative ecosystem impacts (Daily, Matson and Vitousek 1997). Once this damage is done, repair and restoration can be very expensive and labor-intensive; therefore, it is generally more cost-effective to implement projects properly in the first place. However, once damage has been done, repair and restoration are necessary if water quality and ecosystem health are to be reestablished. By replacing components of the larger soil-plant processes such as soil organic matter, seed, mulch, and infiltration, erosion can be reduced and water quality can be restored to background or "natural" levels.

Most of the currently accepted erosion control practices, based on models such as the Universal Soil Loss Equation, focus largely on "C," or the cover factor. Thus, emphasis is placed on plants or revegetation as the primary solution to erosion control on disturbed sites. However, processes must be put back as a complete system rather than as individual components. The Literature Review presents relevant academic research that focuses on erosion, hydrology, and soil-plant processes within the context of keeping soil particles in place on steep slopes.

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EROSION OVERVIEW

Adapted from the International Union of Geological Sciences (1996)

Erosion, or the detachment of particles of soil and superficial sediments and rocks, occurs by the hydrological (fluvial) processes of sheet erosion, rilling, and gully erosion, as well as through mass wasting and the action of wind. Erosion, both fluvial (water) and eolian (wind), is generally greatest in arid and semi-arid regions such as the American West, where soil is poorly developed and vegetation provides relatively little protection. Where land use causes soil disturbance, erosion may increase greatly above natural rates. In uplands (land at higher elevations than the alluvial plain or low stream terrace; all lands outside the riparian-wetland and aquatic zones), the rate of soil and sediment erosion can quickly approach that of denudation (the lowering of the earth's surface by erosion processes). In some areas, however, the storage of eroded sediment on hill slopes of lower inclination, in wetlands and meadows and in lakes and reservoirs can lead to rates of stream sediment transport lower than the rate of denudation.

When surface runoff occurs, less water enters the ground, thus reducing site productivity and lowering the water table. Furthermore, when surface runoff leads to soil erosion, this leads to a reduction in the levels of the basic plant nutrients available for crops, trees, and other plants and decreases the diversity and abundance of soil organisms. Stream sediment degrades water supplies for municipal and industrial use and provides an important transporting medium for a wide range of chemical pollutants that are readily absorbed into sediment surfaces. Increased turbidity of waters due to sediment load may adversely affect organisms such as benthic algae, invertebrates, and fish.

Significance: Soil erosion is an important social and economic problem and an essential factor in assessing ecosystem health and function. Estimates of erosion, including topsoil loss, sediment transport and storage in lowlands, reservoirs, estuaries, and irrigation and hydropower systems, are essential to issues of land and water management. In the USA, soil has recently been eroded at about 17 times the rate at which it forms: about 90% of US cropland is currently losing soil above the sustainable rate. Soil erosion rates in Asia, Africa, and South America are estimated to be about twice as high as in the USA. The Food and Agricultural Organization (FAO) of the United Nations estimates that 140 million ha of high-quality soil, mostly in Africa and Asia, will be degraded by 2010 unless better methods of land management are adopted.

Human or Natural Cause: Erosion is a fundamental and complex natural process that is strongly modified (generally increased) by human activities such as land clearance, agriculture (plowing, irrigation, grazing), forestry, construction, surface mining, and urbanization. It is estimated that human activities have degraded some 15% (2,000 million ha) of the earth's land surface between latitudes 72° N and 57° S. Slightly over half of this is a result of human-induced water erosion, and about a third is due to wind erosion on lands disturbed by human activity (both leading to loss of topsoil), with most of the balance being the result of chemical and physical deterioration.

SECTION 1: EROSION – KEY CONCEPTS

Section Overview

This section describes several concepts essential to a full understanding of erosion and key terms used throughout the discussion and practice of sediment source control. This section also includes general information about the state of erosion control knowledge, the extent of the erosion problem, and prediction capacity.

Sediment Source Control

The process commonly called *erosion* actually consists of both erosion and sedimentation (See Framing the Issue, page 194). Whether we address erosion or sedimentation will dictate to a great extent the overall cost and effectiveness of treatment as well. For instance, by focusing on erosion, we attempt to keep soil particles in place, an approach commonly referred to as *sediment source control.* Dealing with sedimentation, on the other hand, commonly involves *treatment* of sediment-laden water downstream or downslope from the sediment source.

An innovative program exists within the Lake Tahoe Basin in California and Nevada, where a consortium of entities has developed the "Preferred Design Approach" (California Tahoe Conservancy 2008) for planning and designing erosion control projects. The key to this approach is the order in which design solutions are prioritized and evaluated. The approach, in order of importance, is:

1) Sediment source control;

2) Hydrologic design and function; and

3) Conveyance and treatment.

This approach assumes that keeping sediment on site and in place is more cost- and ecologically effective than attempting to capture and treat it downstream. This approach is based on the understanding that the most cost-effective method of reducing sediment pollution is to ensure that sediment particles are not mobilized in the first place.

Drastic Disturbance

Drastic disturbance defines areas where "the native vegetation and animal communities have been removed and most of the topsoil is lost, altered, or buried. These drastically disturbed sites will not completely heal themselves within the lifetime of [a person] through normal secondary successional processes" (Box 1978). The term "drastically disturbed sites" describes the CAREC treatment areas discussed in the publication, including ski runs, road cuts and fills, and building sites as well as other disturbed sites outside of ski resorts that are also of interest when dealing with sediment source control. These areas must be considered as functionally and biogeochemically distinct from the pre-disturbance (native) site condition, and treatment must focus on restoring structure and function, especially in the soil, if long-term or sustainable solutions to erosion are to be implemented (Kay and Angers 2002; Torbert, Burger 1994 and 2000; Bradshaw 1992; Whitford and Elkins 1986). While some sites focused on by practitioners utilizing this Handbook may be only lightly disturbed and may subsequently support vegetation, drastically disturbed sites most often require soil amendments and tilling or loosening.

A Dose-Response (Agronomic) vs. Capitalization (Wildland) Approach

When addressing approaches to revegetation, erosion control, and restoration it is useful to differentiate between agricultural and "ecological" approaches. The two main approaches are:

1. **Dose-Response** – refers to a system in agriculture or landscaping, such as a field of corn or a backyard garden, where a specific amount of fertilizer is applied with a pre-defined output or response. These types of systems are designed for a continual dose (input) and response (output) for as long as the desired process is in place. Generally, this type of system is artificially imposed in an area and is not designed to be self-sustaining.

2. **Wildland** – refers to a one-time investment or re-capitalization of a disturbed site. The desired outcome of a wildland treatment is typically a no- or low-maintenance, self-sustaining site because continual input and maintenance are not practical or cost-effective. Adequate amounts of materials and physical manipulation must be used to "capitalize" or "invest" in the system with nutrients, organic matter, carbon, or other needed elements.

A Functional Approach

The ability to develop and apply effective erosion control techniques and materials depends to a large degree upon an understanding of the processes of erosion over time. If an erosion control practice is to be effective, it must directly address one or more of the processes involved in erosion for the long term. For many years plant cover (revegetation) alone has been used as a measure of erosion control effectiveness. While plant growth can be forced via the ongoing use of adequate water and nutrients, the literature summarized here strongly suggests that 1) an erosion-resistant landscape is the result of a robust and well-functioning soil-plant system, and 2) the effective control of erosion on disturbed sites depends largely on re-creating and re-integrating ecosystem function.

Cummings (2003) suggests that when assessing restoration or treatment "success," we look not primarily at structure (the makeup of the physical plant community) as much as essential functional elements such as nutrient cycling, infiltration (hydrologic function), and energy capture (plant growth/carbon storage) on those sites. This approach is gaining popularity since it is becoming more apparent that while a site may *look* good, visual interpretation is prone to individual bias and that bias is largely dependent upon levels of training and experience, which can vary widely between individuals. Furthermore, simple visual observations cannot discern functions such as infiltration or soil nutrient cycling, yet these functional elements are central to understanding erosion processes.

State of Erosion Control Knowledge

A great deal of information has been put forth over many years regarding erosion and its control. Unfortunately, some of this information is inadequate for planning and implementing erosion control projects. We suggest at least four reasons for this situation, based on Sutherland 1998a and 1998b and Benoit/Hasty 1994.

1. **Single variables:** Many if not most studies tend to look at one or two variables. Multi-variate studies are difficult to implement and interpret. However, restoration of a drastically disturbed site includes a wide range of variables. Therefore, single-variable studies may be misleading or difficult to understand in a multi-variate environment.

2. Site specificity: Studies and tests done in locations with different climates, soil types, and types of disturbance may not be relevant to sites in the Sierra Nevada or the arid West.

3. Inadequate experimental design: A number of erosion control studies have not been adequately designed and therefore the information derived may not be robust or dependable. For instance, Sutherland, in a critical review of rolled erosion control product studies, found that very few studies had the scientific rigor to be dependable (Sutherland 1998a and 1998b). An explanation for this lack of rigor is that many erosion control studies have been conducted by product manufacturers or suppliers, and the implementers did not set them up as scientific experiments with statistical accuracy. Further, most of these studies were not presented to peer-reviewed scientific journals, but rather were presented in trade journals.

4. Time: Most studies are not tracked over a long enough time period. Even Sutherland has only suggested that studies be more rigorous but does not consider effectiveness over time. Time is a critical consideration when designing and assessing projects, especially where soil restoration is important (Richter and Markewitz 2001; Bloomfield, Handley and Bradshaw 1982).

Extent of the Problem

How important or pervasive is erosion? One often hears the comment, "But isn't erosion a natural process?" Several sources were considered in attempting to answer this question. According to Gray and Sotir (1996), annual sediment yields for the US range up to at least two billion tons per year. Of the total amount eroded, between one-quarter and one-third reaches the ocean. The rest is deposited in flood plains, river channels, lakes, and reservoirs. They report that "siltation and nutrients (nitrogen and phosphorus) from erosion impair more miles of rives and streams than any other pollutant."

Estimates of erosion rates vary. According to an EPA study, rates range from a low of fifteen tons/mile^2/year for natural or undisturbed areas to a high of 150,000 tons/mile^2/year for highway construction sites, or a maximum difference of 10,000 times (US EPA 1973). According to Scheidd (1967), roads may be associated with erosion rates 10-50 times above background levels. According to Wark and Keller (1963), "exposure of soil during the construction period can result in sediment production equal to ten times the rate from cultivated land, 200 times the rate from a grassland, and 2,000 times that from forest land."

The California State Division of Soil Conservation found that roadways in the South Lake Tahoe area were the source of 78% of the total sheet and road erosion. Further, they noted that "ski slopes that are established by clearing mountainsides have marred the landscape and created erosion problems at the Heavenly Valley ski area in South Lake Tahoe. Erosion and land scars are noticeable, even though considerable effort has been expended to establish vegetation on the sterile granitic soil" (Resources Agency 1969). Grismer and Hogan (2005a), in Tahoe-specific rainfall simulation research, measured erosion rates on disturbed sites that were up to an order of magnitude greater than similar native areas.

Predicting Erosion

The ability to predict erosion has been important in designing and justifying many erosion control projects in the past. Erosion prediction is usually based on one or more currently used models. Many of the current models address erosion primarily as a surface phenomenon. However, commonly used models such as the Universal Soil Loss Equation (USLE) and other related models (RUSLE, MUSLE, CREAMS, GLEAMS, WEPP, etc.), have proven inadequate to effectively predict erosion in wildland settings. Therefore, these models may be misleading when used to quantify the effect of specific form-based elements such as plant cover or mulch cover on erosion rates.

While models are useful as ways to envision erosive processes, a number of researchers suggest that actual control of erosion is more likely to be enhanced by focusing on physical processes in the soil and interactions between components than by focusing on model outputs (Bradshaw 1992; Torri and Borselli 2000; Whitford and Elkins 1986; and Wilkinson, Grunes and Sumner 2000). For instance, Agassi (1996) suggests that "the successful design of soil conservation programs will be more easily achieved by studying the relationship between rainfall characteristics, sealing of the soil surface, and the ensuing decrease of infiltration rate than by studying and modeling erosion processes, as is currently being done." Section Three of this Literature Review addresses specific approaches to erosion based on ecological processes rather than model assumptions.

"Science does not know
its debt to imagination."
– Ralph Waldo Emerson

NOTES

SECTION 2: VARIABLES THAT INFLUENCE EROSION RATES

Section Overview

This section describes the types of erosion and the variables that define whether, and to what extent, erosion occurs on a given site. Each variable affects the rate of erosion. An excellent description of types of erosion, and erosion processes, is provided by Gray and Sotir (1996) in "Biotechnical and Soil Bioengineering Slope Stabilization" (pp 19-30). When more than one variable is impacted in a disturbance event, erosion is likely to increase. Table 1 lists the various types of erosion, what they are caused by, and what influences them.

Table 1: Types of Erosion

Process	Cause	Variables
Splash Detachment	Raindrop impact	Amount, size of droplets
Shear Detachment	Surface flow	Amount of water
Freeze-Thaw	Water expansion upon freezing	Amount of water in soil, surface mulch cover, air temperature, cloud cover
Transport	Water velocity	Amount and speed of water
Deposition	Slowing of water; filtering of water; exceeding waters capacity to suspend particles	Velocity change, filtration mechanism
Mass Failure, Rotational Failure	Differential soil densities, sliding layer, differential pore pressure	Different infiltration levels (including over-saturation) of one layer relative to another

Types of Erosion

Erosion is generally split into two categories: water and wind. A third type of erosion that is also related to water is referred to as "frozen water" or "winter" erosion, and includes snow and snowmelt erosion and frozen soil or "freeze-thaw" erosion (McCool 2002). Additional types of erosion such as colluviation and mass failures are also important.

Water

Liquid water erosion is the most commonly cited, and possibly best understood, type of erosion. There is a strong linkage between this type of erosion and water quality. Splash detachment, transport, sheet flow, rill, and gully concepts are part of water erosion. A great deal of literature describes these processes such as Torri and Borselli (2000), Le Bissonnais and Singer (1993), Moore and Singer (1990), Wischmeier and Smith (1978), and many others.

Freeze-thaw erosion showing detached soil particles.

Freeze-Thaw

Soils subject to freeze-thaw conditions have different processes affecting erosion and runoff measurement. Edwards and Burney (1987) used a laboratory rainfall simulator to test three Prince Edward Island agricultural soils (varying in soil texture) for runoff, splash volume, and sediment loss under varying conditions of freeze-thaw, ground cover, and potential for erosion.

With bare soil, freeze-thaw significantly increased sediment loss by about 90%. Using the same procedures, Edwards and Burney (1989) examined the effects of freeze-thaw frequency and winter rye cover. They incorporated cereal residue and subsoil compaction on runoff volume and sediment loss. Wooden soil boxes were subjected to simulated rain 1) at the end of a ten-day freezing period and 2) at the end of the fifth 24-hour freezing period of a ten-day alternating freeze-thaw cycle (freeze-thaw). Where the soil was continuously frozen for ten days, there was 178% greater sediment loss and 160% greater runoff than with daily freeze-thaw over the same period, but there was no difference in sediment concentration in runoff. Incorporated cereal residue decreased sediment loss to 50% and runoff to 77% of that from bare soil, suggesting that mulch can significantly reduce erosion in freeze-thaw conditions. Winter rye cover decreased sediment loss to 73% of that from bare soil. Simulated soil compaction caused a 45% increase in sediment loss. The loam soil showed 16.5% greater loss of fine sediment fractions >0.075mm than the fine sandy loam, which showed 23.4% greater loss than the sandy loam.

Frozen Water and Wind

Little research is available regarding the amounts and types of wind or frozen water erosion in the Sierra Nevada or other ski resort regions, even though the bulk of precipitation falls as snow in these resort regions. However, wind may represent a more insidious (and effective) erosive agent on bare, disturbed areas than water. Evidence indicates that wind erosion is significant and can have devastating effects on soil quality, soil nutrient cycling, and long-term soil productivity (Fryrear 2000; Leys 2002; Stetler 2002a). According to Fryrear (2000), "while the transport capacity of the wind is much less than that of water, wind erosion can remove the entire nutrient-rich soil surface regardless of field size or location." In other words, while wind may not move as much sediment as water, the material that is preferentially moved by wind is the lighter soil fraction, such as organic matter and fine soil particles, which have a much higher propensity for negative water quality impacts than do the coarser particles.

Thus, wind erosion is a highly important degradation variable that should not be overlooked. Furthermore, wind is less noticeable but possibly more constant than water erosion in the Sierra. Each time a gust of wind affects a bare area, the soil that is moved can be significant over time, since it is ongoing over an entire dry season. Wind erosion also has a negative impact on air quality.

This photo of the American River shows a mass failure that temporarily blocked the river. This slide was believed to be the result of lack of vegetation from a previous fire, defoliation efforts, and water associated with a 100-year precipitation event (1997).

Mass Failures

Mass failure involves a downward and outward movement of soil on a slope. According to Gray and Sotir (1996) "...mass movement [of soil] involves the sliding, toppling, falling or spreading of fairly large and sometimes relatively intact masses." Mass failure usually occurs along a failure plane, is the result of loss of shear strength, and is exacerbated by positive pore pressure within the soil itself.

Mass failures have the potential to do a great deal of damage over a short period. Mass failures include rock falls, rotational slides, translational slides, lateral spreads, flows, creep, and slumps. Mass failures can sometimes be controlled, reduced, or eliminated by plant roots when the roots are deep and strong enough.

In January 1997, a mass failure occurred along Highway 50 west of Kyburz, California, that crossed and blocked the American River. This mass failure was partly the result of a forest fire that had occurred on the upland area adjoining the river. The fire had burned very hot and removed all plant material. Several houses were completely destroyed in the mass failure. Property damage exceeded several million dollars. The ecological damage that occurred along the river has not been financially assessed, but must be considered major. Such damage is difficult to estimate.

Colluviation

Colluviation is a lesser-known type of erosion that can be significant on bare areas. Colluviation is erosion due to gravitational forces. Saprolitic granite soils are especially prone to colluviation, but all bare soils on steep slopes can be affected by gravity erosion. In fact, freeze-thaw sometimes acts as the disturbing element that can make soil particles available for transport by gravity at some later time.

NOTES

Variables Affecting Erosion in the Soil Structure

Soil structure is defined as the combination or arrangement of primary soil particles into secondary units called "peds" (Brady and Weil 1996). Soil structure may be the most important element controlling erosion in upland sites because structure depends upon many physical and biological elements and processes (Kay and Angers, 2002).

These interrelated elements include aggregate stability, infiltration, soil strength, pore space, soil density, water holding capacity, soil organic matter, plant growth, and microbial activity. Soil structure is a critical element of a site's predisposition toward erosion. According to Kay and Angers (2002), "soil structure has a major influence on the ability of soil to support plant growth, cycle C and nutrients, receive, store and transmit water, and to resist soil erosion and the dispersal of chemicals of anthropogenic origin. Particular attention must be paid to soil structure in managed ecosystems where human activities can cause both short- and long-term changes that may have positive or detrimental impacts on the functions the soil fulfills." This statement, and the research that supports it, suggest that soil structure is of primary importance to sediment source control. When soil structure is severely disrupted (see discussion of "drastic disturbance," page 197), that structure must be rebuilt if erosion is to be controlled. The following sections discuss some of the attributes and elements of soil structure.

Infiltration

To the extent that water infiltrates into and through the soil, it does not run off (Radcliffe and Rasmussen 2002). In fact, runoff can be defined as the point at which water input exceeds the soil's capacity to absorb or infiltrate water (Eagelson 2002). Infiltration is influenced by a number of factors, including antecedent soil moisture, soil texture, surface relief, restricting subsurface layers, organic matter, pore space, and soil density (Battany and Grismer 2000; Brady and Weil 1996; Radcliffe and Rasmussen 2002). High infiltration rates generally result in low runoff. Runoff rates and volumes are critical variables in the erosion process. The literature reported here, as well as rainfall simulation under way in the Lake Tahoe area, suggest that sediment source control projects will generally be successful to the extent that water can infiltrate into the soils (Arst and Hogan 2008; Schnurrenberger, Hogan and Arst 2008). A primary goal of erosion control projects is to develop a system of maximum, sustainable infiltration of water into the soil relative to a native and/or adequate reference site. This state of maximum infiltration is usually related to high organic matter, low-density soil, and a robust soil-plant community (Kay and Angers 2002).

This road cut exhibits evidence of high runoff and erosion resulting from lack of infiltration capacity and vegetation.

Infiltration is heavily influenced by soil density. Each "native" soil has a density associated with it. Generally, the more dense a given soil, the lower the infiltration rate (Frits, De Vries and Craswell 2002). When a soil is disturbed by any type of physical activity, especially when the soil is wet, that soil becomes compacted, resulting in a soil with higher density, lower pore space, and a lower infiltration rate. The terms "compaction" and "high density" are used interchangeably although they are not always synonymous. A particular soil in its native or undisturbed state exhibits a particular density (also called "bulk density") usually given in mass (or weight) per volume. A soil bulk density is usually given in g/cm^3, kg/m^3, or mg/m^3. Once a site has been drastically disturbed and/or impacted with heavy equipment, that soil's bulk density increases. This results in a loss of pore space. Lack of pore space results in increased runoff and thus increased erosion (Kay and Angers 2002; Radcliffe and Rasmussen 2002).

A compacted soil is by its nature high-density. Subsoil and parent material tend to also be high-density by nature. In cases where reconfiguration of a site results in topsoil loss and subsoil exposure, such as a road cut or deeply incised ski run, soil density may be so high that it practically precludes infiltration. In all of these cases, some type of soil loosening treatment must be implemented in order to increase infiltration to levels where plant growth can proceed and where runoff can be reduced.

Plant growth can be severely limited by compaction. For instance, Josiah and Philo (1985), in contrasting physical properties of mined and unmined soils, found that the bulk density of native and ungraded soils were both 1.3 mg/m^3, whereas graded high-density soils were 1.8 mg/m^3. Four years after planting, Black Walnut (*Juglans nigra L.*) trees were 35% taller and stem diameter was 31% greater in the ungraded versus the graded and compacted site. Torbert and Burger (1990) compared the survival rate of six commercially important tree species on soil of two different densities. The soil that had been left uncompacted demonstrated a 70% survival rate compared to the 42% survival rate for the compacted soil. For some species, height was almost double on the uncompacted site. An extensive discussion of the impacts of compaction to forest and other impacted sites can be found in *Forest Land Reclamation* (Torbert and Berger 2000), a chapter in a highly useful book *Reclamation of Drastically Disturbed Land,* edited by Barnhiesel, Darmody and Daniels (2000).

Depth to Restricting Layer

Depth to restricting layer is defined as "the depth at which a soil layer or condition severely restricts root penetration. A root restricting layer results in no greater than 'few' roots being present. Examples of root restricting layers include pans, cemented horizons, compact or high-density parent materials, chemical concentrations such as salts, bedrock, and saturated soil conditions" (Luttmerding et al. 1990). According to Torbert and Burger (2000), "depth to a restrictive layer is an especially important physical property controlling productivity of trees [and by inference, other plants as well]. In a study to evaluate the effect of various mine soil physical and chemical properties...the most important mine soil property was rooting depth." While rooting depth is seldom considered in most erosion control projects, field experience and numerous measurements of unvegetated sites clearly suggest that shallow rooting depth is often associated with lack of vegetative cover.

Two considerations connecting rooting depth and erosion are:

1) Plants need a certain quantity of available nutrients and water. Water, in particular, is associated with the volume of pore space in a soil. A restricting layer tends to limit the amount of pore space in a soil, thus limiting water availability.

2) When water reaches a restricting layer, the infiltration rate is slowed, thus tending to saturate the soil. Two things can then occur. First, more water will flow over the surface as

runoff, and second, positive pore pressure in the soil and the different soil densities can lead to mass movements, such as landslides.

Nutrient Cycling/Soil Organic Matter

Soil organic matter has been linked to both establishment and persistence of plant communities in the Lake Tahoe Basin and elsewhere (Claassen and Hogan 2002; Baldock and Nelson 2002; Reeder and Sabey 1987; and Bradshaw 1997) as well as an increase in the soil's ability to resist erosion. Torri and Borselli (2000) have found that "increasing organic matter content makes aggregates more resistant to sealing and consequently decreases runoff and erosion." Further, "...those relationships indicate that soils with good granular structure (high Fe oxide and organic matter content) are less erodible." McBride (1994) summarizes the functions of organic matter as follows: "In partnership with the clay fraction, organic matter has an extremely important influence on the chemical and physical properties of soils. Critical and beneficial functions of organic matter include:

1. Maintenance of good pore structure accompanied by improved water retention;

2. Retention of nutrients (e.g. Ca_2^+, Mg_2^+, K^+, NH_4^+, Mn_2^+, Fe_3^+, Cu_2^+) by cation exchange;

Example of a well-aggregated soil with high organic matter content. This soil was sampled from a native forested area near Mammoth Lakes, CA.

3. Release of nitrogen, phosphorus, sulfur, and trace elements by mineralization, the microbial process by which organic compounds are decomposed and carbon dioxide is released; and

4. Absorption of potentially toxic organics (pesticides, industrial wastes, etc.)."

Aggregates

According to Cambardella (2002), a soil aggregate is formed when closely packed sand, silt, clay, and organic particles adhere more strongly to each other than to surrounding particles. The arrangement of these aggregates and the pore space between them is referred to as "soil structure." Soil aggregates are held together by three classes of binding agents: 1) humic material (highly decomposed organic material); 2) polysaccharides (organic sugars); and 3) temporary elements (roots, root hairs, and fungal hyphae) (Tisdale and Oades 1982). Soil aggregate formation has been shown to be dependent upon soil organic matter content (Baldock and Nelson 2002; Blackmer 2000; Wilkinson, Grunes and Sumner 2000). Stable aggregates in the soil are closely linked to the ability of a site to resist erosion (Kay and Angers 2002).

Soil aggregate formation has been shown to be closely linked to soil organic matter content (Baldock and Nelson 2002; Blackmer 2000; Wilkinson, Grunes and Sumner 2000; Kay and Angers 2002). Soil organic matter is also the primary source of food and energy for microbial populations, whose production of extracellular polysaccharides enhances soil structure and increases soil's ability to resist erosion. These data suggest that organic matter plays a number of very specific roles in reducing erosion and is of critical importance for encouraging soil aggregation.

Surface Cover/Mulch

Soil surface cover plays a critical role not only in erosion reduction but in other ecosystem processes as well. According to Pritchett and Fischer (1987), "plant and litter cover is the greatest deterrent to surface erosion. The tremendous amounts of kinetic energy expended by falling rain are mostly absorbed by vegetation and litter in undisturbed forests. Disturbances caused by logging and other activities reduce infiltration rates and increase surface runoff and erosion."

Surface cover provides the following services:

- Reduces raindrop force (splash detachment)
- Reduces surface flow velocities (shear detachment of soil particles by both wind and water)
- Reduces evaporation (water loss reduction)

Raindrops exert forces that detach soil particles, which can be easily mobilized by flowing water. Mulch helps to protect soil from these forces.

- Reduces radiation influx and efflux
- Increases soil nutrients (some mulches) (Woods and Schuman 1986)
- Increases seed germination at some levels (Molinar, Galt and Holechek 2001)
- Protects soil from sealing and pore clogging (Singer and Blackard 1978)

Grismer and Hogan (2005b) have shown that mulches alone can reduce soil erosion from bare slopes by an order of magnitude. However, the type, age, and fiber length of the mulch material are important.

Plants

Plants play an important role in erosion processes. Plants are closely linked to the elimination or reduction of erosion and have commonly been employed as the chief line of defense against surface erosion. Gray and Sotir (1996) describe the various services provided by plants including surface protection, surface and subsurface reinforcement of the soil, and influence on subsurface hydrology. They describe differences between woody and non-woody plants as well as provide limited shear strength values for some plants. The role of plants cannot be overstated. Since these roles are so complex, we refer to Gray and Sotir as well as other references where these roles are discussed in detail. Plants provide an indirect service by providing surface protective mulch. According to Torri and Boreselli (2000), "...the most effective action (of plants) is due to dead leaves and branches lying on the soil surface (mulch)." This mulch, as well as senescent plant roots, plays a major role in establishing and maintaining the soil nutrient cycle (Baldock and Nelson 2002; Pritchett and Fisher 1987; Paul and Clark 1989). Plant roots are a host to soil microorganisms and provide some of those organisms with a source of energy and nutrients (McBride 1994; Paul and Clark 1989; Reeder and Sabey 1987; Smith, Redente and Hooper 1987).

While plants do play a number of essential roles in stabilizing soil and reducing erosion, plants alone do not always limit erosion to acceptable levels (Elliot 2002; Zhang 2002). In recent rainfall simulation experiments on a range of cover types and amounts throughout the Tahoe region, Grismer and Hogan (2005b) found that plant cover did not always correlate with sedimentation rates, and in fact found that some sites with extremely high levels of plant cover produced extremely high erosion rates, similar to adjacent bare plots (Grismer and Hogan 2005a).

Soil Microbial Communities/ Mycorrhizae

Microbial activity is the chief driving force behind most soil function (McBride 1994; Paul and Clark 1989; Reeder and Sabey 1987; Huang and Schnizer 1986; and Whitford and Elkins 1986). Microbial populations are closely linked to and dependent on soil organic matter and soil quality. Microbes contribute to nutrient cycling and availability, aggregate formation, erosion resistance, water-holding capacity, disease resistance, etc. A number of microbial types coexist in the soil. While a great deal is known about soil microbes, an even greater amount remains to be discovered. Soil microbes are grouped into broad categories of *bacteria, actinomycetes,* and *fungi.* Soil microbial communities are known to convert most nutrients from an organic form into a plant-available form (Blackmer 2000; Killham 1994; Paul and Clark 1989; Tisdale and Oades 1982; Tisdale et al. 1993; Buxton and Caruccio 1979). In some cases, specific fungi are known to enhance uptake of both nutrients and water (Killham 1994 and Allen 1991). These fungi are categorized as *mycorrhizal.*

Mycorrhizae, which means "fungus roots," are an important element of the soil ecosystem. Mycorrhizae have received a great deal of attention with respect to their function and potential for use in disturbed site revegetation (Allen 1992). Mycorrhizae are a specific type of fungi that form a symbiotic relationship with plants. They are just one part of the incredibly complex ecosystem of soil microbes.

Surface Roughness

Surface roughness is often overlooked as a significant variable in erosion (Torri and Boreselli 2000; Battany and Grismer 2000). Surface roughness helps determine the velocity at which overland flow can occur, thus influencing both flow velocities and infiltration. Further, surface roughness is often associated with soil clods or aggregates and thus suggests soil stability, at least in an undisturbed and/or stable soil.

Soil Surface Sealing/Pore Clogging

Surface sealing and pore clogging are two potentially related processes. When infiltration of water occurs, fine clays, silts, organic matter, and other elements entrained in downward or interstitial flow can contribute to the clogging of pores. This process is especially related to splash detachment of fine sediments and subsequent redistribution. In some cases, these fine sediments are redistributed across the soil surface and subsequently dry into a hydrophobic layer called a soil crust. In other cases, this material makes its way into the soil and fills soil pores. In either case, the result is loss of infiltration and subsequent increase in overland flow and related erosion (Moody 2002). Over time, pore clogging and surface sealing may reduce infiltration to a level similar to highly compacted soil. This is an insidious issue in settling ponds.

SECTION 3: TREATMENTS FOR SEDIMENT SOURCE CONTROL

Section Overview

This section describes various functional tools that can be used to develop a sustainable, robust erosion control program. The term "functional" refers to the various functions that exist in an ecological system. Many planners attempt to establish grasses and other plants on a highly disturbed site much as one would plant a lawn or pasture. However, recent research has clearly indicated that vegetation alone may not always be adequate to control erosion (Grismer and Hogan 2004; Grismer and Hogan 2005a; Grismer and Hogan 2005b). To create a self-sustaining soil-vegetation community, this section addresses the restoration of actual functions that have been disturbed or destroyed during disturbance.

A great many erosion control projects are designed and implemented with the project proponent assuming that specific BMPs (Best Management Practices) have been tested and "proven" or that information gathered from various publications or conferences will actually perform as indicated across a range of site conditions. Unfortunately, that is not usually the case. The following section discusses tools used in site-specific erosion control and restoration treatments.

Refer to the Toolkit (Part Two) for complete descriptions of tools.

Defining Success as Improving Functions

All erosion control treatments define success either implicitly or explicitly. How project success is defined will determine a project's approach. For instance, if we envision a successful erosion control project outcome as primarily a well-vegetated area, then we are likely to focus on revegetation as our primary treatment. We will seed, fertilize, possibly mulch, and irrigate to establish that vegetation. Erosion itself may actually take on a secondary level of importance. As an example, some erosion control projects have actually *produced* erosion (sheet erosion or rills) as an outcome of irrigation that was used in an attempt to establish vegetation on treated areas. Some of these sites have been considered "successful" because grass had been established (Arst and Hogan 2008; Schnurrenberger et al. 2008).

If we define success in terms of *function* (such as hydrologic function, nutrient cycling, or energy capture), rather than *form* (how a site looks), it is likely that we will be much more accurate in assessing "success." In other words, we will be able to determine how a project is working rather than simply how it looks. According to Cummings (2003), the ability to restore function within the soil-plant ecosystem is likely to be the most powerful approach we can take to control sediment at its source. Cummings suggests that restoration of function within a disturbed system should be a primary goal. The usefulness of this concept can be seen in some projects where surface treatments are aimed at plant growth as a primary objective. Recent research on ski runs and highway road cuts has shown that, while it is possible to actually force plants to grow, these plant-dominated projects do not automatically equate to greater erosion control because runoff can still be quite high (Grismer 2004).

According to Cummings and others, the main functions of concern are:

1) Hydrologic function (infiltration, storage, transfer of water into and through the soil);

2) Nutrient cycling (cycling of nutrients within and through the soil); and
3) Energy capture (processing, storage, and transfer of energy from the sun as well as capture and transfer of water energy within and through the watershed).

For example, if water infiltrates into the soil, it will move through the watershed more slowly, resulting in a lower runoff rate as well as lower volume and velocity of water in the streams. This attenuation of energy will lower overall erosive forces. Without restoring soil hydrologic function, including infiltration, the goals of erosion control are not likely to be met, even though a site may support plant growth (for as long as fertilizer and irrigation are applied).

Energy capture may be described in two contexts: 1) energy captured and stored in the biota, or living things such as plants and soil flora and fauna; and 2) energy stored as water within the soil. Energy capture describes the plant community as well as links to the hydrologic function within a project area. Beyond simply describing plants as a "form," this approach recognizes the plants' function within the ecosystem—they store and then transfer energy to the soil and to animals as food.

This approach also discusses the energy function of the water within an ecosystem as well. For instance, a storm and/or runoff hydrograph represents an energy distribution graph. A hydrograph with a large peak early in the runoff cycle indicates a much higher probability of erosion than a lower peak later in the runoff cycle. This is also known as peak flow attenuation. A high-peak hydrograph describes a much more erosive runoff force than a low-peak hydrograph. Water that is stored in the soil as energy is available for plant growth throughout the growing season.

We therefore focus on three main functions: *hydrologic function, nutrient cycling,* and *energy capture* for planning and implementing treatments. By maximizing these three functions, soil will tend to remain in place and water within the watershed will tend toward a more natural or background behavior.

Three Common Treatment Indexes

While most sediment source control efforts focus on liquid water erosion, many of the same processes used to control liquid water erosion are also effective for wind and frozen-water-caused erosion (McCool 2002; Fryrear 2000; Tibke 2002). According to Reichert and Elemar (2002), "Water erosion is caused basically by raindrop impact and runoff of excess water, thus erosion and sedimentation control strategies must be based on covering the soil against raindrop impact, increasing water infiltration to reduce runoff generation and increasing surface roughness to reduce overland flow velocity."

The same techniques that are used to protect the soil surface against raindrop impact, namely mulch and live plants, are also effective for protection against wind erosion (by deflecting wind from the soil surface) and for protection against frozen-water erosion (by insulating soil against freeze-thaw and by providing additional surface roughness for snowmelt). Traditionally, live-plant cover has been considered of primary importance in erosion control. However, a great deal of research has shown that total ground cover, especially mulch, provides the most critical short-term impact or protection against erosion (Zhang 2002; Elliot 2002; Grismer and Hogan 2005b).

There is an extremely large number of attributes that define a site's ability to resist erosion, such as the extent of the microbial community, particle size distribution, plant type, and so forth. However, the three most accessible attributes that we often choose to serve as indices or site indexes for erosion resistance, given that they increase sediment source control in areas with water and wind pressures, are:

1) Cover (plant and mulch);
2) Soil organic matter and associated nutrients; and
3) Levels of infiltration.

Soil Nutrient Treatment Issues

Nutrients are critical for both plant and microbial growth in the soil. There are a broad range of both macro (N,P,K), secondary (Ca, Mg, S) and micro (Zn, Fe, Mn, Cu, B, Mb, Mo, Cl, Ni) nutrients. Typically, in the Sierra Nevada and other western mountain ranges (in non-mined sites), most macro and micro nutrients may be adequate, even on disturbed sites, with the exception of nitrogen. However, this is not always the case. Further, in disturbed sites, nitrogen (N) and carbon (C) are often deficient. Therefore, the ability to gather soil nutrient data from surrounding "reference" sites and comparing that to data from the disturbed site is an important step in understanding what is required in a native or self-sustaining system.

N is clearly recognized as the most important or generally most limiting nutrient involved in plant growth on disturbed sites (Marrs and Bradshaw 1993; Palmer 1990; Reeder and Sabey 1987; Bradshaw et al. 1982; Bloomfield, Handley and Bradshaw 1982; Wilkinson, Grunes and Sumner 2000; Palmer 1990; Claassen and Hogan 2002; Cummings 2003). N is used in the greatest quantities by plants and can be very mobile in mineral form.

While N is known to be limiting, caution should be exercised when determining which material may be needed to replace N or other nutrients. Many water bodies, such as Lake Tahoe, are known to be phosphorus (P) limited. If a fertilizer or amendment contains relatively high levels of P and the soil contains adequate P, additions may result in loss of P from the soil into nearby waterways, becoming a water body pollutant. Therefore, knowledge of both existing soil nutrient conditions as well as release characteristics of the fertilizer or soil amendment itself is important for effective use that minimizes runoff-pollution prevention.

N can be a limitation in both agricultural and wildland ecosystems. An important difference between these two types of ecosystems is that agricultural systems ("dose-response") are designed to receive an input (fertilizer) that is then removed from the system after producing a response (plant growth). The following season, the same cycle is repeated. Wildland systems, on the other hand, are self-sustaining. That is, they cycle most of their nutrients internally. In a pine forest, for instance, pine needles fall to the ground, are broken down by microbial activity, and eventually turn into nutrients for plants, microbes, and macrobes. Therefore, when planning and implementing an erosion control project, an understanding of the soil nutrient content (load) is critical.

In preparing project plans, it is important to understand three things:

1) The amount of nutrients and organic matter that are presently in the project site soil;
2) The amount of nutrients and organic matter that should be in the soil (measuring a reference site and/or using data from similar sites); and
3) The amount and what type of nutrients and organic matter need to be added to assure a self-sustaining system.

Several studies suggest that a certain level of nutrients, especially N, must be present in the soil before an adequate plant cover can be established and maintained (Claassen and Hogan 2002; Bradshaw 1997; Li and Daniels 1994; Reeder and Sabey 1987; Bradshaw and Chadwick 1980). Research on disturbed sites in the Lake Tahoe Basin shows a correlation between certain nutrient pools, especially nitrogen, and plant cover on previously disturbed sites (Claassen and Hogan 1998). Therefore, knowledge of current soil nutrient conditions allows the planner to specify amendments and fertilizers with the appropriate amount and type of nutrients.

Bradshaw et al. (1982) discuss the development of N cycling on mined land. They suggest that a pool of at least 1,000 kg/ha N must be accumulated, after which N cycling by mineralization, plant uptake and litter fall will support a self-sustaining ecosystem. This is comparable with Claassen and Hogan (2002), who found that well-vegetated, previously disturbed sites in the Lake Tahoe Basin are located at sites where there is a pool of at least 1250 kg/ha total N.

While N is understood to be a critical limiting nutrient in most terrestrial semi-arid ecosystems, and N is largely derived from organic matter in those ecosystems, the capacity for the total N contained in that organic matter to mineralize is not consistent or well understood (Baldock and Nelson 2002; Blackmer 2000). Reestablishment of nutrient cycling on disturbed sites is seen as a primary cornerstone in the successful re-creation of a sustainable terrestrial ecosystem capable of resisting erosion, improving water quality, enhancing wildlife habitat, and improving other beneficial uses (Haering, Daniels and Feagley 2000; Macyk 2000; Marrs and Bradshaw 1993; Palmer 1990; Reeder and Sabey 1987; Dancer, Handley and Bradshaw 1977; Cummings 2003; Bradshaw et al. 1982; Bloomfield, Handley and Bradshaw 1982; Dodge 1976). Woodmansee et al. (1978) report that N deficiency can affect the long-term stability of a site by limiting plant growth, thereby increasing erosion from that site.

Organic Matter Treatment Issues

Soil organic matter drives a number of processes in the soil, as discussed in previous sections. Powers (1990) suggests that a decline in forest productivity is linked directly to losses of soil organic matter. It thus may be one of the most important elements of soil function. Noyd et al. (1996) report that compost has a primary impact on reestablishment of both plant communities and mycorrhizal fungi colonization on taconite mine spoils in the Mesabi Iron Range in Minnesota while arbuscular mycorrhizae (AM) inoculation played a secondary role. Johnson (1998) suggests that manipulating edaphic factors through additions of soil organic matter may be more cost-effective on low P sites than large-scale mycorrhizal inoculation. These edaphic factors include adequate organic matter in the soil and many of the connected elements, as mentioned above.

The inclusion of organic material in a depauperate (low-nutrient) soil may provide additional benefits beyond nutrient additions, such as increased water-holding capacity,

Tub-ground wood shreds ("tub grindings") can be used as a soil amendment to add organic matter to disturbed soils. Tub grindings and other woody amendments support critical soil functions such as microbial activity, water infiltration, and water storage.

increased microbial activity (enhanced cycling of pre-existing nutrients), increased infiltration rates, and a higher cation exchange capacity (Brady and Weil 1996). Soil organic matter has been linked to establishment and persistence of plant communities in the Lake Tahoe Basin and elsewhere (Claassen and Hogan 1998; Baldock and Nelson 2002; Bradshaw 1997; Woodmansee, Reeder and Berg 1978) as well as to an increase in the soils ability to resist erosion. There are a number of types of organic matter including compost, wood chips, manure, and others. Each has its own strengths and weaknesses and should be considered carefully before use, especially for amounts and release rates of nitrogen and phosphorus.

Fertilizer Treatment Issues

The use of fertilizer for erosion control projects has been a standard practice for many years. Essentially, fertilizer is used to make up for inadequate amounts of nutrients in the soil (Soil Improvement Committee 1998). Much of the information on and the approach to fertilizer use comes from agricultural research. Much less research has been done on wildland system restoration. However, some work has been done by Bradshaw and others in mine reclamation to focus on rebuilding and re-capitalizing the nitrogen cycle in "derelict" or drastically disturbed sites. These researchers generally found that adequate N cycling was directly linked to organic matter in the soil (R. D. Roberts et al. 1980; Bradshaw, Marrs et al. 1982; Bloomfield, Handley et al. 1982; Marrs and Bradshaw 1982; Woodmansee, Reeder et al. 1978). Further, Classen and Hogan (2002) found that adequate organic matter and mineralization of the N in organic matter was directly linked to plant growth. While some of this research has been available since 1980, few findings have been incorporated into ski area work.

Bradshaw and others (1982) suggest that rebuilding of the nitrogen cycle is the underpinning of most reclamation or restoration on drastically disturbed land. Reeder and Sabey (1987) and many others support the importance of this approach. Their findings clearly suggest that fertilizers alone are unlikely to rebuild these soil-plant systems to adequate levels of N in a reasonable time unless a very careful application regime is instituted. Yearly applications may increase nutrients to the point of self-sustainability, as Ray Brown was able to show on a mine site in Idaho. However, 25 years were required to do so. In this project, cost was not evaluated, but estimates of labor alone could be as high as $25,000 (Brown and Johnson 1978).

When using fertilizers, it is essential to understand their strengths and limitations and not expect fertilizers alone to completely regenerate self-sustaining nutrient cycling (Tisdale et al. 1993). Fertilizers will be seen as part of an overall package of treatment. It is also critical to understand what type and how much fertilizer is actually needed in any particular situation so that under- or over-application does not become a problem (Tisdale et al. 1993; Soil Improvement Committee 1998).

Fertilizers come in many forms and nutrient amounts. The two most common fertilizers are the mineral and the organically based fertilizers. Some mineral fertilizers are coated so that the nutrients are released more slowly. Specific information on fertilizers can be found in Tisdale et al. 1993 and Soil Improvement Committee 1998.

Mycorrhizae Treatment Issues

Mycorrhizal fungi play an important role in most ecosystems. Mycorrhizal fungi are a group of fungi that have the ability to form a relationship with certain plants that is mutualistic.

Mycorrhizae can be considered an important subset of soil microbial components. A broad range of information about mycorrhizal physiology, morphology, and classification can be found in Walling, Davies and Hasholt 1993; Paul and Clark 1989; and Killham 1994.

In terms of the benefits of mycorrhizae, there is little doubt that these types of fungi play a critical role in the life cycles of many plants. Paul and Clark and Killham discuss the myriad of benefits associated with the range of mycorrhizal fungi. The two types of mycorrhizae that are of chief concern in wildland systems, especially relative to restoration, are the vesicular-arbuscular subgroup of the endotrophic mycorrhizae and the ectotrophic mycorrhizae, which form relationships with temperate trees and shrubs (Paul and Clark 1989). Endotrophic mycorrhizae are found on about 90% of the world's plants (Israelsen 1980) and thus are of critical concern.

The microbial community within a soil is known to drive conversion of most nutrients from an organic form into a plant-available form (Paul and Clark 1989; Killham 1994; Tisdale et al. 1993; Buxton and Caruccio 1979; Killham 1994; Buxton and Caruccio 1979). In some cases, specific fungi are known to enhance uptake of both nutrients and water (Killham 1994). A great deal of attention is currently being placed on mycorrhizal fungi and specifically on use of commercial, non-native or non-indigenous inoculum. Noyd et al. (1997) and others reported that compost had a primary impact on reestablishment of both plant communities and mycorrhizal fungi colonization on taconite mine spoils in the Mesabi Iron Range in Minnesota while arbuscular mycorrhizae (AM) inoculation played a secondary role.

Johnson (1998), in studying plant response to mycorrhizal inoculation across a phosphorus gradient, reported that inoculation with AM fungi reduced growth at high soil P levels. This finding is relevant to Tahoe and Sierra Nevada soils that tend to be high in P (Rogers 1974), suggesting that AM inoculation may not play an important role and may in fact reduce plant growth on some revegetation sites. This finding is further supported by an unpublished study of a variety of treatments (Longenecker, senior thesis) on Tahoe granitic soil, including inoculation with non-native (cultured) mycorrhizae. Measurement of growth rates in a sixty-day experiment showed that soil inoculated solely with mycorrhizae resulted in a growth rate lower than the control, while soil with compost and organic fertilizer resulted in growth rates over twice as high as either the control or the inoculated plots.

Further, Johnson (1998) suggests that manipulating edaphic factors through additions of soil organic matter may be more cost-effective on low P sites than large-scale inoculation. In support of this approach, Sylvia (1990) reported that after initial infection by vesicular arbuscular mycorrhizae (VAM) on plants used in a mine reclamation site in White Springs, Florida, there was no plant effect at 18 months and that VAM inoculation had no effect on transplant survival. These soils were low in nutrients, thus supporting the nutrient-addition findings of Noyd, Pfleger and Norland (1996), Johnson, and others.

In another study, Noyd et al. (1997) reports that adequate rates of compost added to taconite mine tailings produced biomass equivalent to or surpassing a native tallgrass prairie in three years. At the same time, organic matter accrual increased and the litter breakdown rate decreased, implying long-term plant community sustainability. In a greenhouse study, Stahl et al. (1998) discuss the greater capacity of VAM-inoculated Big Sagebrush to withstand drought than non-inoculated plants. However, the substrate used was collected from an undisturbed, nutrient-adequate site, further supporting the adequate-nutrient concept. Weinbaum and Allan (1996), in a reciprocal transplant study between San Diego and Reno, showed that non-local mycorrhizal inoculum always declined at the exotic site and with exotic hosts, arguing for both locally collected inoculum and locally sourced plants.

Native plants, such as this Penstemon newberyii, can thrive and grow vigorously in low-density, high-nutrient soil conditions.

Plant Treatment Issues

Plants play an extremely important role in practically all ecosystems. Plants are linked to and supported by the soil community. For many years, researchers and erosion control writers and practitioners have emphasized the plant or vegetative component of erosion control projects and have in fact referred to erosion control projects as "revegetation," with the assumption that vegetation controls erosion (California Tahoe Conservancy 1987; US Department of Agriculture 1982; Nakao 1976; Leiser et al. 1974). Plants play many roles in restoration and erosion control, especially on disturbed sites. Plants are closely linked to the elimination or reduction of erosion and have commonly been employed as the chief line of defense against surface erosion. However, while plants play an essential role in stabilizing soil and reducing raindrop impact, they do not always limit erosion to acceptable levels (Elliot 2002; Zhang 2002). We suggest that by linking the plant and soil elements, a more effective outcome can be produced.

A healthy, robust soil will be a critical issue for planting of any kind. Drastically disturbed soil will have very different attributes from a slightly or non-disturbed site. Reestablishment of a sustainable plant community on severely disturbed upland sites in the Sierra Nevada has proven difficult (Erman et al 1997; Leiser et al. 1974).

Aside from surface stabilization, plants also contribute to subsurface stabilization. An increase in root biomass typically results in an increase in physical soil stabilization due to shear and tensile strength (Gray and Sotir 1996). This fact is useful in ski areas to counter some county ordinance interpretations that may require ski runs to be compacted in order to provide soil strength. However, when soil is compacted, infiltration is decreased and plant roots cannot penetrate easily, thus reducing plant growth to minimal levels. (For discussion of soil density, see "Infiltration" page 204). Further, plants have been used successfully in the Lake Tahoe and Truckee areas to successfully hold loose soils on up to 1:1 slopes (Hogan 2005). One additional consideration for plant use is that claims made by suppliers may not live up their billing, given that site conditions vary widely.

Mulch Treatment Issues

A great deal of information exists regarding the effectiveness of mulch to control erosion. Agassi (1996) states that "mulching is a very efficient means to dissipate raindrop impact and to control the ensuing soil surface sealing, runoff, and erosion. Mulching can also reduce evaporation of rainwater and overhead irrigation water. Therefore, mulching can be a vital factor in improving water use efficiency." Mulch provides a number of "services." These services are listed in Table 2.

In the Lake Tahoe Basin, an ongoing study by Grismer and Hogan (2005b) found that mulches can reduce sediment delivery by an order of magnitude. Edwards and Burney (1987) found that mulch minimized the effects of both compaction and freeze-thaw on a range of soils (silt, sandy loam, fine sandy loam). Battany and Grismer (2000) showed that in a California vineyard, soil loss was linked to soil cover.

Pine Needles

Pine needles have been used in the Lake Tahoe Basin and elsewhere as a surface mulch since 1992. However, little research has been done on pine needle effectiveness. Pannkuk and Robichaud (2003) studied pine and fir needle cast following fires on both volcanic and granitic soils and found that a 50 % cover of Douglas fir needles reduced interrill erosion by 80% and rill erosion by 20%. A 50% cover of Ponderosa pine needles reduced interrill erosion by 60% and rill erosion by 40% (Wright, Perry and Blaser 1978).

Pine and fir needles offer advantages over some short-lived mulches such as straw because

Table 2: Mulch Services

Service	Description	Notes
Surface Protection - Rain	Protects soil surface from raindrop splash detachment	
Surface Protection - Wind	Protects soil surface from detachment and transport of soil particles by shear forces	
Overland Flow Reduction	Reduces overland or surface flow of water by creating a maze of "mini-dams"	Longer fiber length provides a higher level of protection. Blown-on mulch results in greater soil surface contact.
Temperature Protection	Reduces solar input to the soil by reflecting solar energy	The color of a particular mulch plays an important part in this process. Darker mulch absorbs more heat energy, for instance.
Evaporation Protection	Reduces evaporation by reducing surface temperatures as well as by creating a physical barrier	
Nutrient Addition	Organic mulches contain carbon and other organic nutrients that can enhance both organic matter and nutrients in the soil	Nutrient and energy additions are variable and depend upon the material. For instance, straw is known to contain very little C and N while pine needles can be much higher. Wood chips may lock up N but contain high amounts of C.

they last anywhere from two to ten times as long, thus providing services over longer periods of time. Grismer and Hogan have been assessing pine needle mulch effectiveness since 2003. Several reports and publications have quantified the positive effects of pine needles on both plant growth and erosion reduction at a wide range of sites (Grismer and Hogan 2005b; Arst and Hogan 2008; Schnurrenberger, Hogan and Arst 2008). These reports have shown that some of the highest infiltration rates, as well as the highest levels of plant cover on restoration sites, have been measured at sites where pine needles were applied as the mulch material. Modeled after native forest surface cover, the use of pine needles has shown very promising results. Pine needle mulch has the additive benefit of being native and locally-sourced throughout the Sierra Nevada, thus reducing both transportation costs and the risk of importing weeds.

Tilling Treatment Issues

Removal of compaction and/or reduction of soil density is a critical component of restoring hydrologic function to soil. Froehlich and McNabb (1984) show that compaction may last up to 30 years and can reduce stand growth in

Tilling has proven to be a highly effective method for loosening dense soil and incorporating organic matter.

Pacific Northwest forests by up to 15%. Tillage of compacted soil can be effective in reversing compaction. Luce showed that on a highly compacted road that had been ripped, saturated hydraulic conductivity can be up to 35 mm/hr, or approximately half of the natural background. However, Luce (1997) also suggests that this rate represents a significant increase in infiltration and would effectively reduce runoff and thus erosion during rainfall events of over one inch per hour.

Grismer and Hogan (2005b) measured infiltration rates of more than four inches per hour on a Tahoe area ski run where wood chips had been tilled into a highly compacted soil. Torbert and Burger (2000), reporting on research by Larson and Vimmerstedt (1983), state that compaction is likely the most important mine reclamation problem in need of solution. They state that compaction is caused during several steps of reclamation construction such that soil bulk density is reduced to root-limiting levels.

Economic Considerations in Treatments

An extremely important consideration in designing and implementing a restoration, erosion control, or revegetation project is cost. One approach that needs further study is the cost over time or cost per unit time aspect.

The cost of implementing an erosion control project is often measured as the cost of applying material to the project area. However, if we regard the replacement of function to that site as a primary goal and add the element of time, the question becomes, "How well does this project function and for how long?" For instance, if straw mulch is used and lasts two seasons and costs $1000/acre compared to pine needle mulch which may initially cost $2500/acre but lasts five seasons, then the actual cost would be exactly the same per year effectiveness. More cost-effectiveness assessments will be critical to determine the actual costs of projects, not just the application cost. Many projects in the Lake Tahoe Basin have been re-treated using the same relatively inexpensive techniques (hydroseeding, no soil preparation) two and three times and still have not performed adequately (personal communication, Jason Drew—NTCD; Joe Pepi—California Tahoe Conservancy; Larry Benoit—Tahoe Regional Planning Agency). This raises the question, "How many times do you apply something that doesn't work before realizing that resources are not being spent effectively?"

> "Equipped with his five senses,
> man explores the universe around him
> and calls the adventure Science."
>
> – Edwin Powell Hubble, The Nature of Science, 1954

CONCLUSION

Disturbance and erosion need to be considered in a holistic, systemic, and functional context to develop effective strategies to reduce or control that erosion (Dudley and Stolton 2003). If the *system* within which erosion takes place is ignored, erosion control measures are unlikely to succeed over the long term. It is useful to present information and techniques that clearly show how to stop erosion successfully. The paucity of this information has led to the implementation of a wide range of CAREC test areas.

While a great deal of information has been published regarding the control of erosion, little of the information provides a complete picture of what is required at each site. Furthermore, most erosion-related research tends to be single-variable manipulation studies such as mulch, seed, fertilizer, plant type, etc. (see "State of Erosion Control Knowledge," page 198). Beyond the single-variable consideration, most studies are also point-in-time studies, and thus do not typically measure results over a multi-year period. This type of information can be incomplete at best and misleading at worst. Field practitioners must deal with multiple variables and do so over several seasons.

Based on this Literature Review, the following information gaps have been identified as key areas for additional inquiry, research, and documentation in alpine areas:

- Direct measurement and quantification of treatments versus modeling or guesswork
- Long-term trends
- Runoff (overland flow) simulation
- Aging wood chips for use as a soil amendment
- Tilling depths and amendment concentrations
- Seeding rates and plant response
- Shrub seeding response and timing
- Effects of different irrigation types and cycles on plant establishment and rooting depth
- Measurements of shear and tensile strength provided by plant roots
- Effectiveness of biological and soil-based BMPs
- Direct measurement of temporary BMP effectiveness
- Freeze-thaw protection with mulch and organic matter
- Improved calibration of the runoff ("C") coefficient for erosion models
- Low-impact ski run construction techniques

This situation presents us with both restrictions and opportunities. We are restricted by a lack of complete knowledge on effective erosion control treatments in disturbed alpine areas. However, we are offered the opportunity to gain missing knowledge on our own projects through the use of an adaptive management approach (see Guiding Principles). CAREC has been committed to improving the understanding of effective sediment source control treatments in and beyond ski resorts. This Handbook contains a large amount of information that has been gained through the cooperative CAREC process. We encourage others to expand this important work so that we can continue to improve our collective understanding of erosion processes, sediment source control techniques, and restoration of disturbed ecosystems.

GLOSSARY

Anthropogenic – Caused or produced by humans.

As-built – A report and/or drawing that is prepared in order to document the specific treatments and techniques used in the construction of a project. An as-built should include information such as specific treatments implemented, materials used, construction dates, project personnel, project goals, site description, and photo points. As-builts can be used to inform future monitoring efforts and should be detailed enough to replicate the treatment.

BMP (Best Management Practice) – A technique, process, activity, or structure used to reduce the pollutant content of a storm water discharge. BMPs include simple non-structural methods, such as good housekeeping and preventive maintenance. BMPs may also include structural modifications, such as soil and vegetation treatments or the installation of bioretention features. BMPs are most effective when used in combination with one another and customized to meet the specific needs (drainage, materials, activities, etc.) of a given site and operation.

Concentrated flow – Surface flow that has assembled into a single flow path. Rills and gullies result from concentrated flows. However, the term is often used to describe gully-sized flows and greater.

Cone penetrometer – An instrument used to assess soil density and/or compaction at different depths. May be equipped with a gauge that measures resistance to force, typically in pounds per square inch.

Ephemeral – Said of a stream that flows only in direct response to precipitation or storm runoff in the vicinity and whose channel is usually above the water table. Also refers to the flow of such a stream.

Erosion – The detachment or breaking away of soil particles from a land surface by some erosive agent, most commonly water or wind, and subsequent transportation of the detached particles to another location.

Fluvial – Used in geography and earth science to refer to the deposits and landforms created by the action of rivers or streams and the processes associated with them.

Groundwater – Subsurface water in the zone of saturation in an aquifer or soil.

Gully – A landform created by running water eroding sharply into soil. A gully often begins as a rill and then enlarges to a greater size. While there is no widely agreed-upon size at which a rill becomes a gully, gullies are generally considered to be at least twelve inches in depth or width but may be as large as tens of meters in depth and width.

Hydrophobicity – The property of being water-repellent. On hydrophobic soil, water tends to collect on the soil surface rather than infiltrate into the ground.

Infiltration – The process of water entry at the land surface into soil or rock from a source such as rainfall, irrigation, or snowmelt.

Intermittent – Said of a stream along which perennial flow is restricted to certain reaches; Also refers to the flow of such a stream.

Landslide – A geological phenomenon that includes a wide range of ground movement, such as rock falls, deep failure of slopes, and shallow debris flows. Although the action of gravity is the primary driving force for a landslide to occur, there are other contributing factors affecting the original slope stability. Typically, pre-conditional factors build up specific subsurface conditions that make the area/slope prone to failure, whereas the actual landslide often requires a trigger before being released.

Mass failure – The large-scale, downward (and sometimes outward) movement of soil and other earth materials on a slope under the influence of gravity. Mass failures typically occur along a failure plane, result when the stress imposed exceeds the strength of the material to hold itself in place, and can be exacerbated by positive pore pressure within the soil itself. Mass failures include many specific types of falls, slides and flows.

Mulch – 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.

NTU (Nephelometric Turbidity Unit) – A measure of the turbidity in water based upon the amount of light that is scattered as a beam is shone through the water. It is generally considered more meaningful as a measure of turbidity than other, similar measurements.

Nutrient cycling – The processes by which chemical elements or molecules are extracted from their mineral, aquatic, or atmospheric sources or recycled from their organic forms, converting them to the ionic form in which biotic uptake occurs and ultimately returning them to the atmosphere, water, or soil. In effect, elements are recycled, although in some cycles there may be places (called "reservoirs") where the element is accumulated or held for a long period of time. Elements, chemical compounds, and other forms of matter are passed from one organism to another and from one part of the biosphere to another through biogeochemical cycles.

Porosity – Portion (percent) of the total volume of rock, unconsolidated sediment, or soil taken up by open space or pore space.

Pore space – The space between soil particles that contains the liquid and gas phases of the soil components. Pore space provides the capacity to store water and air, as well as enabling drainage and root growth. The ability of a pore to transmit water decreases dramatically with its size.

Pore pressure – Refers to the pressure of groundwater held within a soil or rock, in gaps between particles (pores). "Positive pore pressure" is a phenomenon caused when water tries to enter a pore without any water leaving the pore, resulting in pressure being exerted in an outward direction. If soil cohesion is not strong enough to withstand the outward force, this process will dislodge soil particles, creating erosion or, in extreme cases, mass movements.

Pulse runoff – Rapid runoff caused by high-intensity precipitation events.

Rill – A narrow and shallow (usually less than several inches) incision into soil resulting from erosion by overland flow that has been focused into a thin thread by soil surface roughness.

Rotational failure – Type of mass failure with a curved failure plane that involves the rotational movement of the soil mass. Slumps are a common type of rotational failure. If the soil material has high water-content, slumps and other types of rotational failures can become slides or flows further downslope.

Sediment – Solid fragments of inorganic or organic material derived from the weathering of rock that are carried and deposited by wind, water, or ice.

Sedimentation – The act or process of depositing a sediment.

Sediment source control – Keeping soil particles in place at their source. Sediment source control is an alternative approach to efforts aimed at capturing and treating transported sediment downslope.

Sheet erosion – The process by which water traveling over the ground surface in an unconcentrated configuration picks up and transports detached soil particles. Sheet erosion tends to be uniform, gradual, and difficult to detect until rills develop. If runoff is maintained as sheet flow, the velocity tends to remain low.

Slump – An erosional feature in which a mass of soil has settled or moved downslope due to gravitational forces. Slumping usually occurs on steep hillsides and along distinct fracture zones, often within materials like clay that, once released, can move quite rapidly downhill.

Soil – A dynamic natural body composed of mineral and organic materials and living forms in which plants grow.

Soil aggregation – The physical and biological processes (particularly microbial activity) by which combinations of soil particles are bound together into a single mass or cluster such as a clod, crumb, block, or prism (known collectively as "soil aggregates").

Soil amendment – 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.

Soil cohesion – The physical, biological, and molecular forces that hold soil particles together.

Soil density – Typically described in terms of "bulk density," which is the mass of dry soil per unit of bulk volume, including air space. Soil that has been compacted is said to exhibit higher density.

Soil organic matter – The organic matter component of soil. Soil organic matter is derived from decaying plants and animals, as well as living organisms. It can be divided into three general pools: living biomass of microorganisms, fresh and partially decomposed residues, and humus: the well-decomposed organic matter and highly stable organic material. Surface litter is generally not included as part of soil organic matter. Organic matter stores the majority of carbon in soil (particularly glomalin, a recently discovered glycoprotein in soil organic matter that may store up to 30-40% of soil carbon).

Soil water – Subsurface water in soil or rock within the unsaturated zone; that above the water table.

Soil water content – The quantity of water contained in soil (also called soil moisture), on a volumetric or gravimetric basis. Typically expressed as a ratio, which can range from 0 (completely dry) to the value of the soil's porosity at saturation.

Surface runoff – The water flow that occurs when soil reaches saturation or when the rate of water input exceeds a soil's infiltration capacity and excess water (from rain, snowmelt, or other sources) flows over the land. Surface runoff often causes erosion.

Surface run-on – Surface water that originates from above or upslope of a project site or area of interest (also referred to as "run-on"). Run-on may take the form of sheet flow or concentrated flow. Run-on can cause surface erosion or mass failure (landslides).

Surface water – Water collecting on the ground or in a stream, river, lake, wetland, or ocean (as opposed to groundwater or atmospheric water).

Sustainable – In an ecological context, this term (or "sustainability") is defined as the ability of an ecosystem to maintain ecological processes, functions, biodiversity, and productivity into the future. A common indicator of ecosystem sustainability is the resiliency of an ecosystem following disturbance.

Topsoil – The uppermost and most biologically active layer of native soil. It has the highest concentration of organic matter and microorganisms and is where most of the earth's biological soil activity occurs. Topsoil is typically darker in color (due to a high concentration of organic matter) than the subsoil layer beneath it. Plants generally concentrate their roots in and obtain most of their nutrients from this layer. Topsoil also tends to contain a large store of native seeds, often called the "seed bank," which can contain more than 5,000 seeds per square meter. A variety of soil mixtures are sold commercially as topsoil. While these materials may exhibit some of the characteristics of naturally occurring topsoil, actual topsoil cannot be manufactured.

Upland – Land at higher elevations than the alluvial plain or low stream terrace; all lands outside the riparian, wetland, and aquatic zones.

Watershed – An extent of land where water from rain or snowmelt drains downhill into a body of water, such as a river, lake, reservoir, estuary, wetland, sea, or ocean. The watershed area (or "drainage basin") includes the streams and rivers that convey the water as well as the land surfaces from which water drains into those channels, and is separated from adjacent basins by geographic features known as "drainage divides."

Water bar – An earthen ditch, usually with an associated berm, that is designed to capture and divert water from steep slopes or road surfaces when surface runoff occurs.

"We know more about the movement
of celestial bodies
than about the soil underfoot."
– Leonardo da Vinci

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> "... THE LATIN NAME FOR MAN, HOMO,
> DERIVED FROM HUMUS,
> THE STUFF OF LIFE IN THE SOIL."
> – DR. DANIEL HILLEL

Praise for the Sediment Source Control Handbook

"The production of this *Sediment Source Control Handbook* demonstrates that collaboration can result in the practicable application of science to protect and improve water quality. I am very grateful to the ski areas and land managers that had the vision to participate in this endeavor and to fulfill the goal of this project. Additionally, our collaboration needs to continue such that we can continue to advance our knowledge of successful measures to address sediment at its source and to share this information through updates to the Handbook."

– Harold Singer, Executive Officer, Lahontan Regional Water Quality Control Board

"What has really been gratifying about helping with the *Sediment Source Control Handbook* is the opportunity to work with a diverse group of individuals, regulators, scientists and operational staff to develop treatment approaches that are field tested in our mountain environment."

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