WATERSHED MANAGEMENT GUIDEBOOK

A Guide to Outcome-Based Watershed Management

An Integrated Environmental Restoration Services, Inc. Publication

Produced in collaboration with the Tahoe Resource Conservation District &
Lahontan Regional Water Quality Control Board

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A Publication by Integrated Environmental Restoration Services, Inc.

Produced in collaboration with the Lahontan Regional Water Quality Control Board and the Tahoe Resource Conservation District

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This Guidebook is a manifestation of the vision and commitment of many people and organizations. From regulators to land owners, scientists to citizens, consultants to community organizations. People with diverse backgrounds and a shared interest in improving our effectiveness as watershed managers and stewards have helped see this Guidebook to fruition.

The original vision for the outcome-based management approach presented in this Guidebook came from Martin Goldberg, then of Lahontan Regional Water Quality Control Board (Lahontan), John Loomis, then of Northstar California, and Michael Hogan, of Integrated Environmental Restoration Services. This vision would not have gained traction without the support of Harold Singer, then Executive Officer of Lahontan. Many of the breakthrough results presented in the Guidebook would not have been possible without Art Chapman of JMA Ventures LLC (owner of Homewood Mountain Resort), who's vision to raise the bar on what a "green" ski resort could be laid the ground work for the public-private partnership that created this project. With substantial support from David Tirman and Kent Hoopingarner (JMA Ventures LLC), Homewood Mountain Resort has become a working laboratory for watershed management and research.

Integrated Environmental Restoration Services managed the on-the-ground and scientific work of this project including producing the Watershed Management Guidebook, designing and implementing test plots, assessing the results and synthesizing key findings. This work would not have been possible without our long-term research partnership with Dr. Mark Grismer at the University of California, Davis, whose combination of technical expertise and humility is rare and truly inspiring. We owe a great debt of gratitude to Gerald Rockwell, formerly of USGS' Tahoe Field Office, who came out of retirement to help us develop and implement a targeted water quality monitoring approach that has already produced some breakthrough results.

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Lastly, thanks to my co-author Michael ("Doctor Dirt") Hogan for continually pushing us all to aim higher, test "common sense" assumptions, and embrace unexpected outcomes in our work. Your hard work, collaborative spirit and intelligent optimism are sincerely appreciated.

We are grateful for the opportunity to work with so many energetic and talented people to produce this Guidebook. We sincerely hope you find this Guidebook useful and that it leads to deeper satisfaction in your work and meaningful connections with the watersheds in which we live, work and play.

Kevin Drake

Watershed Planner, Restoration Specialist

Integrated Environmental Restoration Services, Inc.

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COMMITTING TO OUTCOMES

Effective, highly productive watershed management is defined by OUTCOMES. Watershed management includes all actions that take place in a watershed: from small erosion control projects to development to ranching to large-scale restoration. These are all investments, and we strive for a sustained return on our investments. We only know our return on investment by assessing actual project outcomes and comparing them to goals. When project goals are achieved, success can be celebrated; when they are not achieved, project outcomes can be adjusted and a window into learning and improvement is opened. The process is relatively simple but not easy to implement: it requires embracing uncertainty and taking a stand for continued movement toward goals. We still have much to learn in watershed science and management. This Guidebook is intended to catalyze curiosity, inspire personal commitment, and support a shift toward a new way of doing business we call **OUTCOME-BASED MANAGEMENT**, a process that can produce breakthrough results in watershed projects.

INTRODUCTION TO THE WATERSHED MANAGEMENT GUIDEBOOK

WHY

Watersheds and landscapes throughout the west are under increased pressure from human activities of all types—development, resource extraction, recreation, and environmental changes such as drought and climate change. In the midst of these challenges, environmental managers of all levels and disciplines are seeking a greater understanding of what actual outcomes are produced from investments in watershed restoration and management projects.

WHAT

This Guidebook offers tools to engage in watershed management to achieve regulatory goals, and to achieve the level of resource protection and improvement intended by those regulations. Specifically, this *Watershed Management Guidebook* provides guidance and tools to:

- Enable individuals and groups to engage in cost-effective watershed management and improvement
- Locate sources of sediment loading
- Assess water flow and connectivity
- Scope, prioritize, and implement projects
- Evaluate project effectiveness and outcomes

WHO

This Guidebook is intended to be used by land managers, restoration practitioners, field staff, regulatory/permitting agency personnel, watershed groups, land trusts and other citizen stakeholders. Specific applications of this Guidebook for potential users are outlined below.

WHERE

The information and tools in this Guidebook are intended for use within all watersheds and management contexts. However, the supporting research, data and field methodologies in this Guidebook have been tested (and continue to be tested) in Northern and Eastern Sierra Nevada ecosystems near Lake Tahoe, California.

HOW

This Guidebook can be used in a modular format (e.g. individual tools) or as an entire system (outcome-based management). While it is not intended to be read cover-to-cover, we strongly encourage users to become familiar with outcome-based management in conjunction with exploring technical tools, as this is the process we have used to develop all of the technical content in this Guidebook. See *Navigating this Guidebook* (next page) to get started.

Table 1. Guidebook Applications

Guidebook Users	Potential Applications
Land managers, project implementers	Technical reference for on-the-ground treatments and assessment methods
Field staff, restoration practitioners	Technical reference for on-the-ground treatments and assessment methods
Watershed groups, land trusts	Conducting watershed assessments; preparing grant applications; defining goals and performance metrics for watershed improvement efforts with multiple partners; watershed education for public/volunteers
Agency permitting personnel	Identifying alternative treatment/monitoring approaches; developing permit conditions (monitoring and success criteria)
Citizen stakeholders	Gain understanding of watershed processes and alternative approaches to watershed improvement

What is this Guidebook?

The Watershed Management Guidebook presents a set of principles and practices for managing disturbed watersheds. It has been developed based on years of practice to help link initial project plan to actual outcomes in watershed projects. The Guidebook does not provide all the answers or completely prescriptive approaches. Instead, it offer tools to help achieve greater alignment between intentions and outcomes. There is a growing recognition that relying solely on mathematical models to help us manage dynamic watersheds and their complex processes is not practical. By assessing outcomes and embracing the uncertainty inherent in managing watersheds, we can produce not only high quality results but we can continue to add to our knowledge base and improve future projects.

This Guidebook was created to share a process that has been evolving for over 20 years and that has produced surprising results. This process has achieved results by valuing direct assessment over expert opinion, embracing unexpected outcomes, and in the process, building relationships and a common language among participants at every level in watershed management efforts.

Unexpected outcomes achieved by using the Outcome-Based Management Process

This Guidebook is an outgrowth of more than 20 years of applied research and watershed management projects throughout the western United States. Here are a few unexpected outcomes we have achieved and things we have learned along the way:

- **Outcome-based management can actually save money** in the short and long run. By focusing on goals and actual outcomes, regulatory requirements can often be achieved in a more targeted, streamlined manner.
- **Soil conditions are usually the primary determinants of erosion.** Stated differently, vegetation alone does not necessarily control erosion. By focusing on actual outcomes, costs can be reduced by not spending money on unproductive treatments.
- **Inexpensive soil amendments can produce surprising and superior results.** Use of locally-available materials such as wood chips/shreds and pine needle mulch can dramatically reduce runoff, resulting in infiltration rates greater than 4.7 inches per hour in dry soil conditions. Wood chips also add carbon, can reduce weeds and support robust microbial activity in depleted soils.
- **Outcome-based management can improve compliance and reduce violations.** By focusing on actual outcomes rather than solely on compliance, violations on a large construction project were reduced from several thousand to zero in one year. This process not only achieved positive outcomes in the field but also built relationships and credibility along the way.
- **Targeted water quality monitoring can be used to measure daily and annual watershed sediment loading at a similar cost to typical weekly stream monitoring.** A 40% reduction in annual sediment loading was measured in the Homewood Creek watershed between 2010 and 2011 following targeted treatment of erosion hot spots.
- **Outcome-based management can reduce the probability of legal battles.** By focusing on field-measurable outcomes rather than EIR 'findings of no significance', which are opinion-based, outcome-based management became the alternative to a legal challenge over the potential erosion impacts of a proposed ski area expansion. Field assessment of actual (rather than predicted) outcomes and effectiveness of mitigation measures was conducted before and after construction, which verified no increases in erosion (often reductions), thereby avoiding substantial legal fees and multi-year construction delays.

Navigating this Guidebook: Breaking it Down

This Guidebook is comprised of three main parts. Taken as a whole the Guidebook offers many levels of management tools, from big picture to specific treatment and monitoring tools. Most Users of this Guidebook will access different sections or tools as it applies to their project. In order to gain the most from this Guidebook, a review of the management steps in **Part One** will be useful. Specific tools are found in **Part Two**. Relevant research is summarized in **Part Three**, which provides a foundation for much of the thinking and approaches found in the rest of the Guidebook. We hope that this Guidebook will serve as a valuable roadmap and practical resource that supports your efforts to manage and improve watersheds.

Part One: Managing for Watershed Outcomes

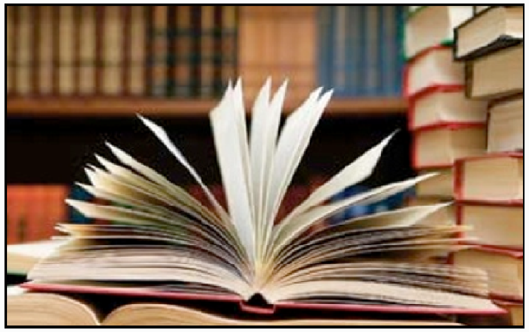
Part One lays out a stepwise, outcome-based management process through easy-to-use steps for achieving breakthrough outcomes in watershed management.
As you review these steps, we suggest that you pick a real-world project you are working on or about to begin and apply the steps to that project.

Part Two: Toolkit

Part Two offers specific practices and technical 'tools' for implementing the management steps covered in Part One. These tools are organized in the same structure as the steps in Part One and provide specific details and options for implementing each step.

Part Three: Literature Review

Part Three summarizes research results and journal articles that support and provide background for the tools in Part Two. This literature summary is written in a way that is intended to be accessible and interesting to all people engaged in watershed management, not just scientists or highly technical people.



OUTCOME-BASED MANAGEMENT: BRIDGING THE PREDICTIVE & PRODUCTIVE APPROACHES

Environmental managers of all levels and disciplines strive to attain a greater understanding of what actual **outcomes** are being produced from their watershed management projects. Historically, we have focused on a predictive process, which assumes that a well-crafted plan, properly carried out, will produce the results intended. Predictive plans are often based on models or expert opinion. Predicted outcomes are assumed to have been achieved, though actual outcomes are seldom rigorously checked against the prediction. We assume that taking action in and of itself will produce a positive outcome. This default process is common in both the development and restoration worlds, and yet watersheds and water quality continue to degrade.

The "productive" approach is a hands-on adaptive process that focuses on outcomes. It relies on actually doing a project, adjusting it along the way, and then checking back at the end of the project to ensure the desired outcomes are achieved. We propose that the product is much more powerful than prediction, and that we must always check the outcomes of our predictions or we will have no way of knowing whether we have achieved our goals. As more and more pressure is placed on watersheds, and watershed managers are being held increasingly accountable, we must be able to assess whether we are achieving our goals and we must be able to use that information to shift both our understanding and our actions when goals aren't being achieved.

This Guidebook is designed to build on the premise that not only do we not **KNOW** enough about watershed management to be fully effective, but that by recognizing our limitations, opportunities to gain insights arise that will lead to better management. In the following pages you will find a **cost-effective process** that bridges the gap between the predictive/planning elements of a project and the product/outcome elements. By considering the whole watershed, aiming at specific outcomes, and checking those outcomes, we can substantiate results and actually be able to determine if our watershed projects are effective, and to what degree. We will also be able to improve our efforts by learning from what does and does not work.

Figure 1. Utilizing the Watershed Management Guidebook to bridge the gap between predictive and productive approaches.

INTEGRATING WATERSHED AND PROJECT SCALES

Watershed restoration is undertaken one project at a time. In other words, we do not "manage watersheds," we "do projects." While this statement may seem like semantics, it shapes the way we understand and relate to the work of watershed management. For instance, it is a paradox that many watershed-scale planning efforts devote little attention to defining specific projects and, conversely, that some project-scale designs give little consideration to the watershed context in which the project is located. Effective watershed management depends on our ability to integrate our plans, actions and monitoring efforts across scales, from entire watersheds to small projects. A core purpose of this Guidebook is to provide **practical tools** to **link watershed-scale planning efforts to on-the-ground outcomes** and, conversely, to plan and implement individual projects in a more integrated manner that adequately considers the watershed context.

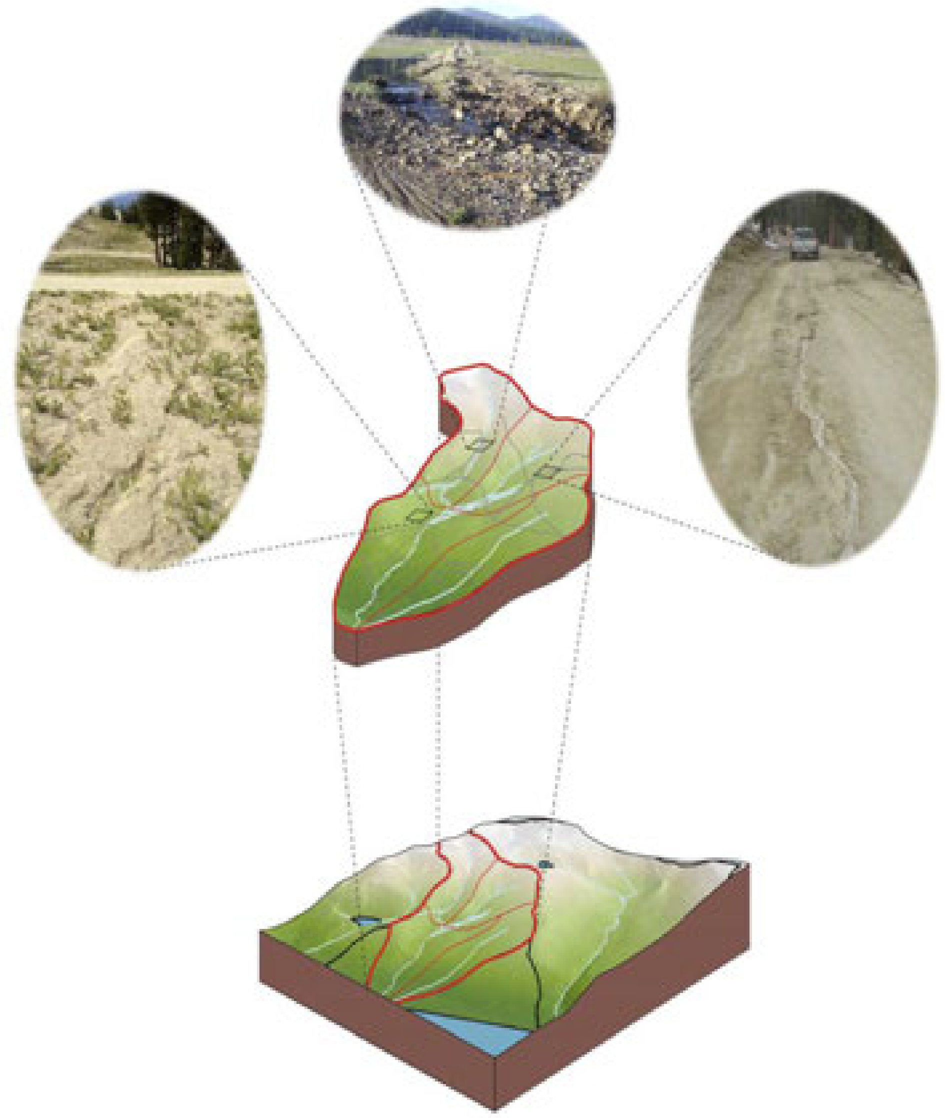


Figure 2. Looking at specific project sites within a watershed transforms the abstract idea of restoring a whole watershed into tangible actions. It is important to consider both the watershed and project scale to ensure effective restoration work.

THIS GUIDEBOOK OFFERS TOOLS FOR:

- Rapidly assessing erosion problems and connectivity within a watershed and targeting treatment actions for maximum benefit (see Tool 2.1 Erosion-focused Rapid Assessment)
- Measuring project-scale sediment reductions to understand and improve source control effectiveness (see Toolkit Section 4.0 - Achieving)
- Measuring watershed-scale sediment load reductions to track progress toward TMDL and/or watershed restoration goals (see Tool 2.6 Targeted Water Quality Monitoring

From Sources to Streams: A Whole-Watershed Approach

Streams integrate entire watersheds – from uplands to wetlands, from meadows to floodplains. In one sense, streams represent the circulatory system of a watershed, and stream flow is the analogue of blood flow in the human body. Diurnal variation in stream flows, particularly during runoff periods, can be thought of as the pulse in the human body. Runoff pulses are like the body's circulatory response to exercise. In the human body, veins and arteries make up a small portion, but integrate almost infinite operations. Similarly, streams make up a small portion of the watershed, but are vital to understanding what is happening throughout the watershed.

The impacts from human activities in watersheds – such as logging, home construction, development, recreation – take place largely in upland areas. These impacted watersheds are riddled with compacted surface area causing snowmelt and rain to runoff the surface instead of soaking into the soil. This causes water to find its way more quickly into streams, causing flashier flows (higher volume and velocity over a shorter time period), increased sediment transport potential and a higher 'pulse rate'. The hydrologic connections between degraded upland areas and stream channels are extremely complex and difficult if not impossible to fully track. With that foundational understanding, we have developed this Guidebook on the premise that disconnecting known upland sources of accelerated runoff and erosion from streams by getting water back into the ground is a critical element of creating more resilient, high-functioning watersheds.

This Guidebook focuses largely on upland restoration and management. We have focused on addressing the sources of watershed degradation, many of which occur in the uplands, in an integrated, whole-watershed context. Many of the techniques covered in this Guidebook will prove useful for projects focused on riparian and wetland restoration as well. While we have not provided approaches specific to riparian and wetland restoration projects, the outcome-based *approach* presented here can translate directly to stream-related projects. Further, because a large body of high quality work has already been done elsewhere and is readily available, we have not recreated it here.

Resources & References for Stream, Wetland & Meadow Restoration

California Salmonid Stream Habitat Restoration Manual – a comprehensive guide to restoring riparian areas with an emphasis on salmonids and fish passage design.

- CA Department of Fish and Game. 1998. California Salmonid Stream Habitat Restoration Manual. Third Edition. Inland Fisheries Division. California Department of Fish and Game. Sacramento, CA.
- **http://www.dfg.ca.gov/fish/resources/habitatmanual.asp**

Stream Corridor Restoration: Principles, Processes, and Practice – a comprehensive guide to planning, implementing and assessing stream restoration projects.

- USDA. 1998. Stream Corridor Restoration: Principles, Processes, and Practice. Federal Interagency Stream Restoration Working Group.
- http://www.nrcs.usda.gov/wps/portal/nrcs/detailfull/national/water/manage/?&cid=stelprdb1043244

A Guide for Restoring Functionality to Mountain Meadows of the Sierra Nevada – resource guide for land managers involved preserving, rehabilitating, and restoring mountain meadows in the Sierra Nevada.

- Stillwater Sciences. 2012. A guide for restoring functionality to mountain meadows of the Sierra Nevada. Prepared by Stillwater Sciences, Berkeley, California for American Rivers, Nevada City, California.
- http://www.stillwatersci.com/resources/2012meadowrestguide.pdf

Water in Environmental Planning – advanced undergraduate level text showing how knowledge of hydrology, fluvial geomorphology, and river quality are used in environmental planning.

- Dunne, Thomas and Luna B. Leopold. 1978. *Water in Environmental Planning*. W. H. Freeman & Co.

Tools in Fluvial Geomorphology– provides an integrated approach to the interdisciplinary nature of geomorphology.

- Kondolf, Mathia and Herve Piegay. 2005. Tools in Fluvial Geomorphology. John Wiley & Sons, Ltd, Chichester, UK.

“The great thing in the world is not so much where we stand, as in what direction we are moving.”

Oliver Wendell Holmes

Part One

Managing For Watershed Outcomes

Part One: Managing For Watershed Outcomes

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Introduction to Managing For Watershed Outcomes

What are the steps to achieve Watershed Outcomes?

These outcome-based management steps are the guiding principles that shape a watershed management framework.

What is the purpose of the Outcome-Based Management STEPS?

The following steps (pg 17-41) are intended **to serve as the framework to achieve watershed outcomes**. These steps support planning, implementing and assessing watershed improvement efforts. They are not guidelines or standards per se, but are instead a set of principles that, taken together, represent an applied outcome-based management process.

What do the steps do?

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 steps are not intended to be a substitute for actual field experience. Successful watershed improvement projects usually require an adequate understanding of the setting where one works. However, these steps will help first-time as well as experienced project planners and implementers ask appropriate questions and take actions that have a higher probability of success.

How do they work?

The steps are divided into five main sections: 1) Aiming, 2) Gaining Understanding, 3) Doing, 4) Achieving, and 5) Improving. These steps describe an **applied outcome-based 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.**

The Outcome-Based Management Model

Outcome-Based Management

Outcome-based management is a stepwise process that enables effective watershed management by embracing the fact that we do not fully understand the range of complex variables within a watershed. It is based on the notion that you must adapt or adjust a project as you discover how various components of the project are responding to the treatment. Outcome-based management has gained extensive attention in recent years as a go-to management process. It is an extremely powerful tool to help protect and improve water quality. It differs from current regulatory framework but is also complimentary. Outcome-based management is relatively flexible, but requires engagement and commitment on behalf of the project managers. It also requires accountability while supporting innovation.

Given the myriad challenges to protecting and improving water quality today, this process can move us from **compliance to competence**.

Outcome-Based Management for All

Outcome-based management applies to everyone regardless of their technical expertise or experience. It levels the playing field within personal ownership of the outcome at hand. Experienced managers bring existing knowledge, but are still able to learn from unexpected results, while novices are able to learn from the ever changing process. This process honors the existing knowledge and experience of everyone involved in the project.

This Guidebook, and the steps that follow, are designed within an outcome-based management framework and are intended to model a highly effective process that has been evolving over fifteen years in and around the Tahoe-Truckee region.

Outcome-based management differs from other planning processes in that it is **linked directly to an outcome, rather than to a plan**. Well-developed and well-considered plans are the first step to achieving intended outcomes. When properly and completely applied, this process incorporates planning and guides the user to the intended outcome. While this statement may seem basic, most environmental regulations and projects focus on the plan and assumed outcomes. Much less attention is paid to actual outcomes. Outcome-based management, as applied through this Guidebook, keeps conversations and actions focused on achieving specific, tangible outcomes.

Outcome-based Management is the foundation and overarching framework for this Guidebook. The five main categories of Outcome-based Management are shown below: **Aiming**, **Gaining Understanding**, **Doing**, **Achieving**, **Improving**. Part One walks you through the various steps that make up these categories. Once you understand how to use the outcome-based management approach, you will find the tools to execute specific tasks in Part Two.

Figure 3. Outcome-based management model for watershed management.

SECTION 1: AIMING

Aiming is one of the simplest elements of a project and can actually be the most difficult and elusive of all of the steps. Why? There are many potential reasons, a few of which are described below. We offer this as things to reflect on before a project begins so that goals may be more consistently and accurately achieved.

Aiming for an outcome is a critical 1st step in achieving a goal and as simple and obvious as this statement is, it can be so simple as to be overlooked, especially in projects dealing with the vast complexity of natural systems.

ASSUMING THE GOAL

Goals and outcomes are too often assumed. For instance, one may identify the goal of planting grasses and other plants for erosion control. However, the real goal is preventing soil movement (erosion). That plants in and of themselves do not always control erosion is not considered. **A goal** (growing plants) may be reached without reaching **THE goal** (controlling erosion).

ASSUMING KNOWLEDGE

We often embark on projects assuming that knowledge or information available has been tested and/or is true for all situations. This is most often not the case. We assume, for instance, that Best Management Practices (BMPs) are universally effective. This is seldom the case. Further, some BMPs and standard practices have not been adequately tested, especially throughout the full range of variables. A prime example are the settling ponds that have been so widely used to capture storm water runoff. Many of those ponds actually collect sediment which can be mobilized during large storms. Those ponds were assumed to be effective because it was shown that they could retain a certain amount of runoff. However, the larger question regarding how to reduce sediment in waterways was not considered. Thus, we end up aiming at the wrong target (collecting water) rather than the real target (reducing sediment in water).

INCOMPLETE KNOWLEDGE

We are almost always dealing with inadequate knowledge. This often leads to well meaning but poorly functioning responses to specific problems. For instance the settling ponds previously mentioned, at their best, tend to capture coarse and medium-sized sediment. More recent research and re-emergence of older work, shows that fine sediment tends to be the most problematic for water clarity in Lake Tahoe. Settling ponds do not tend to capture fine sediment when there is through-flow, which is almost always the case. Thus, many of our assumptions about effectiveness are associated with some incomplete knowledge about the process at work.

We will nearly always be faced with one or more of the challenges mentioned above. If we recognize them, we will have a much better chance of seeing and aiming for the goal in a more complete manner. Aiming is never as easy as it seems but is an essential and powerful step in any project. Goals and plans may change. Aiming should always be the foundation. As Lewis Carroll said, "***If you don't know where you're going, any road will get you there***."

STEPS

1. Identifying the Need for Action and/or the Problem

2. Assembling a Team and Engaging Partners

3. Stating Project Goals and Objectives

4. Defining Success

Step 1: Identifying 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.

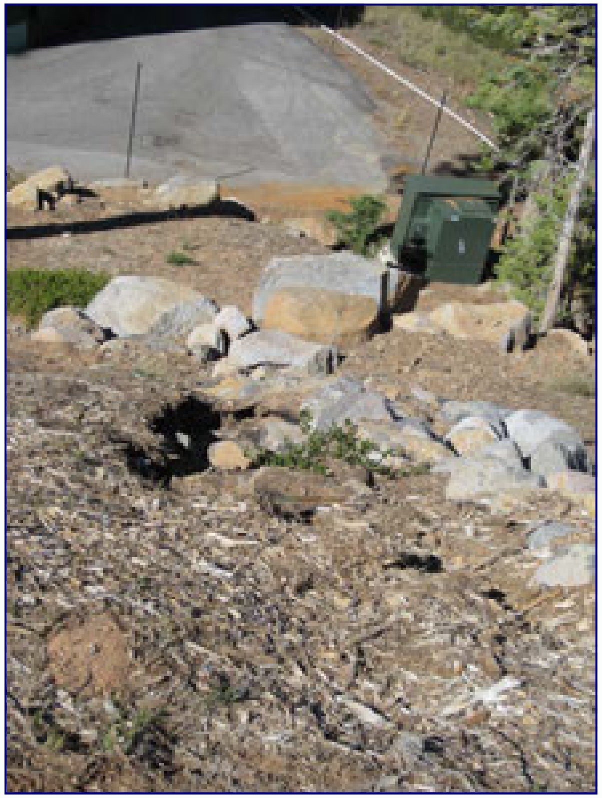
Description

The steps are to 1) decide or understand why action is being taken and then 2) identify the problems. The need for action may often seem straightforward. Identifying the nature and cause of the problem is more difficult. 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 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 assessing site conditions or water flow patterns.

Example

Cripple Creek had exceeded the sediment concentration standards defined in the land owner's Waste Discharge Permit for 4 of the last 5 years. A long stretch of road with known erosion issues near the creek was identified as a primary cause of increased sediment concentration in the creek. Water bars were installed every 25 feet to reduce slope length by shunting water off the road surface more frequently in an effort to reduce erosion. Continued monitoring of the creek indicated that the sediment concentration standards were still being exceeded 2 years after installing the water bars.

Solution



A gully on this slope indicates active erosion, which is the need for action at this site.

During a rainstorm, the land manager went to the area to observe for himself how water was draining off the road and noticed that 1) rilling was still occurring on the road surface between water bars and 2) the water bars had created concentrated flow paths and gullies that routed road runoff directly to the creek. To address the first issue, he spread a layer of gravel on the road to protect the surface from eroding. To address the gullying issue below the water bars, he created small depressions at water bar outlets and tilled wood chips into the soil to infiltrate runoff and disconnect road drainage from the creek. Over the next two years, sediment concentration in the creek was reduced by 50% and he was regularly seen inspecting his other projects during rain storms.

Relevant Tools:

- Tool 1.1 Identifying the need for action

Step 2: Assembling a Team and Engaging Partners

Goal

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

2) To include, to the appropriate extent, 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. An effective team will include, at a minimum, a team leader/project coordinator and people with expertise directly relevant to the problem areas. Another element of this step is the process of engaging other interested parties or partners in the project. Early engagement of individuals or groups is likely to produce a better long-term outcome if they are engaged with a common, positive outcome in mind.

Steps in developing a team/engaging parties:

1. Select a Team Leader/Project Coordinator
2. Assemble a team with appropriate expertise
3. Identify and engage interested parties

Example

A road slope has been identified as not meeting specific success criteria. It shows evidence of rilling, a large bare area, and two failed water bars. The transportation manager and the Regional Water Board representative discover these conditions during a routine walk through. They agree that the transportation manager will provide the Regional Board with a plan to repair the problems and then, upon review, implement the plan. The transportation 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 (transportation manager), the planner/implementation director (erosion control manager) and the implementation team (3-person crew).

Reviewing goals, project plans and monitoring strategies with the project team in the field helps to ensure that everyone is on the same page.

STEP 3: STATING 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 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. Project goals and objectives should be reference points that define and guide the rest of the project. They should also be the foundation for monitoring and success criteria, which are described later in this document. Goals should be clearly stated and direct, general and non-specific, inclusive (sediment control AND wildlife habitat maximization) and flexible enough to persist over time. Objectives should be specific, measurable, realistic and attainable (physically and economically), directly related to the problem and time specific.

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 slope" 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. Instead, the goal could be defined as focusing on rebuilding soil function to prevent erosion. Objectives need to be quantitative. 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 slope) through functional soil restoration treatment and native vegetation community establishment.

Identify Objectives: To establish an infiltration rate on the 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.

Relevant Tools:

- Tool 1.2 Setting goals and objectives

STEP 4: DEFINING 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 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 measurable "success" value based on actual verified field plots and research. For example, 75% plant cover and 90% mulch cover would provide a measurable success criteria. Based on the differing objectives, each project will probably have different site and project-specific success criteria.

Relevant Tools:

- Tool 1.3 Developing Success Criteria

SECTION 2: GAINING UNDERSTANDING

INTENT

The ability to truly understand the watershed and project site may be the most important building block of watershed management. Information gained as described in this step will serve as the foundation of all further actions. This section is built on the premise that we never have all of the information we need to ensure project success at the beginning of the project, yet we must proceed and gather information along the way.

Generalizations of watershed and site conditions seldom hold true, and can lead to expensive mistakes, including failed projects. Some information will be readily available and some information you must seek out. There is also information that is not available at all. It is critical to acknowledge this last factor. Where information is not available, there are methods to gain that information within the project and there are techniques to move forward without that information. One way to do this is through developing test plots to determine how the site will respond to various treatments (see Tool 3.2 Test plot development for more information). This is one of the most powerful elements of outcome-based management as laid out here.

Most projects, if managed in a truly adaptive fashion, will reveal new and valuable information throughout the course of the project. This type of information is unforeseen and unanticipated and it is often some of the most important information discovered. It is important to maintain flexibility within a project and to incorporate feedback from the land and people involved in into the project wherever possible.

The next three steps are intended to set in motion a process of learning and discovery as you gain greater understanding.

STEPS

5. Understanding Your Watershed

6. Understanding Your Site/Project

7. Assessing Strategies for a Site-Specific Implementation Plan

Step 5: Understanding Your Watershed

Goal

To develop an understanding of watershed-specific conditions, features, and especially the soil and hydrologic processes that drive and define watershed function.

Description

Watersheds are the context for projects, be they development, restoration or general management efforts. Understanding as much of the relevant or functional aspects of the watershed as possible is the goal. Obviously, time and funding are often limited. This Guidebook is based on the premise that a **basic understanding of water flow patterns and soil function is critical to achieving watershed improvement goals.** That is, how erosion-resistant is the watershed? Is the plumbing working effectively? Specific tools for gaining this understanding—including the Erosion-focused Rapid Assessment (EfRA) methodology—can be found in the toolkit section of this Guidebook.

Homewood Creek, Quail Creek and Madden Creek watersheds. Lake Tahoe, CA.

Example

A small Land Trust was successful in raising enough money to purchase a 400 acre property that includes mixed conifer forest, several streams, and a meadow. The property is intended to be protected for its ecological value, particularly water quality and groundwater recharge, and a small amount of funding has been set aside for restoration. Several hikes following the purchase revealed a large network of legacy roads from past logging, an incised channel through the meadow, and several severely eroded sections of road. The Land Trust's restoration manager wondered how she would ever be able to afford to address all of these issues with her limited budget.

Solution

The restoration manager decided to conduct a targeted assessment of the watershed, starting with mapping roads, areas of high erosion and seasonal flow paths. In the field, she also mapped the connections between erosion source areas and streams/meadows. She used this initial assessment to prioritize treatment efforts, develop a phased plan, and was successful in securing a substantial grant from the EPA to fund a 3-year, phased restoration program based on her initial assessment. By understanding the problem areas within the watershed, the restoration manager was able to successfully address them to prevent further degradation.

Relevant Tools:

- Toolkit Section 2.0 Gaining Understanding
- Tools 2.1-2.6

Step 6: Understanding Your Site/Project

Goal

To gain as much understanding of the physical and hydrologic processes of a specific site as possible. Physical processes include natural (soil, topography, etc.) and anthropogenic factors (traffic patterns, legacy impacts, etc.).

Description

The ability to understand the soil, drainage and other aspects of a site will be critical to developing a plan that is implementable and has a high likelihood of achieving the goals and objectives of the project. Too often, a project is developed and designed from drawings and/or maps without a firm grasp of flow and runoff patterns, soil conditions, vegetation and overall site potential. Many important elements of a site do not show up on drawings and can only be discerned in the field by experienced and observant field staff. Funding and other time constraints often minimize or eliminate adequate field assessment time. This is usually a critical mistake.

Achieving project goals is far more likely if designs or treatment plans are developed based on an understanding of site-specific conditions and limitations. A small upfront investment in assessment of conditions at a project site during the planning/design phase can save time and money later in the project by ensuring that limited resources are targeted at addressing the root cause(s) of a problem.

Example

The High Flyer ski run was a perpetual erosion problem for Jimmy, the ski area general manager. Once a year, he would review erosion control efforts with regulatory agencies and his engineering consultant would specify additional seeding and irrigation in areas where erosion was deemed to be a problem. Nearly every summer, Jimmy's re-vegetation crew would remove the rills with pick mattocks, re-seed and irrigate the High Flyer ski run. After the third year in a row of re-treating the same area of the ski run due to erosion, Jimmy decided to take a closer look.

Solution

A short hike up the ski run following the rills revealed that the concentrated runoff was coming from an old road near the top of the run. The road had not been driven on in at least 10 years and had shrubs growing all over it, but Jimmy could see that the road prism was still there, and that the soil was still very compacted. Now that Jimmy had found the source of the erosion, he had his re-vegetation crew recontour the unneeded problem road, loosen the soil, and apply seed and mulch. By addressing the source of runoff, Jimmy eliminated the erosion problem on the ski run and began training his crew to trace erosion to the source rather than applying the usual (and expensive) routine of repeated seeding and irrigating problem areas.

Severe erosion at abandoned road-stream crossing.

Relevant Tools:

- Tool 2.4 Water flow/connectivity assessment
- Tool 4.2 Site condition assessment

Step 7: Assessing Strategies for a Site-Specific Implementation Plan

Goal

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

Description

This is perhaps the most complex Management Step and actually includes several sub-steps. There are two main elements of this step: 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.

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 (or 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.

Solution

This baseline assessment data clearly indicates that the treatment site is deficient in soil nutrients and has compacted soil, thus suggesting that soil tilling and organic matter amendments will be required as part of the treatment.

Table 2. Assessing strategies for a site-specific implementation plan.

1. Assess site conditions
2. Choose a reference site to compare with the project site
3. Develop an implementation plan based on the difference between the reference site and project site conditions
4. Consider potential alternative treatments
5. Maintain natural conditions to the greatest extent possible
6. Incorporate tests where information gaps exist
7. Choose appropriate treatments
8. Identify and address potential threats to project success

Relevant Tools:

- Tool 3.1 Treatment planning
- Tool 3.2 Test plot development
- Tool 4.2 Site condition assessment

Section 3: DOING

Intent

DOING is, of course, the most obvious element of a project. It can also be the most nuanced and changeable element of the project. Some foundational elements of successful 'doing' or implementation include:

Full Understanding of Plans

Implementers will carry out plans that they understand. Spending time to make sure the contractor is fully familiar with plans is critical and often overlooked. This often results in costly mistakes.

Properly Implemented Plans

As obvious as it seems, plans are not always implemented properly for a range of reasons. Implementation monitoring and project oversight are sometimes thought to be an unneeded expense, but are necessary to check if plans are implemented as they were intended. Generally, project oversight and implementation monitoring are well worth the effort both financially and physically.

Anticipating Unforeseen Variables

Projects seldom go as planned. Planning for the unplanned can be a powerful tool. When an implementer expects that the plan will go exactly as expected and has not developed contingencies, costly and time consuming re-planning often results.

Complete Project Understanding

Similar to having a full understanding of the plans, implementers may not always have a full understanding of the project goals and objectives. Making sure the implementers are familiar with the reasons for the project and the thinking behind project design, can help implementers respond to the unforeseen variables discussed previously.

Experience

Implementers will not always have the full range of experience needed. If that is recognized, planners can provide additional input to help sort out any questions. When lack of experience is not recognized, costly results often follow.

Commitment to Outcome

A personal and professional commitment to a positive outcome is often required in order to attain that outcome. As simple and obvious as this seems, full commitment is not always the case. Common low bid contracting processes do not tend to embrace this element in contracts, as contractors are hired to get a job done and are not required to prove its effectiveness.

Steps:

8. **Training Staff and Project Personnel**
9. **Overseeing and Documenting Implementation Activities**
10. **Protecting/Optimizing Surface Hydrology and Drainage Patterns**
11. **Protecting/Optimizing Soil Function**
12. **Protecting/Optimizing Mulch and Surface Protection**
13. **Protecting/Optimizing Appropriate Vegetation Community**
14. **Protecting Project Area from Further Disturbance**

Step 8: Training Staff and Project Personnel

Goal

To increase the level of awareness and understanding of the 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 protocols and practices.

Description

Training is critical to develop competence in and raise awareness of project components (such as 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 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. For a ski resort, this may include addressing use by mountain bikes, ATVs, etc. 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

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.

Training construction personnel is a key component of successful restoration projects.

Solution

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

Step 9: Overseeing and Documenting Implementation Activities

Goal

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.

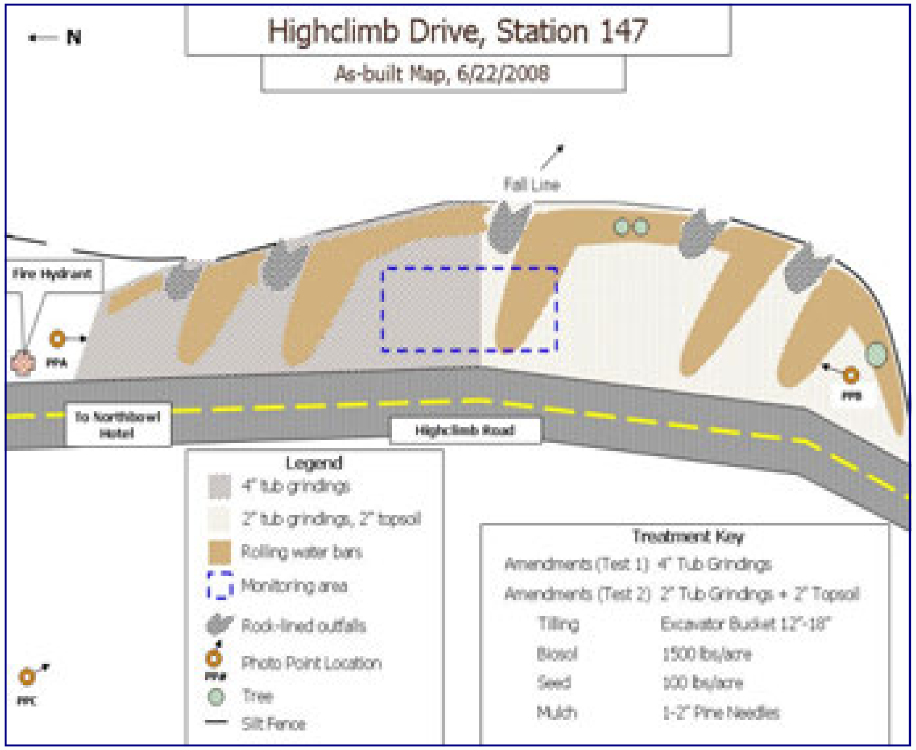
3) For contracted projects, to provide assurance that the contractor is doing the best job possible, thus providing high value to the owner.

Description

Implementation oversight, sometimes called implementation monitoring, assures that treatments are implemented as defined in project plans and specifications. It allows project managers 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, it is important to document 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. The project 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.

Example

A trail crew manager instructs his crew to seed a temporary road that was to be decommissioned after installing a cellular tower and transmission line. The manager is not able to supervise the project. After the roadbed is loosened and wood chips incorporated, the crew begins seeding the road, but the seed runs out before the seeding is complete. The crew supervisor finds another bag of seed left over from another project and uses it to finish the treatment. The next year, one section of the road had a thick cover of chest-high Squirrreltail while the other section had sparse vegetation and some weeds. The crew leader from the previous season had moved to Saipan so the trail crew manager had no idea which seed mix had been used on each section.



Example as-built map for restoration and drainage improvement project.

Solution

A simple as-built map noting the different seed mixes applied would have enabled the crew manger to determine which seed mix produced the successful vegetation and use that on upcoming projects.

Relevant Tools:

- Tool 3.4 Documenting treatments

Step 10: Protecting/Optimizing Surface Hydrology and Drainage

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

A road was built that intersected an existing drainage, and old flow paths were not accommodated in the original design. This led to continual damage of the road during runoff events.

Solution

An armored infiltration basin was built to capture and then infiltrate runoff along and across the road. This resulted in a stable road that is capable of carrying seasonal and pulse runoff without eroding or causing further erosion downslope.

Example of installing an infiltration swale to prevent road runoff from causing erosion further downslope.

Relevant Tools:

- Tool 2.4 Water flow/connectivity assessment
- Tool 4.2 Site condition assessment

STEP 11: PROTECTING/OPTIMIZING SOIL FUNCTION

GOAL

To create physical and biological soil conditions that optimize water infiltration, 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 by:

- 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/compaction 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 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

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 the 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.

SOLUTION

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 achieve the type of vegetation community desired and could be considered in the cost-benefit of a wider range of treatment alternatives.

Relevant Tools:

- Tool 3.1 Treatment planning
- Tool 3.6 Topsoil salvage and reuse
- Tool 3.7 Soil physical treatment
- Tool 3.8 Soil amendments
- Tools 4.2 Site condition assessment

Step 12: Protecting/Optimizing Mulch and Surface Protection

Goal

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.

Thanks to pine needle recycling programs, pine needle mulch is now available for large erosion control projects in Lake Tahoe and many other communities.

Example

A planner identified bonded fiber matrix (BFM) as the mulch of choice for a new road cut. The BFM was intended to be a permanent installation. A wood fiber BFM was mixed with seed and fertilizer, and 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

Mulch selection and application should be linked to project goals and the service life of the mulch. If a short-term project, temporary mulch such as bonded fiber matrix (BFM) can be used (1-2 year service life), but 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 more costly full treatment was applied and has maintained a high level of plant cover and erosion resistance over many years. Conversely, the site treated with BFM was inspected by a county inspector who required that it be re-treated due to the large amount of sediment the site was delivering to a nearby creek. Re-treating the BFM site required additional and unplanned costs that could have been alleviated is the proper mulch and soil preparation had been considered.

Relevant Tools:

- Tool 3.11 Mulches

Step 13: Protecting/Optimizing 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.

Example

A steep-cut slope consists of high-density soil. This site is revegetated with expensive native shrub plantings 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 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. 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.

Native grasses well-established two years after restoration treatment with no irrigation. Incline Village, NV.

Relevant Tools:

- Tool 3.10 Vegetative treatments

Step 14: Protecting 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

Construction of Bubba's Ski 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 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 large gullies and transported sediment into a nearby creek.

Solution

Step 8 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,

One way to protect project areas is by posting a 'Keep Out' sign, like the one above.

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.

Relevant Tools:

- Tool 3.5 Protecting treatment areas

SECTION 4: ACHIEVING

INTENT

Projects are planned and implemented with the intent of achieving outcomes. Many, if not most projects are never adequately assessed to determine success. This problem cannot be overstated. Whether from a sense of pride (believing it has to come out the way we expected it to), fear of being wrong, or any number of reasons, when we do not assess the outcomes, we have little idea of whether we really achieved the goals for which time, money and labor have been spent.

Perhaps the biggest loss related to lack of assessment is the inability to learn from what did and did not work. If we do not know what did not work, we will not be able to improve it. Given that so little is actually known about ecological systems, lack of assessment robs us of gaining the understanding that comes with 'mistakes'. Our very future may depend upon gaining a more complete understanding of the physical, ecological systems that support us. Assessment, interpreting that assessment, and then converting it into improved practices, is one of the primary benefits of assessment. Ultimately, achieving depends on assessment.

STEPS:

15. Checking the Outcome

16. Taking Follow-Up Actions to Achieve Project Goals

Step 15: Checking the Outcome

Goal

To assess project performance in a quantifiable manner against project success criteria and to gather information for future project improvement.

Description

There are three main types of monitoring:

• Compliance monitoring (meeting regulatory standards, such as water quality standards)

• Implementation monitoring (was the project implemented as planned?)

• Performance monitoring (how the project is functioning or performing?)

Performance monitoring will determine whether success criteria are met and trigger management responses 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 ski run-smoothing project is constructed on the Lower Left Out run of Inner Mongolia. Success criteria list, among other things, requires that no bare areas greater than 15 square yards shall exist in the treatment area and that of the 300 shrub seedlings planted, a survival rate of 50% is 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 and some re-seeding was done followed by mulching and irrigation. Since only 120 of the 300 seedlings survived the winter and a plant census showed that two particular species had the best survival rates of 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.

The results of clearly specified success criteria and management response enabled the ski area staff to take action in areas that needed help. When the Forest Service came out to inspect the site, the inspection found that no sediment had moved below the Best Management Practices. The inspection was positive and non-confrontational.

Relevant Tools:

- Tool 1.2 Setting goals and objectives
- Tool 1.3 Developing success criteria
- Section 4.0 Achieving tools

Step 16: Taking Follow-up Actions to Achieve Project Goals

Goal

To address project areas that fail to meet success criteria by taking additional action (water, seed, treatment area protection, etc.) in subsequent seasons to assure project success .

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 does not 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

An emergency fire access road was built then inspected the season following construction. A small rotational failure (mini-landslide) was observed on a cut slope with a small rill above it. The inspector followed the rill upslope and discovered that a water bar on another road segment had filled with sediment and breached. The water bar had a slight level spot, which accumulated sediment, thus causing the breach and releasing concentrated runoff downslope. The water bar was re-shaped, the rill was hand tilled and re-mulched, and the rotational failure was rebuilt, seeded and mulched. All treatment areas were irrigated for 2 months to expedite vegetation growth.

Solution

The solution described in this example, 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 another key service road, requiring expensive re-engineering of the road. By addressing the source of the erosion problem, they achieved the project goals and eliminated the need for expensive road repairs in the future.

Spreading additional pine needle mulch to meet project success criteria.

Relevant Tools:

- Tool 4.13 Management response

SECTION 5: IMPROVING

INTENT

Improvement, growing in our understanding and/or ability to achieve goals, is an essential human process. An essential foundation of improvement is the recognition that what has been produced may be inadequate. Improvement depends on the willingness to move in new directions, to try new things. This process is not necessarily one of criticism as much as it is one of humility. That is, to strive for a better outcome, we must realize that the outcomes we are getting might need to be improved. Improving is based on discovery and then moving that discovery forward.

This section develops at least two critical elements of that process within an adaptive context. One step involves sharing information that we have gained from projects with others and the other involves applying what we have learned in future projects. Both of these steps are based on using the steps previously described in **aiming**, **gaining understanding**, **doing** and **achieving**.

STEPS:

Step 17: Exchanging Information

Goal

To discuss lessons learned and information gained in a project so that other project planners, implementers, and assessment personnel can improve their practices.

Description

Where information is shared effectively, it benefits the environment and others doing similar work. It can also 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 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 construction 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 restoration website that lists local results from a number of erosion focused field tests. She sees that in high alpine situations on soils similar to her site, hydroseeding produced inconsistent and typically poor long-term results. However, a more expensive integrated soil treatment that included tilling wood chips into the soil and seeding 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 integrated soil treatment. She reasons that four hydroseed treatments would roughly equal one integrated soil treatment. She implements this treatment, achieves success and, since the results are verified the following season, solidifies her job as well.

Discussion of monitoring results with regulatory agency partners following tour of restoration projects.

Relevant Tools:

- Tool 5.1 Exchanging information

Step 18: Improving Future Projects

Goal

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

Description

When gathering information from existing projects, 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 do not meet success criteria hold great potential for improving practices as project managers adjust, alter, and change those practices.

Example

Hydroseeding and fertilizing with ammonium phosphate or ammonium nitrate (16-20-0) has been used in treatment areas for more than twenty years. No goals, success criteria, or monitoring has 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 may 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 steps described in this Guidebook are designed to fill that critical gap.

Relevant Tools:

- Tool 5.2 Improving future projects

“Progress is impossible without change, and those who cannot change their minds cannot change anything.”

George Bernard Shaw

Part Two

Toolkit

Part Two: Toolkit

Table of Contents

Introduction to the Toolkit

Getting it all to Work

At the core of every restoration effort, project partners just want to "get it all to work." But what do we mean by "working" and what are the pieces of the puzzle that need to be addressed to create a "successful" restoration project? The tools in this Guidebook are based on the premise that project "success" can and should be defined by how it functions rather than how it looks. This approach acknowledges that watersheds are more than a collection of physical elements – they are dynamic living systems. All physical elements – such as soil, vegetation and water – are interconnected through various ecosystem processes. It is nearly impossible to affect one element without affecting another, which is why one-dimensional treatment approaches often fail to achieve expectations, particularly in the long-term.

Towards Resilience

So what needs to shift if watershed management and restoration efforts are to focus on function over form? First, we need to value long-term **resilience** over short-term **fixes** and reframe watershed restoration as a capital investment. Then we need to define **resilience** in terms of the core ecological functions and processes that can guide planning, implementation and assessment of watershed management efforts. Figure 4 offers a simple framework for defining resilience in terms of three key functional parameters: hydrologic function, nutrient cycling and energy capture (adapted from Cummings 2003). These three key functions are required to rebuild long-term resilience in degraded sites. In a robust and resilient ecosystem, the area of overlap between the three functional parameters (the **resilience zone**) is actually much larger than depicted.

This simple framework can be used to set goals and define project "success," assess disturbed sites to determine what functions are damaged or missing, and develop integrated treatment approaches that rebuild ecosystem **resilience.** This framework is the foundation of the planning, treatment, and assessment tools that follow.

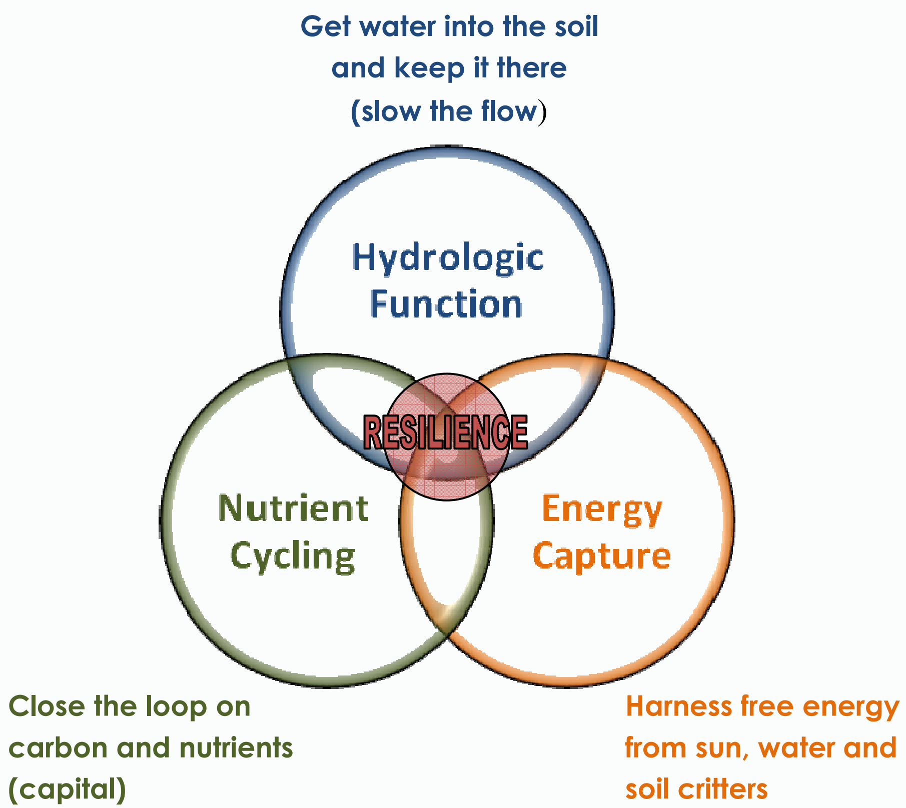


Figure 4. Striving for resilience by incorporating hydrologic function, nutrient cycling and energy capture into treatment and monitoring efforts.

Resilience

In ecology, resilience is the capacity of an ecosystem to respond to a perturbation or disturbance by resisting damage and recovering quickly.

(Source: Wikipedia- Resilience)

TOOLKIT

Hydrologic Function

Hydrologic function involves getting water back into the soil and keeping it there. Degraded hydrologic function is the root cause of most erosion issues. In simple terms, if rain and snowmelt can soak into the soil, there is no runoff or erosion. If the soil has been compacted and cannot soak up that water, surface runoff ensues and often results in erosion and water quality degradation. A soil's ability to soak up water and store it is critical to support healthy vegetation and the soil microbes (bacteria and fungi) that make nutrients available for vegetation and keep soil loose over time. A healthy forest soil can store up to 40% water by volume.

Nutrient Cycling

Nutrient cycling closes the loop on carbon and other nutrients, which is the "capital" of ecosystems. As plants grow and decay, they uptake and then return nutrients such as carbon and nitrogen into the soil (with the help of soil microbes). This is what is meant by nutrient "cycling," and happens on a continual basis to maintain an optimal amount of "capital" in the system. If this cycling is disrupted by human activities (e.g. topsoil removal, compaction), that capital is lost through processes like erosion (carrying soil and soil nutrients away). This decreases vegetation and seed production each season making the system no longer able to sustain itself.

Energy Capture

Energy capture refers to an ecosystem's ability to harness free energy from sun, water and soil microbes. A resilient living system is always capturing energy from the sun through plant growth and photosynthesis, and from water by soaking up rain and snowmelt. The system redirects its potential erosive energy into supporting a robust soil microbial activity and plant growth. Without the core function of energy capture, a site is not able to repair itself following disturbance.

As a species, we are becoming increasingly aware that our quality of life and long-term survival are dependent on our ability to manage watersheds in such a way that their core functions are protected and/or restored. This will require a shift from the dominant paradigm that ecosystems can be understood and managed as individual parts to a more integrated approach that focuses on the processes and interactions at work in our watersheds. This Guidebook offers a roadmap to support such a shift. The tools contained in this section of the Guidebook are intended to offer practical, field-tested approaches for managing watersheds and creating projects that provide a measurable return on our investment.

Cross-section of robust and resilient soil-plant community in a central Sierra meadow.

“If you want to change the culture,
you will have to start by changing the organization.”

Mary Douglas

SECTION 1: AIMING

The following tools: Identifying the need for action, Setting goals and objectives, and Developing success criteria are the AIMING tools. Too often, project managers, technicians and planners tend to take a "ready, fire, aim" approach versus a "ready, AIM, fire" approach within projects. Aiming towards identifying the need of the project, its goals and "how will we know if it's working?" are the first steps in an effective project or management process. Why start a project if there is no need for it? A project cannot set sail without clearly stated goals, objectives and intention. Furthermore, a project has no means of determining success, completion or goal attainment if success criteria are not established in the beginning.

Start with the need, identify and set attainable goals and tangible objectives, and then develop applicable success criteria that will be used to assess if the project "worked" or not. These beginning steps allow any project or management process to come back to its original need, intention and goal, as well as to assess success using success criteria indicators throughout the entire process.

TOOLS:

1.1 Identifying the Need for Action

1.2 Setting Goals and Objectives Specific to the Site

1.3 Developing Success Criteria

Tool 1.1 Identifying the Need for Action

Definition

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

Purpose

The purpose of identifying the need for action is to address the overall intent and driving force behind a potential project, and to keep the need as the main focus throughout the project.

Overview

The steps are to 1) decide or understand why action is being taken and then 2) identify the problems. The need for action may often seem straightforward. Identifying the nature and cause of the problem is more difficult. Action may be triggered by identifying 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 disturbances 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. Time spent defining and understanding the problem(s) early in the planning process 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 4.2 Site Condition Assessment).

The need for action at this Lake Tahoe site was to reduce erosion, yet treatment actions were narrowly aimed at establishing vegetation for permit compliance. To grow vegetation, excessive irrigation was applied causing more erosion – the very problem they were trying to solve. Once the original need for action was re-distinguished, practices were shifted to address the root cause of the erosion problem. This shift resulted in dramatic reductions in erosion were measured, and money was saved.

Tool 1.2 Setting Goals and Objectives Specific to the Site

Definition

A number of definitions have been put forth for the term **goal.** The simplest and perhaps most elegant definition of a 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 Step 3), 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.

Overview

This tool supports Step 3 Stating Project Goals and Objectives found on pg. 22. Setting goals is also included in the toolkit because it 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 sometimes 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 check to see if the newly revegetated slope is contributing sediment and nutrients to a nearby water body.

Setting Goals

Setting goals is a critical first step toward quantitatively defining and determining success (see Tool 1.3 Developing success criteria on pg. 53). Specific goals for a sediment source control or site restoration project may include:

- Reduce sediment yield
- Eliminate sediment yield during a normal (< 2 in/hr) storm
- Infiltrate all rainfall during a normal (< 2 in/hr) storm
- Develop a diverse, self-sustaining, grass dominated vegetation community that will anchor the site and enable a shrub dominated plant community to become established
- Create habitat for the Yellow Warbler
- Reduce in-stream water temperature by providing vegetative (willow) shade cover
- Develop a trail system through a project area that does not increase erosion
- Sink carbon in a ski run soil during run construction
- Reduce the presence of roads within the project area boundary
- 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, "reduce the presence of roads within the project area boundary," may be an objective that is also linked to the goal of "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.

Why Develop Goals and Objectives?

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 sq 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 become the foundation of success criteria, which may also be useful as permit conditions. See Table 3 for examples of goals, objectives, and success criteria.

Tool 1.2 Setting Goals and Objectives Specific to the Site

Success Criteria

Success criteria are included in this Tool in order to demonstrate how they relate to goals and objectives. Refer to Tool 1.3, Developing success criteria, for further guidance on developing success criteria that are linked to goals and objectives. The outcome-based 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 3. 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.

Tool 1.3 Developing 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 should be based on a narrow set of parameters that are useful for determining remedial actions, such as to reduce erosion to a level within the natural range, or to establish a desired vegetation community. The target should be relevant and not based on reference sites that are dissimilar. 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 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/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 (See Tool 4.4 for more information on Rainfall Simulation). 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 4.7 for more information on the 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. Erosion is especially difficult to measure in 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 unreasonable 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.

Tool 1.3 Developing Success Criteria

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 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.

Table 4. 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 than 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-dependent and are impossible to measure without research-level assessment techniques	Mulch cover percentage is relatively quick to measure. Multi-year monitoring can also provide mulch longevity values
Soil Nutrients	• Amount of nutrients available for plant growth • Amount and type of organic matter available for self-sustaining system	Sustainable plant community development requires measurement over many years and then can still be difficult to determine	Measurement of nutrients and organic matter shows the ability or potential of a site to sustain long-term vegetation growth

Defining and Measuring Success Over Time

Sustainable sediment source control is achieved by rebuilding site conditions and repairing functions that are part of a dynamic and ever-changing ecosystem. In a robust ecosystem, soil and vegetation conditions are in a constant state of flux (as illustrated by Figure 5). 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 5) 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

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.

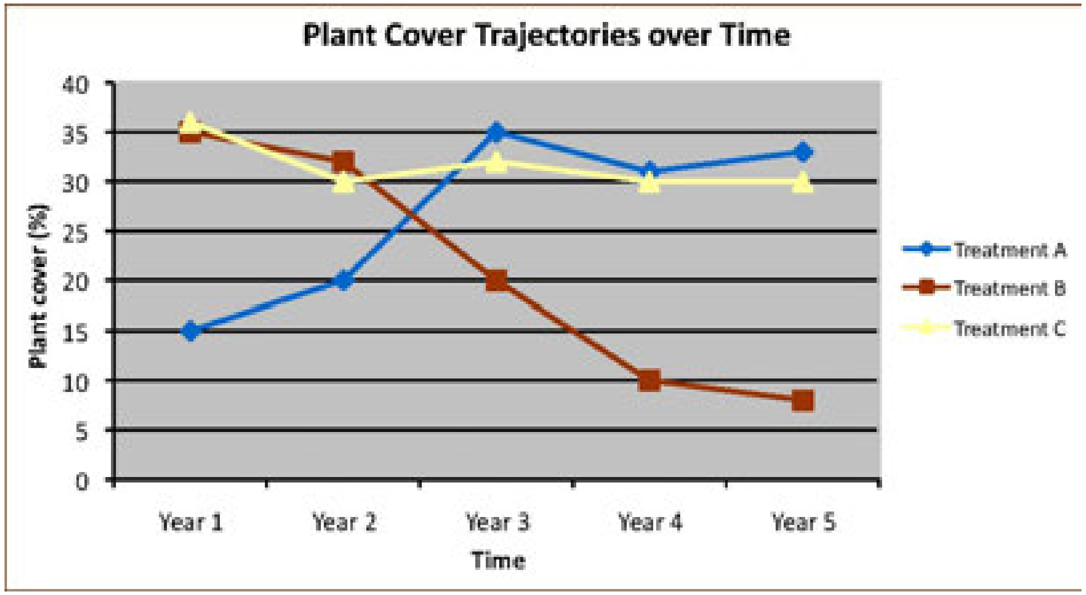


Figure 5. Plant cover trajectories over five years.

TOOLKIT

Tool 1.3 Developing Success Criteria

Table 5. 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 sq meters (m) bare	No areas larger than 3 sq m bare	No areas larger than 3 sq m without vegetation	No areas larger than 3 sq m without vegetation	No areas larger than 3 sq m 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 the follow-up treatment will be developed in a measurable fashion.				
% of Target Total Soil Nitrogen	90-100%	85-90%	80%+	80%+	80%+

A Word About Statistics in Measuring Success

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

SECTION 2: GAINING UNDERSTANDING

The primary step in GAINING UNDERSTANDING in a watershed improvement project is to determine where the erosion issues are, what level of erosion is happening, and how likely they are to deliver sediment to a live stream or conveyance. While this may seem simple, it is rarely practiced. This step in outcome-based management acknowledges and embraces the knowledge gaps that always exist between the plan and the action. Generalizations about watershed and site conditions rarely hold true; in fact, they can often lead to expensive mistakes, including failed projects.

The tools in this section are built on the premise that we never have all of the information we need to ensure project success at the beginning of a project, yet we must proceed and gather information along the way. This section lays out an erosion-focused approach to help prioritize treatment efforts in a watershed as well as tools for whole-watershed assessment and analysis.

TOOLS:

2.1 Erosion-focused Rapid Assessment Methodology (EfRA)

2.2 Characterizing Your Watershed

2.3 Hot Spot Identification

2.4 Water Flow/Connectivity Assessment

2.5 Road Erosion Risk Assessment Methodology

2.6 Targeted Water Quality Monitoring

2.7 Erosion Modeling

TOOLKIT

Tool 2.1 Erosion-Focused Rapid Assessment (EfRA)

Definition

The Erosion-focused Watershed Assessment methodology (EfRA) is a macro-level tool, and is supported by the other tools in the Gaining Understanding section. EfRA provides a highly useful, transparent and effective process to target limited funding on actions that will yield a measurable return on investment in watershed protection and improvement.

Purpose

Watershed improvement needs a simple, direct assessment process that yields tangible outcomes versus elaborate plans. EfRA provides a foundation for taking action and assessing the outcomes of watershed repair and management efforts.

The EfRA process is designed to expand understanding of watershed conditions, hydrologic linkages, watershed repair and management opportunities, and specific treatment approaches. This process needs to be systematic, accessible, easy to use, and serve as a strategic methodology to repair watersheds.

Goals

- To document drainage patterns in the watershed as a context for large-scale understanding of connectivity and potential water quality liability
- To define watershed conditions relative to sediment sources, sinks and water quality
- To identify sediment source areas and restoration opportunities
- To prioritize, group and sequence restoration treatment opportunities into projects for implementation
- To define/suggest tests to develop effective treatment types and techniques
- To define monitoring protocols that assess treatment effectiveness (cost and environmental)
- To establish a framework for future assessment, treatment and monitoring actions

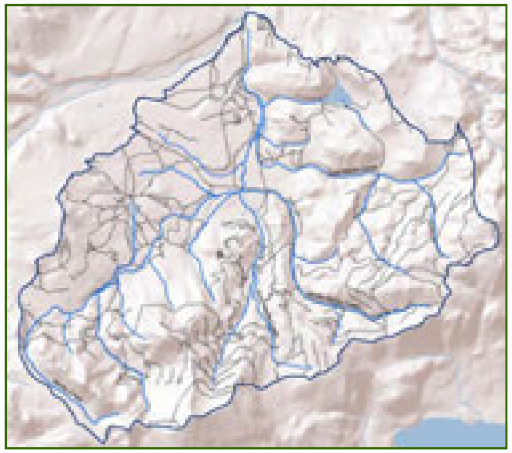
Outcomes

- Understanding of watershed sediment sources and linkages (hydrologic, geomorphic)
- Understanding of erosion potential for identified problem areas
- Understanding of sediment delivery risk level for erosion problem areas
- Improved ability to prioritize and target project implementation plans
- Improved ability to assess project outcomes and benefits
- Improved ability to respond when project outcomes fall short of goals

Outputs

- Mapped problem areas and hydrologic linkages
- Project prioritization framework based on site condition and sediment delivery risk for each site
- Phased project implementation plan
- Outcome-based management process to asses actual project outcomes relative to goals

Tool 2.1 EfRA: Step by Step Guide



1 **Define the goals of the watershed assessment**

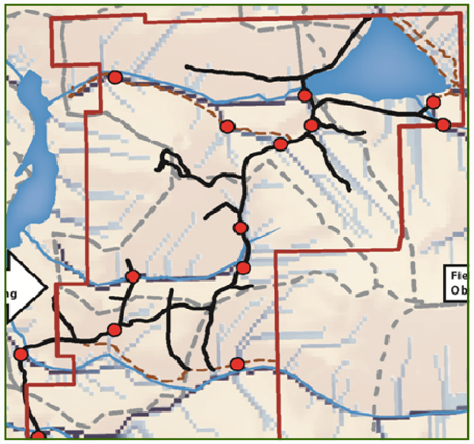
2 **Create base map(s) with key watershed attributes**

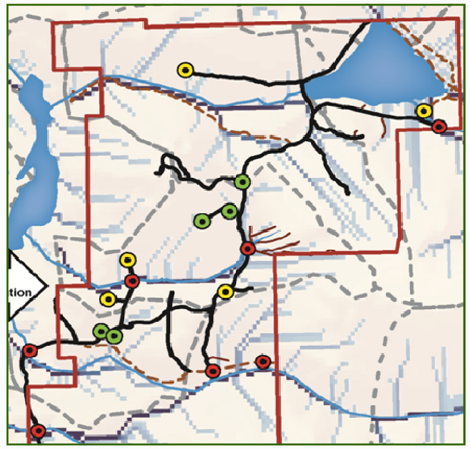
Specific goals for a watershed assessment and restoration effort may include:

- To reduce sediment loading to a stream
- To increase mid-summer stream flows
- To restore spawning habitat for a native trout species
- To create a new road system that does not increase erosion

- Create a base map (or series of maps) with key watershed attributes including streams, roads (active and abandoned), drainage infrastructure, and known water flow areas. The base map can be developed using a Geographic Information System (GIS)
- Where GIS is not available, other map formats can be used such as a 7.5 min topo, high resolution aerial photo, or a high resolution Google Earth image. The base map will be used for both identifying potential problem areas and to locate actual problem areas in the field
- Other watershed features/attributes that can be useful to organize in map format at this point are sub-watershed/catchment boundaries, ownership, land use (zoning), geology/soils, and meadows

Tool 2.1 EfRA: Step by Step Guide



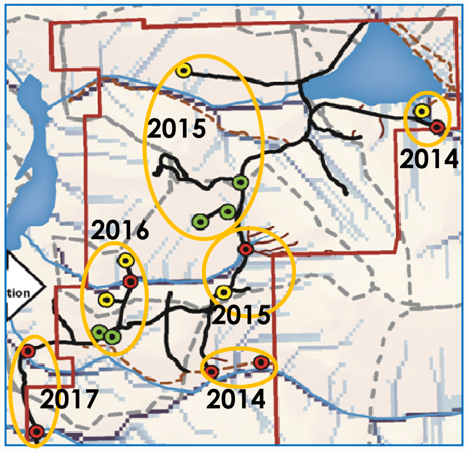


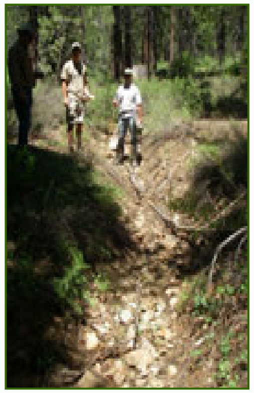
3 Identify known and <u>potential</u> erosion problem areas

- Review the map and identify known and potential erosion problem areas, including disturbed stream reaches
- Identify potential erosion areas and potential "hot spot" locations, such as roads crossing streams or ski slopes
- Erosion problem areas observed by land managers and known locations of historical land disturbing activities, such as logging or grazing, should also be considered potential hot spots and marked on the map
- Identification of potential problem areas provides the basis for a targeted field assessment. It is highly useful for Step 3 to be led by an individual with an understanding of erosion processes and water flow patterns during large runoff events in the watershed of interest

4 Identify <u>actual</u> erosion problem areas and interconnections

- Using the map created in Steps 2 and 3, conduct targeted field assessment to verify and further describe erosion problem areas and key features
- Where problems are identified, trace those problems upslope to their source. Finding sources of drainages and erosion areas is also referred to as erosion forensics and is a critical step in developing comprehensive and effective solutions to erosion issues
- Complete an overall assessment of additional flow patterns and problem areas for the entire watershed, documenting these additional features using GPS. Document connectivity <u>between</u> problem areas and <u>to</u> drainage features (see Tool 2.4 Water flow/connectivity assessment)
- Document all problem areas with photos, field observations, notes, potential treatment approaches, and GPS locations





5 Define and prioritize project opportunities

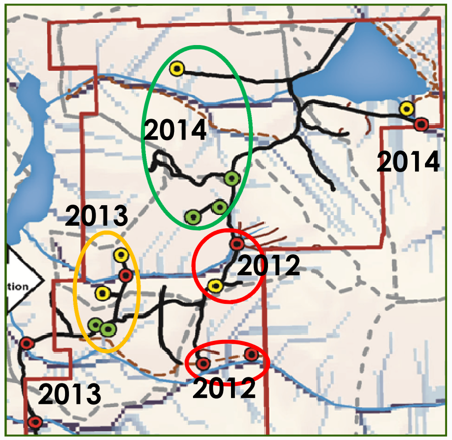
- Develop a project selection and ranking criteria and prioritize areas for treatment
- State preliminary objectives and identify treatment alternatives for each site
- The EfRA process can be used to prioritize treatment areas or projects in a number of ways. For instance, if the goal is to systematically address erosion areas in terms of their sediment contribution, planners may choose to begin with those areas that are closest to a year-round stream, assuming that they don't have upslope contributions from other areas
- If planning a development project, identify whether there are any areas that will contribute either surface flow or sediment to the site and repair those areas prior to the project

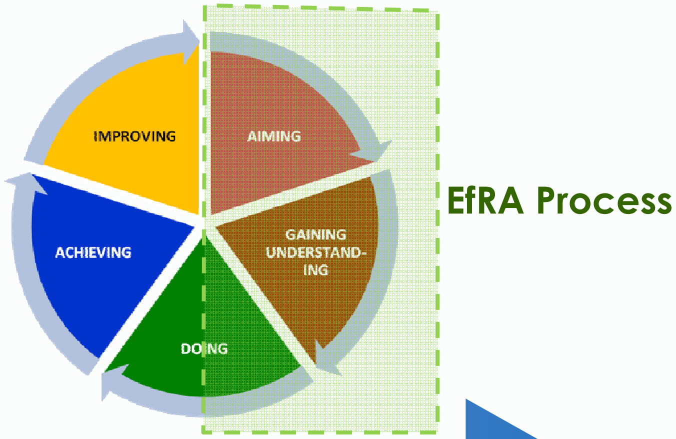
6 Conduct site condition and connectivity assessments

- Return to the sites and conduct design-level assessments of site-specific conditions and hydrologic connectivity to other project sites and water courses
- Focus on conditions known to influence erosion potential such as soil density/ compaction, mulch cover, vegetation, soil nutrients and organic matter, and evidence of erosion or ongoing disturbance
- Document flow paths and drainage features that may connect to other problem areas (particularly upslope) and/or to water courses (see Tool 2.4 Water flow/connectivity assessment)
- Use the information gained in this step to refine your project prioritization list and select treatment alternatives created in Step 5

TOOLKIT

TOOL 2.1 EFRA: STEP BY STEP GUIDE





7 Develop phased implementation plan

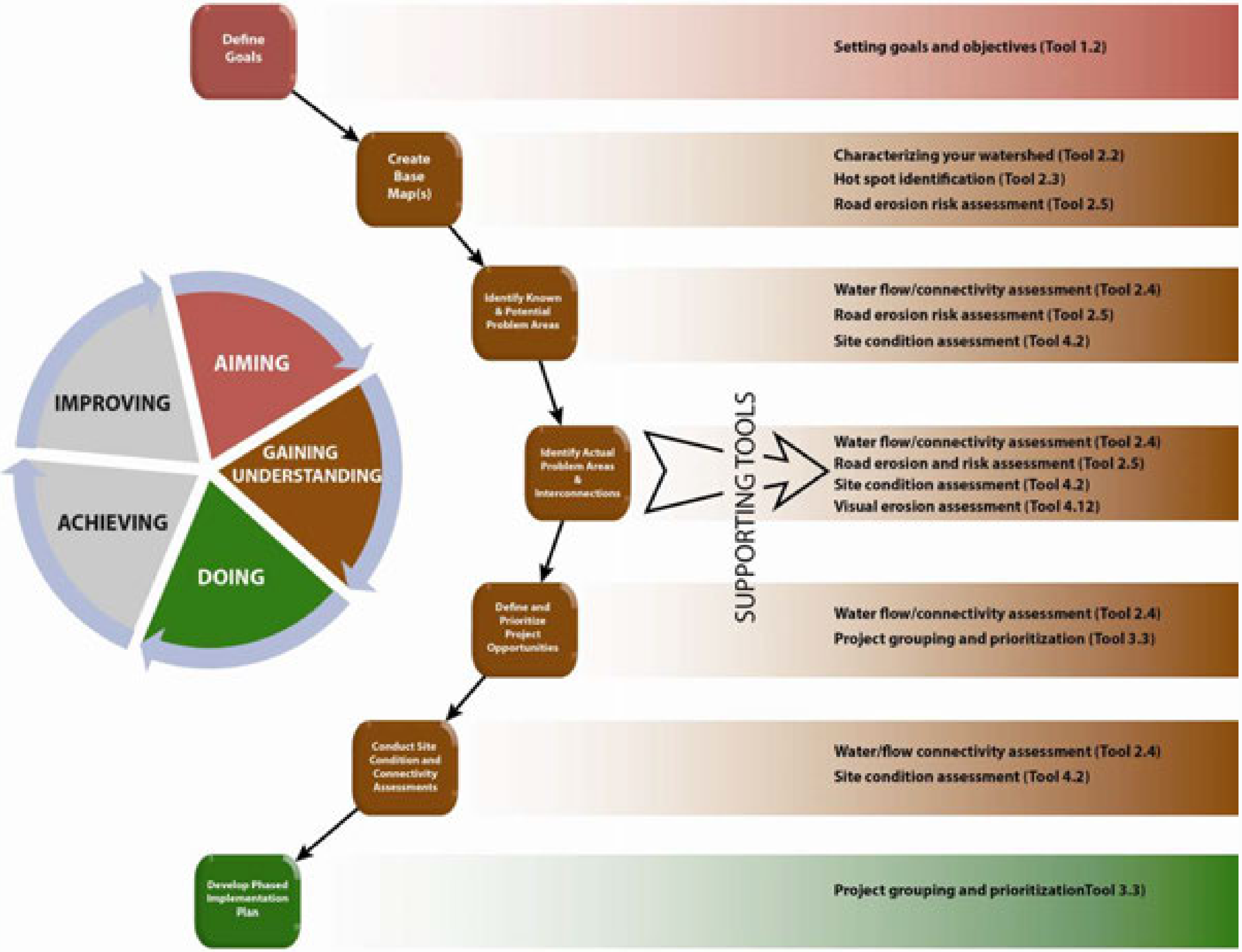
- Refine your project prioritization list and develop a phased implementation plan
- Whenever possible, treatments should begin at the top of the watershed or the upslope origin of the erosion issue. Where this is not possible or practical, treatment area(s) must be protected from run-on from upslope disturbance areas or drainages
- Develop an outcome-based management plan for each project, including: goals and objectives; knowns/unknowns (based on site condition assessments); treatment alternatives; testing/learning opportunities; implementation plan/schedule/budget; monitoring plan and success criteria; and a review, feedback and information sharing strategy

8 Close the loop and manage to outcomes

Congratulations — it's time to implement projects! The EfRA process guides you down a direct path to developing a targeted watershed improvement plan.

- EfRA covers the first half the outcome-based management process (as illustrated above). Completing the remaining steps in the adaptive cycle enables project implementers and partners to manage to a specified outcome such that watershed improvement goals are achieved
- Most importantly, closing the loop on the outcome-based management process sets up a feedback loop where information gained on one project is used to inform and improve future projects, enabling continual improvement and increasing effectiveness

The graphic below illustrates the relationship between the outcome-based management process, erosion-focused rapid assessment (EfRA) and supporting tools.



Tool 2.2 Characterizing your watershed

Definition

Characterizing your watershed is the process of assembling physical, cultural and historical baseline information about your watershed of interest and creating/collecting a series of base maps.

Purpose

The purpose of ***characterizing your watershed*** is to develop a clear understanding of key features and anthropogenic uses and disturbances in order to support targeted watershed assessment and project development. Gathering baseline information about your watershed will also helps reveal gaps in our knowledge about a watershed's conditions and processes.

Approach

This tool is primarily based on the geographic information system (GIS) computer program. There will be call-out boxes for both analog (non-GIS) and advanced GIS options.

This tool supports the second step in the EfRA process, which involves gathering relevant information about your watershed before fieldwork begins. Entering the field with a solid foundation of information enables more targeted, efficient field assessment.

Roads and historic logging are evident in this heavily impacted watershed near Truckee, CA.

The steps are:

1. Create a watershed base map
2. Characterize the land surface of your watershed
3. Review past studies and available data
4. Gather local knowledge

1 Create a watershed base map

This is your reference map (See Figure 6). It is a tool for later fieldwork, as well as for meetings with partners and stakeholders. It is also used for the first cut at identifying potential erosion "Hot Spots" (see Tool 2.3 Hot spot identification). Only the key site characteristics need to be included: **stream and road networks**, **watershed boundaries**, **property boundaries**, **buildings**, **topographic data**, and where relevant, **ski runs** and **ski lifts**.

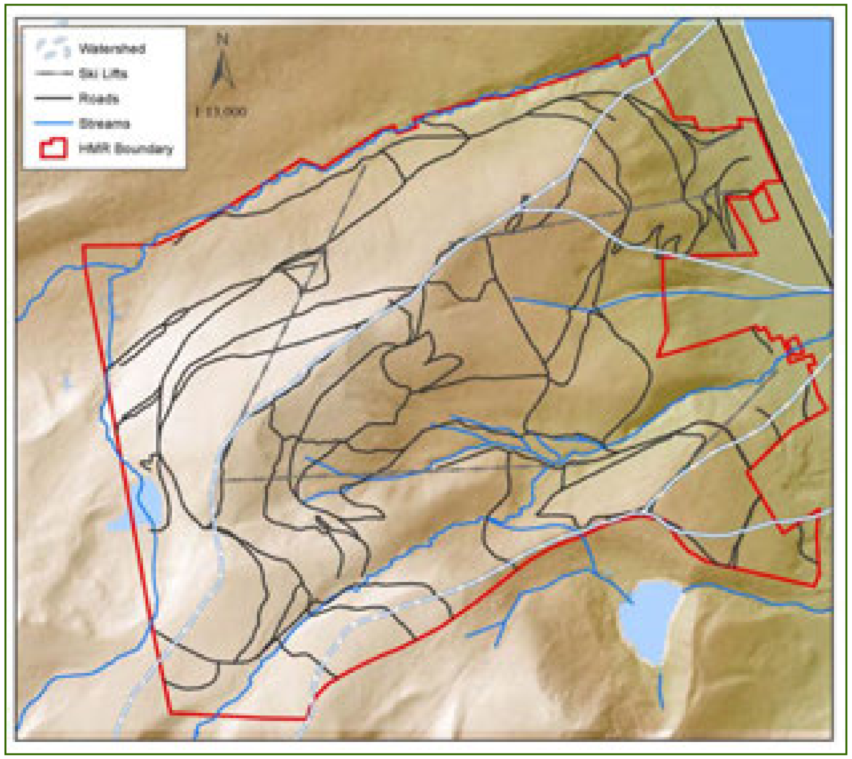


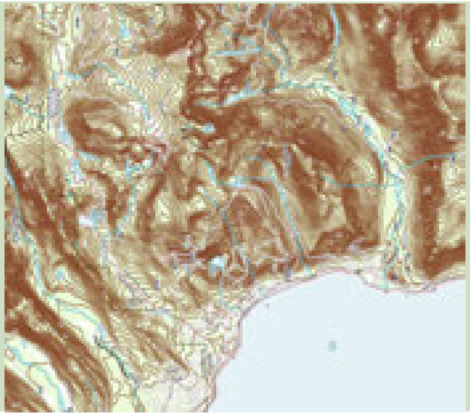
Figure 6. An example of a base map made for restoration planning at Homewood Mountain Resort on the West Shore of Lake Tahoe.

Finding GIS Data

- Begin by collecting geographic data from the stakeholders in the project. For example, at a ski mountain the ownership may have its own geodatabase (collection of geographic data) cataloguing ski runs, maintenance roads, buildings, and other features. Many landowners also work with consulting firms that manage their data.
- Download **elevation data** for your site. Digital Elevation Models (DEMS) are the basic input for understanding the hydrology and surfaces of a watershed, such as slope, aspect, and water flow. This information is important to assess flow paths that may not be captured in GIS stream network files, as well as for other analysis. Find high-quality DEMs at http://nationalmap.gov/viewer.html

Analog Option

Find more traditional maps in the 7.5 minute quadrangle format on the USGS database <http://nationalmap.gov/ustopo/.> These maps can be viewed as PDFs with optional hydrology, transportation, topography, and other feature layers.



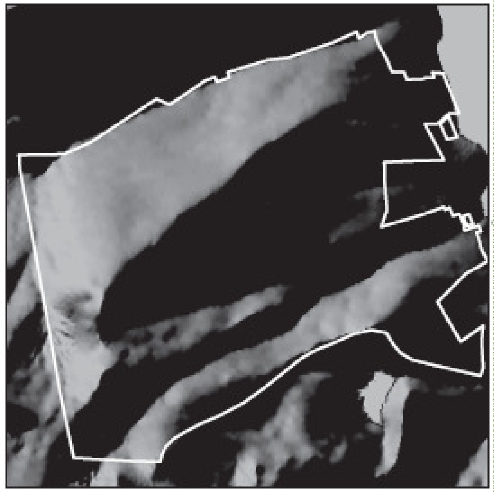
TOOLKIT

Tool 2.2 Characterizing your watershed

GIS BONUS

There may be more accurate elevation data available for your site, including Light Detection and Ranging (LiDAR) data. LiDAR provides sub-meter accuracy and is highly useful for hydrological modeling, and other land surface analyses.

10m Grid Hillshade vs. **LiDAR Sub-meter Hillshade**



Hillshade maps derived from a 10m. X 10m. (100m²) grid DEM compared with a sub-meter LiDAR dataset. Notice the road features, depressional areas, and other topographic features identified by LiDAR.

- Download **hydrologic data**. The State or County your site is located in likely has a GIS database, but you can also download data from the USGS National Hydrology Dataset at http://nhd.usgs.gov/index.html. This data includes streams, watershed boundaries, wetland areas, and other relevant hydrological features.

- Find **aerial photography** (ortho-imagery) of your site. If you are using ArcGIS you can add a world base map, which has high-resolution imagery for the contiguous US. You can also download high-resolution imagery from the relevant State or County GIS data clearinghouse. The USGS offers downloadable ortho-imagery at http://eros.usgs.gov/#/Find_Data/Products_and_Data_Available/High_Resolution_Orthoimagery

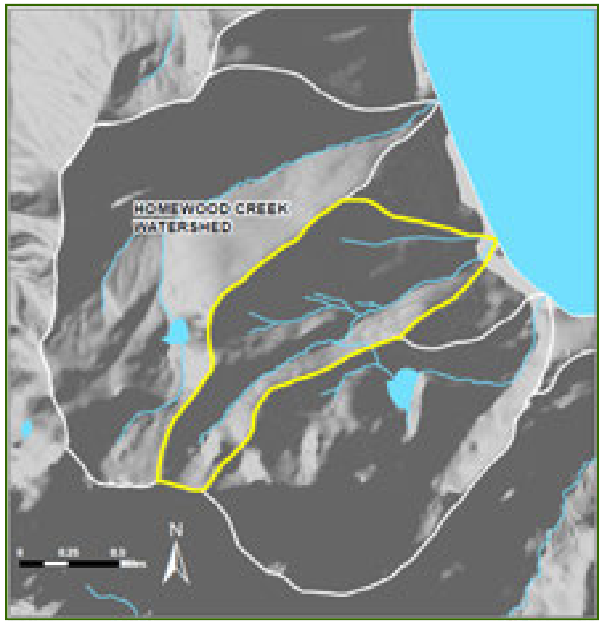


Figure 7. Example map showing basic hydrological features such as streams, lakes and watershed boundaries.

Aerial Imagery

Creating a sequence of historical and recent aerial photography of a site powerfully shows change over time, and can be used to identify changes in land use, channel location, development, and more. The USGS online database at <http://earthexplorer.usgs.gov/> offers a large collection of historical aerial photography. Counties also generally have detected archives available on request.

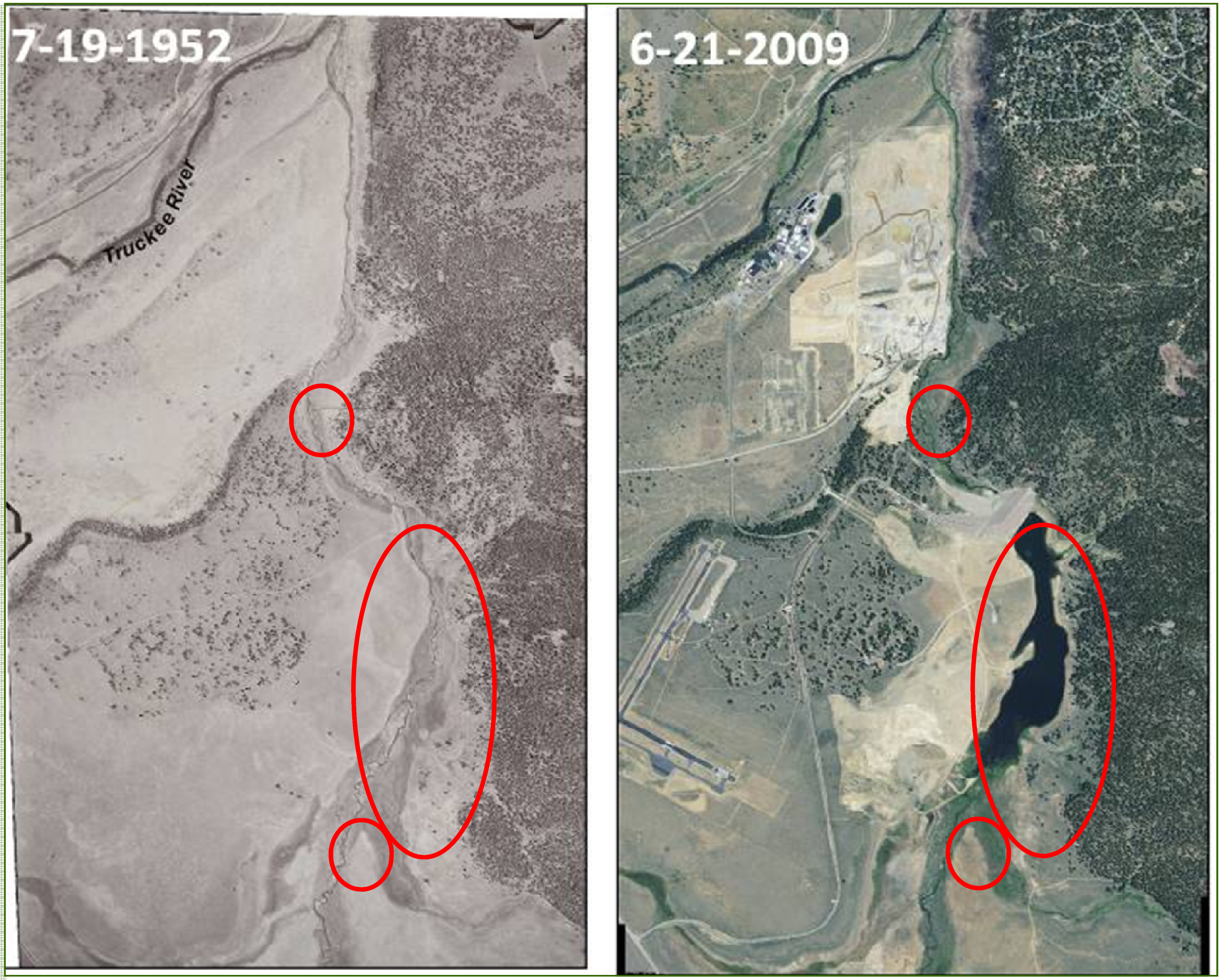


Figure 8. Time-series aerial photography from the Martis Watershed Assessment prepared by Balance Hydrologics, Inc. shows historical development, Martis Dam construction, floodplain conversion, and channel entrenchment.

Tool 2.2 Characterizing your watershed

2 Characterize the land surface of your watershed

Conducting a few additional steps in GIS using the DEM you have already collected can help identify areas to focus field assessment and potential restoration projects. This step is dependent on either ArcGIS with the Spatial Analysis Extension, or a strong knowledge of other GIS surface analysis software. Outputs can include slope, aspect, land use, soils, and geology analysis.

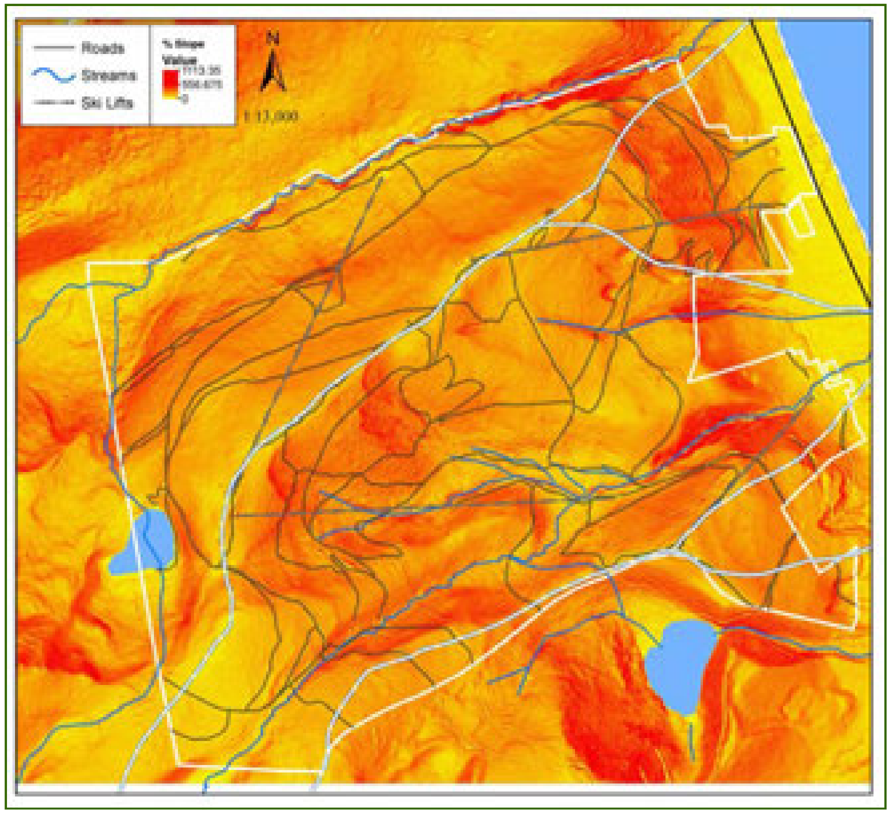


Figure 9. Map illustrating percent slope. Steepest slopes are highlighted in red.

Alpine meadows meet forested hillslopes in the Martis Valley, near Truckee, CA.

Slope Analysis

Slope is a key factor in hillslope erosion, sediment transport, and hydrologic connectivity between sites. Knowing the slope of a site relative to the surrounding features can identify areas of higher erosion potential and help target subsequent field assessment. This is especially useful in larger watersheds where complete field surveys are not possible.

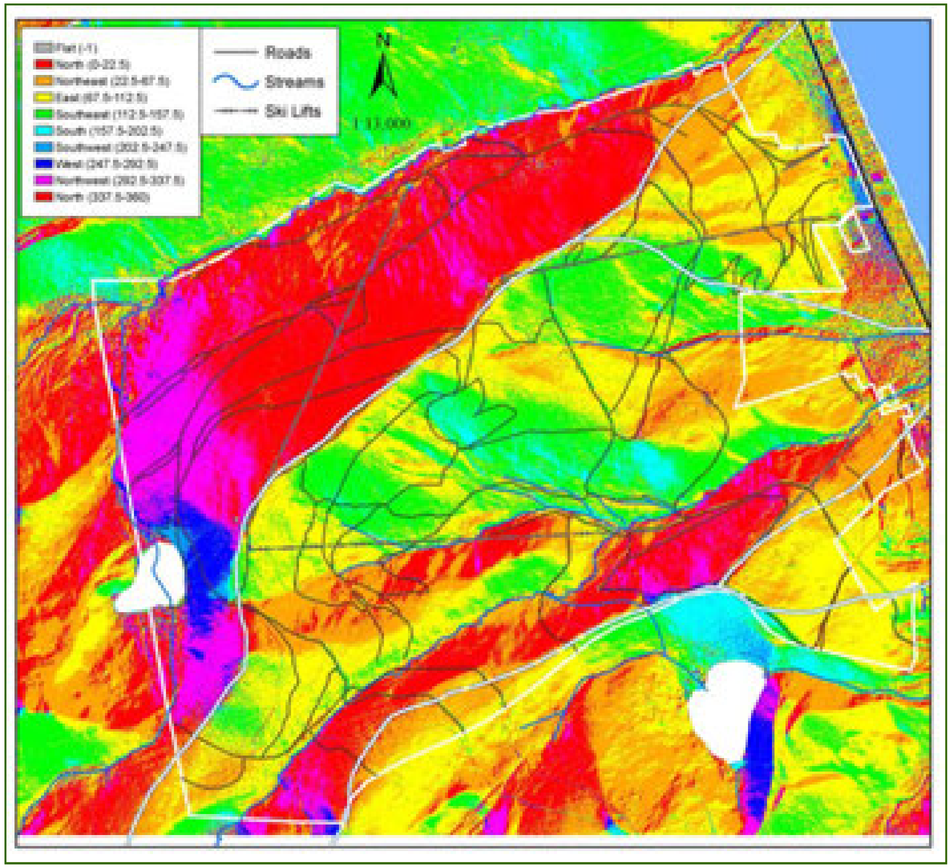


Figure 10. Map showing slope aspect in an upland watershed.

Land Cover/Land Use Analysis

Data available from your local City or County can provide a general overview of land use/land cover patterns in your watershed of interest. Different land uses have different hydrologic characteristics (e.g. infiltration rate); however, assumed hydrologic characteristics for each land use type should be assessed in the field prior to project implementation.

Aspect Analysis

Aspect analysis is used to determine the prevailing aspects and solar exposure of sites in your watershed. Aspect is a particularly important factor in understanding precipitation and runoff patterns in alpine watersheds because of the snowmelt-driven hydrology.

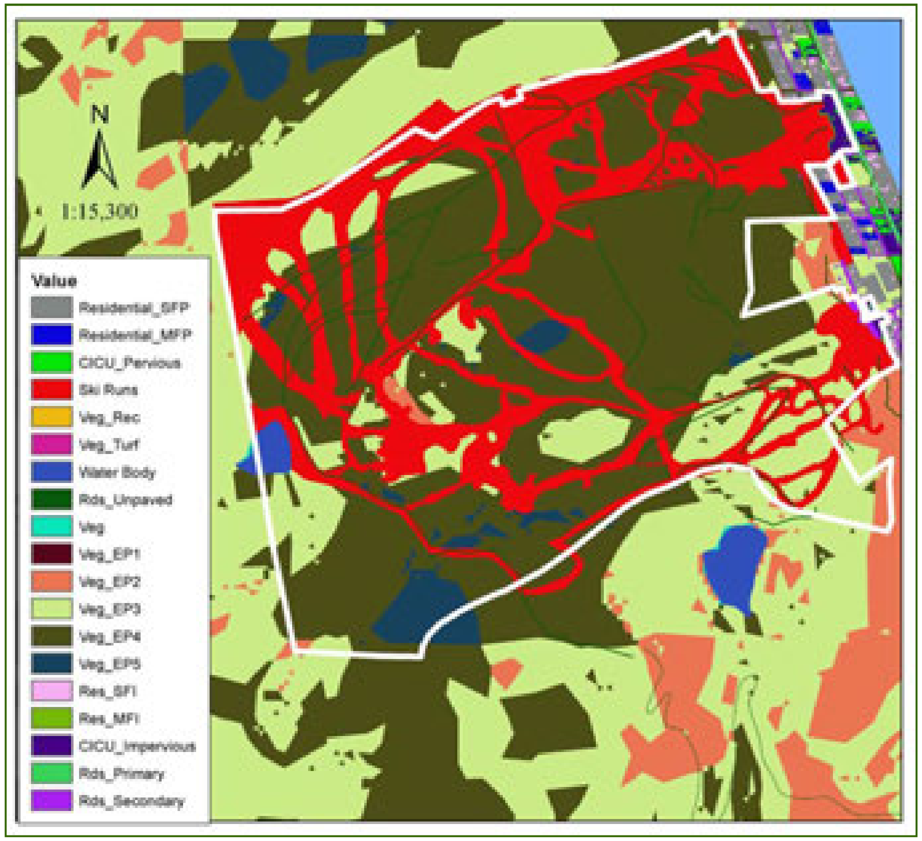


Figure 11. Map showing land use in a watershed on the West Shore of Lake Tahoe.

TOOLKIT

Tool 2.2 Characterizing your watershed

Limitations of GIS Data

All GIS data has limitations that need to be recognized. Maps, while often assumed to be authoritative, do not always "tell the truth." They are visual representations of data, and can be incomplete or incorrect. The features on a map, and the way they are shown, is also affected by the bias of the data collector and of the map maker. **GIS analysis is an important complement to—not a replacement for—field assessment.**

For example, the GIS roads dataset used for modeling sediment loading in the Lake Tahoe Basin did not contain many roads later identified in the field at a west shore watershed. This is important, as unpaved roads in upland areas are likely significant contributors to watershed sediment yield. There are a few ways to address this, and the option you choose depends on budget and capabilities.

This old logging road—now partly covered by shrubs—was discovered through field assessment but not detected by previous aerial surveys. Despite the shrub cover, this road is still heavily compacted and concentrating runoff.

Roads Spotlight

1) Acknowledge that you have incomplete data, and recognize that any modeling or analysis you use it for will also be incomplete.

2) Digitize ('trace' in GIS) roads using the most up-to-date aerial photography you can find.

3) Complete a field-based GPS road inventory. At a watershed on Lake Tahoe's west shore, an additional 22 acres of roadbed area was identified through a field inventory and added to the roads catalogued in the existing GIS database.

3 Review past studies and available data sets

Past studies and data sets can also provide useful information about your watershed of interest. Examples of useful resources may include: watershed assessments, water quality and stream flow monitoring efforts, groundwater studies and management plans, and water-related sections of Environmental Impact Statements/Reports (EIS/EIR). It is very important to understand the goals, scope and limitations of any past studies or datasets you collect and are considering using for future watershed improvement efforts. For instance, studies associated with EIS's usually focus on a discrete study area, not an entire watershed.

Figure 12. Map showing approximately locations of historic logging and ranching activities in the Martis Watershed. Map prepared by Balance Hydrologics, Inc. and Susan Lindstrom.

4 Gather local knowledge

Often times the most valuable information about watershed use patterns, erosion issues and opportunities comes from local historians, landowners, Native American tribes and field staff (e.g. trail crew leaders) who have a long-term perspective and/or a working knowledge of the watershed. Before, or in conjunction with, carrying out the watershed assessment, consult with locals familiar with the watershed to gain insights that may help shape the rest of the assessment.

TOOLKIT

Tool 2.3 Hot Spot Identification

Definition

Hot Spot Identification is a process for identifying erosion source areas (or "hot spots") using a combination of GIS analysis, local input, and targeted field assessment.

Purpose

The purpose of *Hot Spot Identification* is to determine the primary sources of erosion, target field investigations, and support cost-effective treatment.

Approach

Using this tool, you will first identify potential hot spots using GIS maps and information produced in *Tool 2.2 Characterizing your Watershed*, and known hot spots based on input from people familiar with the watershed. You will then head to the field to determine actual hot spots and discover new hot spots through **targeted field assessment**. This process is intended to be iterative, and can be conducted over the course of several years.

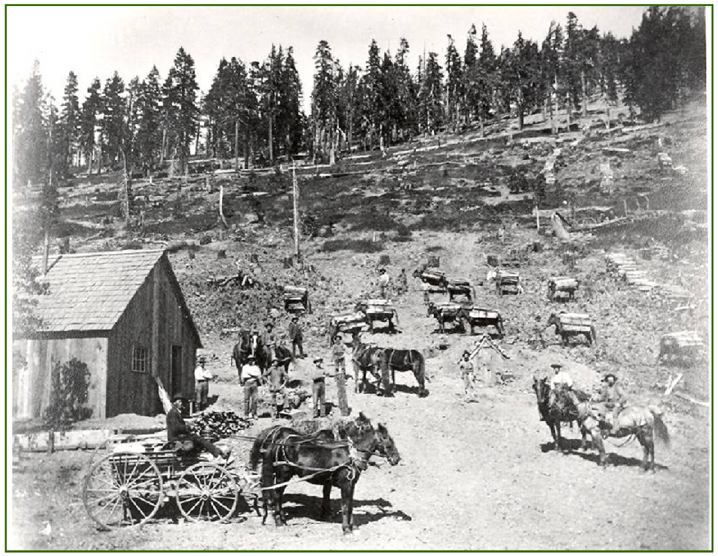
An obvious erosion hot spot on a road segment in the Martis Valley where meadow drainage was not accommodated.

1 Identify Known and Potential Erosion Hot Spots

Review the map and **identify** known and potential erosion hot spots. Potential hot spots may include: steep road segments, road-stream crossings, ski run-road crossings, roads in close proximity to streams/drainage ways, areas of historic logging or mining activity, etc.

Gather local knowledge of the site. The local knowledge of land managers, landowners, field crews, Native American Tribes, etc. is often overlooked. Engage these players in open discussion about locations of recent and historical land disturbing activities, such as logging or grazing. Mark these known and potential erosion source areas on a map.

Note: *It is recommended that this step be led by an individual with an understanding of erosion processes and water flow patterns during large runoff events in the watershed of interest.*



Historic logging activity at the Waddle Ranch left a legacy of unmapped roads, landings and skid trails.

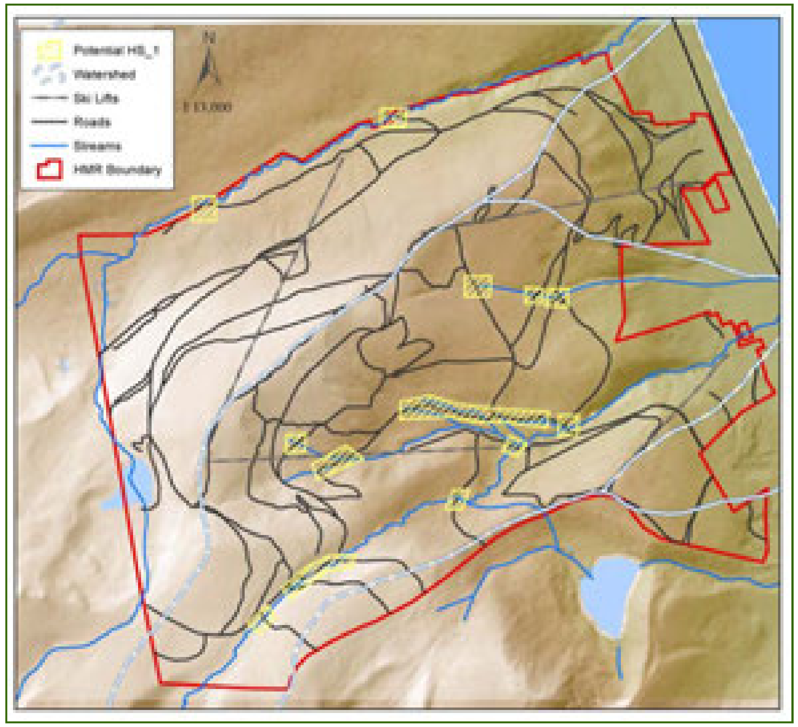


Figure 13. Example map showing potential hot spots identified prior to field investigations.

GIS Bonus

Using a Digital Elevation Model (DEM), you can create a flow accumulation model in ArcGIS. This will help you identify drainages that may not show up on a streams data layer, or may be ephemeral—only running during rain or rain on snow events. For more information about flow accumulation modeling see Tool 2.4 Water Flow and Connectivity Assessment.

TOOLKIT

Tool 2.3 Hot Spot Identification

2 Create a Draft Hot Spot Map for Field Assessment

Prepare a draft hot spot map to take to the field. This map should show the locations of known hot spots as well as locations of potential hot spots based on analysis of key watershed features such as roads and streams and areas suggested by the flow accumulation model to be topographically-disposed to channeling surface flow during large runoff events.

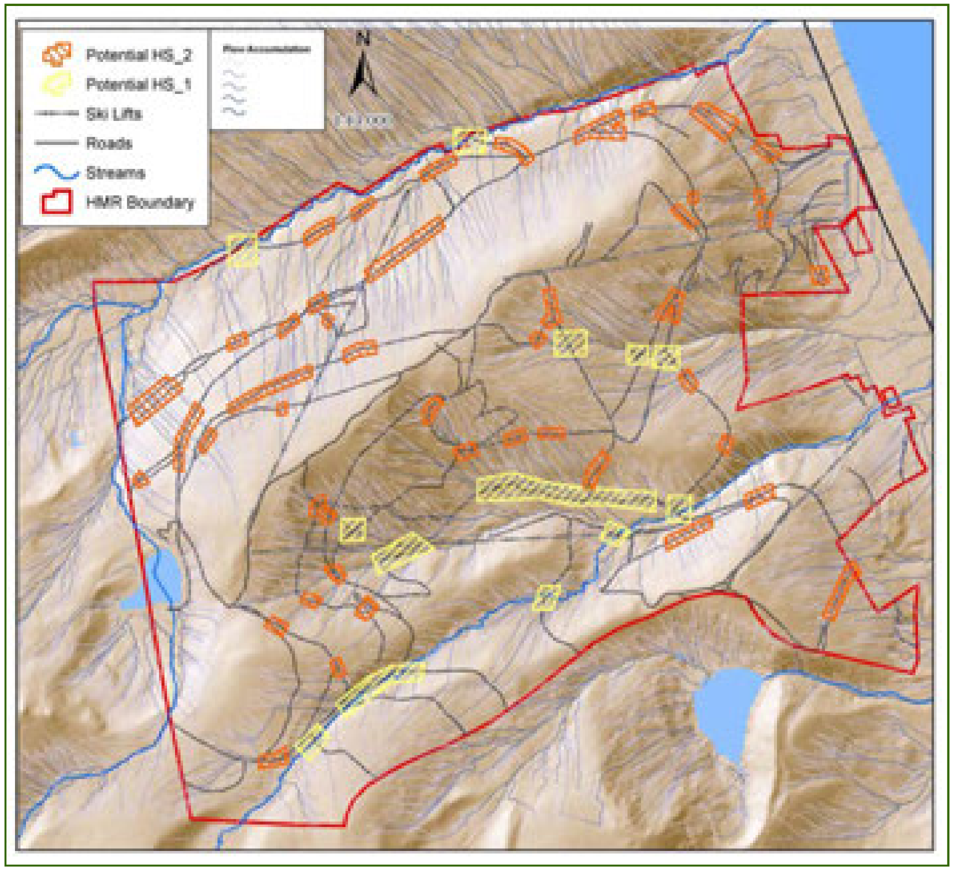


Figure 14. Example map showing known and potential hot spots. Creating a map like this can help to target subsequent field investigations.

GIS Bonus

Conduct overlay analysis to combine collected and generated data

Overlay analysis can be as simple as examining different maps of the site and choosing areas that contain multiple at-risk factors (as illustrated on the map to the right). With GIS capabilities, you can overlay the slope, aspect, and land cover maps you have generated in Tool 2.2 with a flow accumulation map and run a query to spatially select potential erosion areas. This is a very powerful tool that can save time by focusing field assessments on likely problem areas, which can be critical when evaluating restoration opportunities for large watersheds or properties.

3 Conduct Field Assessment to Identify <u>Actual</u> Hot Spots and Interconnections

Field assessment is the most important component of this process. All prior steps have focused on gathering and assembling existing information and generating *hypotheses*. Areas identified as *potential* hot spots should be treated as *hypotheses*, as a foundation for guiding field assessment efforts. For example, if a recent fuels reduction project using mechanical equipment alongside a stream is believed to have compacted soil and increased runoff, that hypothesis can and should be assessed directly in the field (see Tool 4.2 Site Condition Assessment).

Field assessment will reveal that some potential hot spots are, in fact, "cold," and will lead to the discovery of new hot spots not identified through previous information-gathering and analysis steps. Trace each hot spot to their source and end point using Tool 2.4 Water Flow/Connectivity Assessment.

Photos show various erosion source areas and conveyance features the connect runoff to surface waters and have altered the "plumbing" of the watershed.

Tool 2.3 Hot Spot Identifiction

Step 1	Step 2	Step 3
Create an overlay of existing roads and the best hydrological data available to target potential erosion hot spots. In many cases, stream data is incomplete or misleading. The data generally does not distinguish between active and ephemeral channels.	A Digital Elevation Model (DEM) takes the data and generates a flow accumulation model, which can be an important complement to limited stream data. The model can also identify drainage pathways that are usually inactive, yet flow during large rain-on-snow events.	GIS modeling allows us to identify potential problem areas before going into the field, which saves time and energy. Once we visit the field, we can assess the erosion potential of modeled hot spots. We then prioritize hot spots and take action.

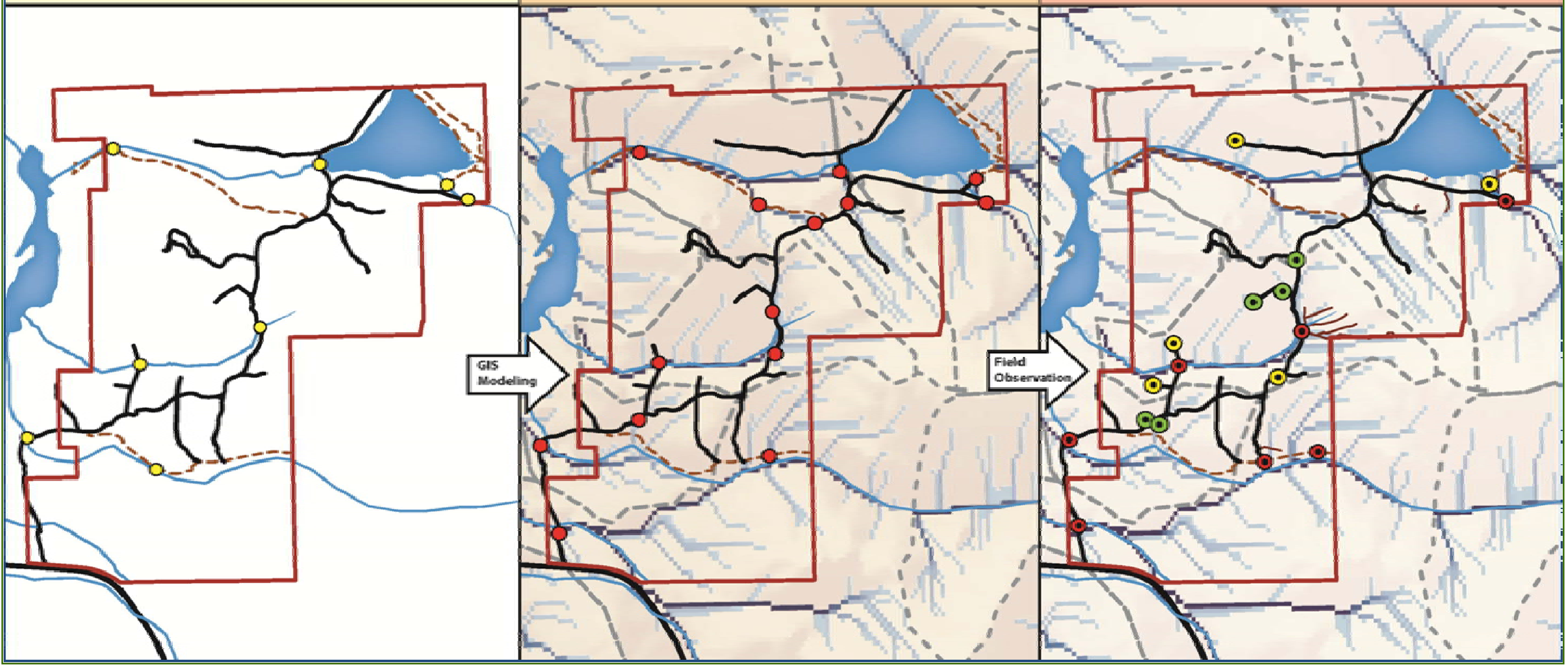


Figure 15. Graphical summary of the hot spot identification and verification process, as applied at Waddle Ranch.

Tool 2.4 Water Flow/Connectivity Assessment

Definition

Water flow and connectivity assessment is the process of identifying, mapping and assessing surface water flow patterns and erosion problem areas ("hot spots") within a specific drainage area such as a catchment, sub-watershed or watershed. This process takes into consideration both year-round and ephemeral drainage patterns as well as anthropogenically altered flow paths.

Purpose

A water flow and connectivity assessment is conducted in order to develop as complete an understanding as possible of existing and potential (seasonal) water flow paths that will influence the design, implementation, and eventual success or failure of a project as well as its connectivity (likelihood of delivering sediment) to surface waters. Information and data collected through water flow and connectivity assessment can be used by the project team as one element to prioritize treatment of problem areas in order to maximize sediment load reductions in a particular watershed or catchment. It can also be used 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.

Approach

Assessing water flow and connectivity must be done in the field. This tool lays out a field-based process for assessing the connectivity of a hot spot or project area to drainage ways as well as the connectivity of those drainage ways to surface waters. In other words, this process is intended to answer the question: if sediment leaves this site, where will it go and how likely is it to be transported to a surface water? This tool also includes a powerful flow accumulation modeling process that can be conducted in GIS to develop a more complete picture of potential drainage ways and connectivity throughout a watershed. This tool builds directly on products from other EfRA tools, such as Characterizing your Watershed (Tool 2.2) and Hot Spot Identification (Tool 2.3).

Accelerated erosion on a Sierra ski run. Runoff from this ski run contributes surface flow to the dirt road downslope, illustrating the interconnected nature of erosion issues in high-use watersheds. in background.

TOOLKIT

Tool 2.4 Water Flow/Connectivity Assessment

Overview

When prioritizing restoration projects on a watershed or property-wide scale, it is important to consider a site's connectivity to drainages and surface waters. That is, what is the likelihood that sediment leaving a site will be conveyed to surface water? Assessing the connectivity between sediment sources and surface waters is an inexact science due to a large range of variables. This complexity is the main reason that watershed models are rarely able to capture actual, complex runoff and erosion patterns. However, the ability to understand this connectivity on the ground is, in many ways, the crux of sediment-focused watershed restoration efforts. Additionally, water flow and connectivity assessment is an important step in planning any sort of development project so that seasonal water flow can be managed effectively rather than having to address unanticipated run-on or concentrated flow issues after the project is completed.

Timing and Training

The best opportunities to assess and understand connectivity in most alpine watersheds is in the field during peak spring snowmelt, as evidence of erosion, deposition and hydrologic connection tend to disappear quickly by early summer. Water flow, especially ephemeral flows, can be difficult to determine in the absence of rain or snowmelt and may require some amount of forensic assessment by experienced individuals trained to recognize subtle surface features.

Methodology in Brief

1 **Create or obtain a water flow base map** (see Tool 2.2, Characterizing your Watershed). If you have GIS capabilities, creating a flow accumulation map can be a powerful resource during the field assessment process and for subsequent communication with the project team and stakeholders.

2 **Visit known and potential hot spots in field** and map (by hand or using GPS) nearby drainage ways and potentially connecting features.

3 **Apply field assessment criteria** to determine relative connectivity of hot spots to surface waters.

Roads and Water Flow

Aside from streams, roads are perhaps the most important flow-routing feature in a watershed and should receive ample consideration in the EfRA process. Refer to the Road Erosion Risk Assessment Methodology (Tool 2.5) for guidance on identifying and prioritizing road erosion issues for treatment.

1 Create or Obtain a Water Flow Base Map

Prepare a base map showing, at a minimum, water features such as streams and wetlands, roads, topography/elevational relief, and watershed/catchment boundaries. Refer to *Characterizing your Watershed* (Tool 2.2) for guidance. Below is an example of a water flow map highlighting road drainage areas prepared based on previous experience in the watershed of interest.

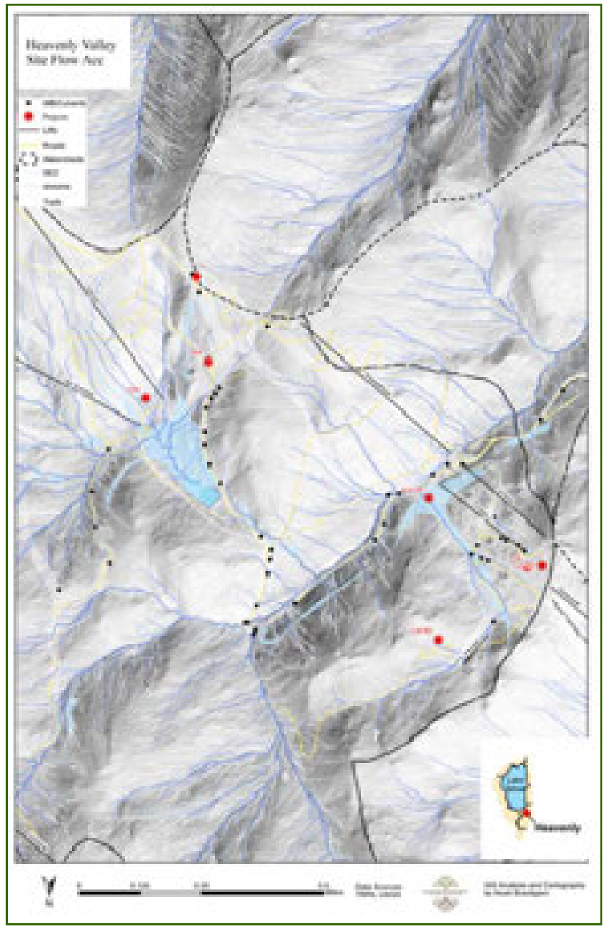


Figure 16. Example water flow base maps. At left is a USGS 7.5 minute quad map with the watershed boundary added. At right is a GIS-derived map showing flow accumulation paths, shaded relief, roads, water bars and ski lifts.

TOOL 2.4 WATER FLOW/CONNECTIVITY ASSESSMENT

GIS BONUS

FLOW ACCUMULATION MAPPING

For a richer understanding of drainage features and hydrologic connectivity in a watershed, you can generate a flow accumulation model in ArcGIS. A flow accumulation model uses a Digital Elevation Model (DEM) to topographically define areas where surface flow is likely to concentrate. Generating a flow accumulation map can help to identify ephemeral drainages and other potential flow paths not represented in typical stream data layers that could transport sediment in large runoff events, such as intense rain storms or during a rain-on-snow event. Where available, LiDAR-based DEMs can provide very high resolution elevation data and even more accurate flow accumulation models (see Figure 17).

This step requires ArcGIS software and the Spatial Analyst extension. If you don't have these capabilities, other forms of data, such as aerial photography analysis, can be used to identify potential drainages and flow paths prior to field assessment.

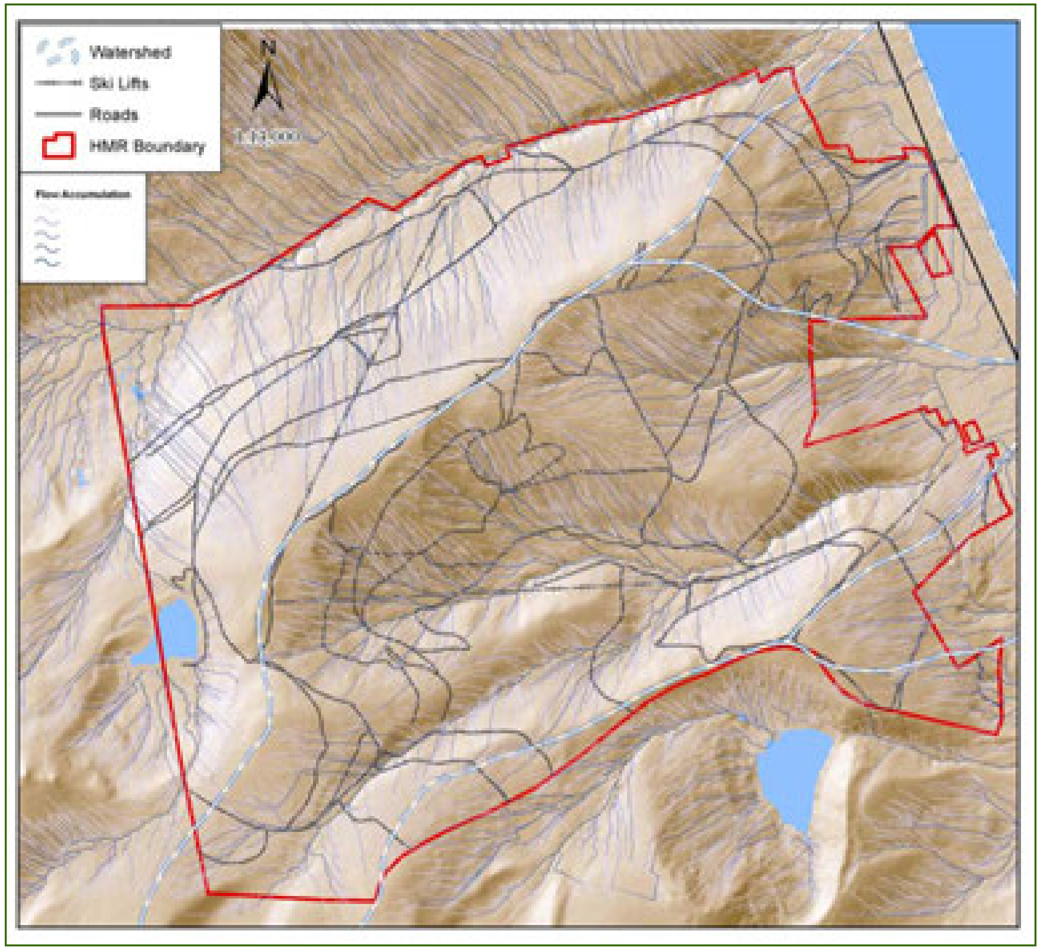


Figure 17. Example flow accumulation map showing LiDAR-derived flow accumulation paths.

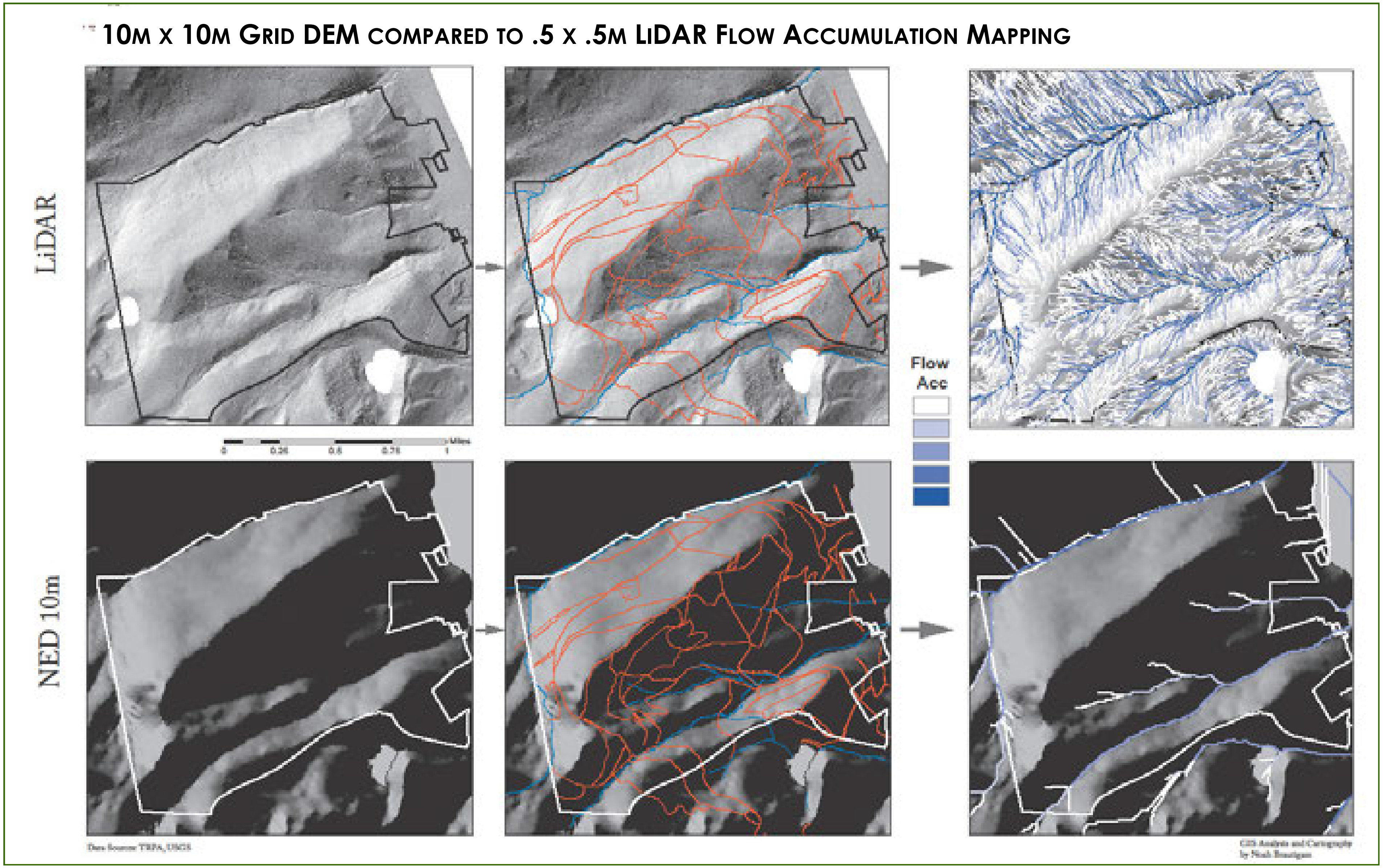


Figure 18. Where available, LiDAR data is very useful for characterizing the land surface and processes of your watershed.

Tool 2.4 Water Flow/Connectivity Assessment

2 Map Water Flow Paths and Connectivity

In the field, trace water flow areas from their source to their end-points, particularly those that end at a well-established stream channel. Map these water flow areas either by hand on a map or using GPS. Take photos and notes describing each flow area, as these will be useful in the next step.

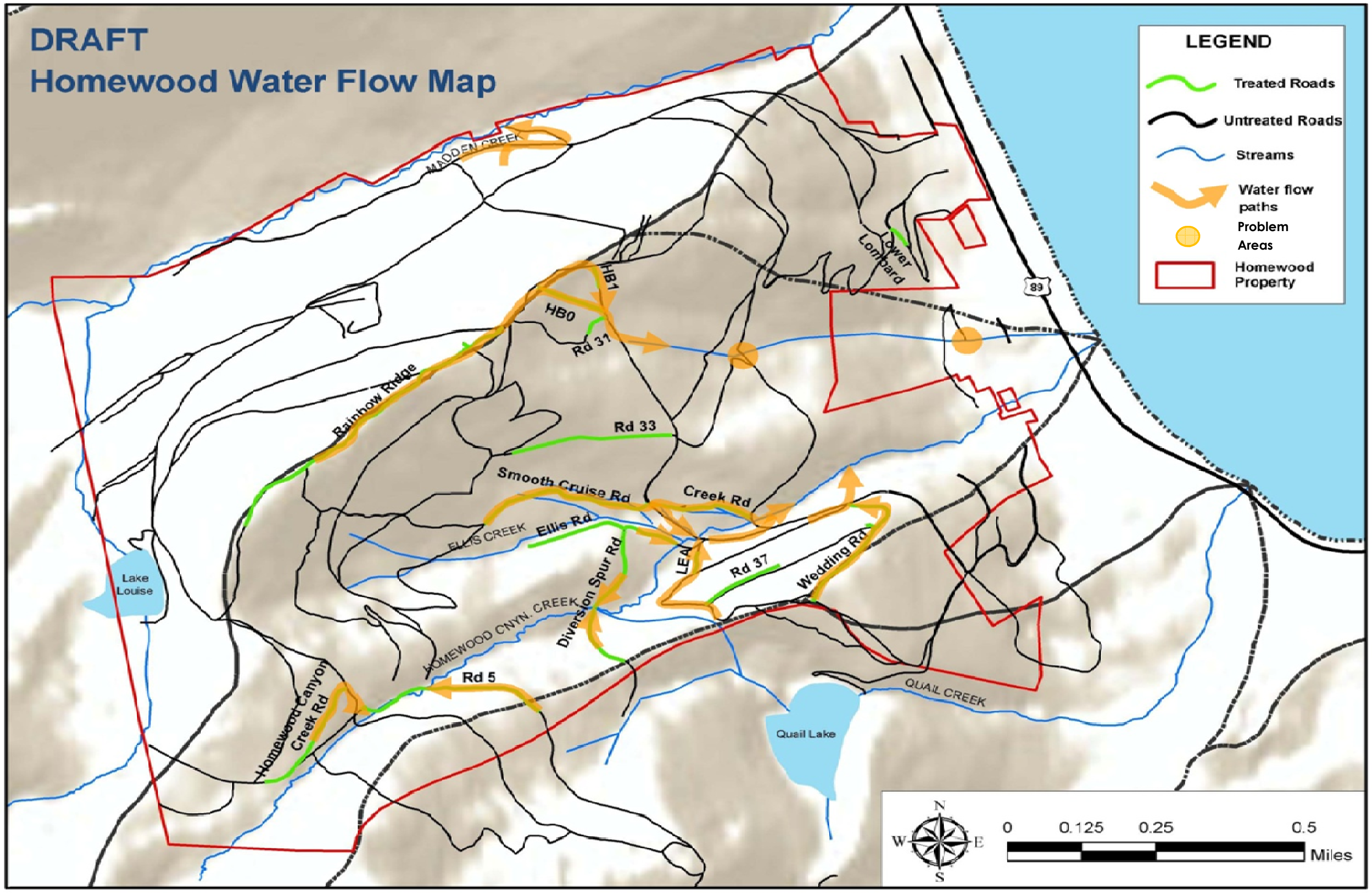


Figure 19. Example water flow and connectivity assessment map showing key upland water flow areas and connectivity to streams.

3 Assess Connectivity in Field

Once water flow areas are located and mapped, particularly those that connect to and from hot spots (identified in Tool 2.3 Hot spot identification), you are ready to assess connectivity in the field. Below are suggested criteria that provide a simple framework for objectively assessing relative hydrologic connectivity within a catchment or watershed.

Table 6. Example framework and criteria for assessing connectivity of hot spots to surface waters. Note: field assessment criteria should be adjusted to reflect the range of features and site-specific conditions of each watershed. The numeric and descriptive criteria provided here are only intended as examples.

Connectivity – Field Assessment Criteria			
	Low = 1	**Med = 2**	**High = 3**
Proximity to drainageway[1] (within same catchment)	>500 ft	100-500 ft	<100 ft
Connectivity of drainage way	Broad topographic definition; accumulated duff/litter; well-established vegetation; no visible sediment deposition	Defined channel or flow path; visible sediment deposition; mostly rock substrate; may have some vegetation. Steeper roadways functioning as drainage ways may also be included in this category	Ephemeral stream channel; may have hydrophytic vegetation
			

[1] A drainage way is defined as any feature that could collect and convey runoff water toward a surface water

Tool 2.5 Road Erosion Risk Assessment Methodology

Definition

The *Road Erosion Risk Assessment Methodology* is a targeted assessment process used to characterize the relative potential for erosion from unpaved road segments. Both an **analog** and a **GIS-based** methodology are provided.

PURPOSE

Unpaved roads in upland watersheds are known to be significant contributors to watershed sediment yield. This tool is intended to provide a practical approach for targeting and prioritizing road maintenance and treatment efforts based on observed erosion conditions and measured (and/or GIS-derived) site attributes known to influence erosion.

METHODOLOGY IN BRIEF

1. **Choose** the roads to be analyzed (those with the greatest importance in the watershed, and those with the highest connectivity to drainage ways) and map if road data is not available. Include someone who knows the area well in this process.
2. **Find** "flow breaks" along the road. This is where runoff either leaves the road on its own, or is channeled by a waterbar or other manmade feature. Break the road into segments.
3. **Collect** additional attributes (erosion, deposition, gullying) that further describe each road segment while simultaneously establishing flow breaks. Assign a value between 1 and 3 to each the three variables for each road segment—1 for less visible evidence of the variable, 3 for high visible evidence.
4. **Calculate** the gradient and length of each road section.
5. **Combine** the variables gathered for each road section and weight each differently based on how much it is known or believed to contribute to overall erosion potential. Color-code each road segment based on its overall erosion risk.

Roads tend to capture and concentrate runoff, which can cause erosion and alter drainage patterns in watersheds.

Analog Method (best for small road networks)

1 **Obtain base map.** Find a base map that shows the road network of interest. Ideally, this map should include other features such as streams and key landforms (e.g. USGS topographic map). You can use the reference map generated in Tool 2.2. An additional source for this data is <http://nationalmap.gov/ustopo/>

2 **Locate flow breaks along roads.** Low breaks include both natural grade changes where a road flattens out as well as structures installed to divert surface runoff, such as water bars or rolling dips. Mark flow breaks on map to define discrete road segments. Assign each road segment a unique ID.

3 **Observe and record actual erosion conditions for each road segment.**

Note: this portion of the assessment should be done as soon after rain or snowmelt as possible, as evidence of erosion can disappear quickly after even several days of dry weather.

a. **Erosion** (of the road surface above the flow break)

b. **Deposition** (at the flow break)

c. **Gullying** (of runoff from the road at the flow break)

d. **Assign** a relative score of 1-3 for each erosion attribute using the key in **Table 6.**

e. **Calculate** an average **OBSERVED EROSION** value for each segment using the assigned scores. These attributes (and additional attributes, if desired) can be weighted differently based on site-specific conditions, results of testing, available data, anecdotal observations, etc. For instance, if a road segment is located near a stream channel, gullying might be weighted more heavily than other attributes if road runoff is more likely to be delivered to the stream. See Tool 2.4 Water flow/connectivity assessment for more information.

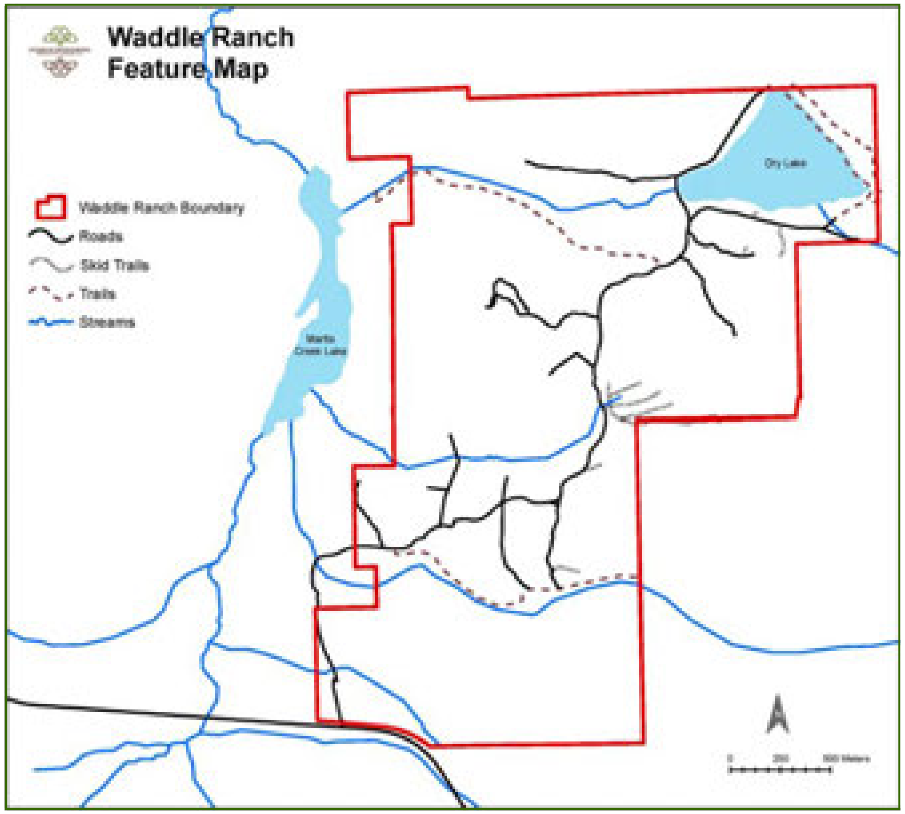


Figure 20. Road network and basic hydrological features mapped at the Waddle Ranch Property, Truckee CA.

Tool 2.5 Road Erosion Risk Assessment Methodology

4 **Measure and record the length and average slope of each road segment.** In general, the longer and steeper a section of road, the higher its propensity to generate runoff and erosion.

a. **Slope** can be measured using a clinometer if road segment breaks are within sight of each other, or by taking elevation values at the top and bottom of a road segment and using the length of the segment to calculate percent rise.

b. **Length** can be measured on the base map, or in the field using a GPS device.

c. **Assign** a relative score of 1-3 for each SITE ATTRIBUTE using **Table 6.**

5 **Calculate an average EROSION RISK value for each road segment using the scores from steps 3 and 4.** These attributes (and additional attributes, if desired) can be weighted differently based on site-specific conditions, results of testing, available data, anecdotal observations, etc (See Table 8).

6 **Create a map and/or table** to display the EROSION RISK assessment results for the road network.

a. Individual road segments can be color-coded based on their relative erosion risk.

b. A table of road segments can be sorted by erosion risk to prioritize road maintenance and treatment efforts.

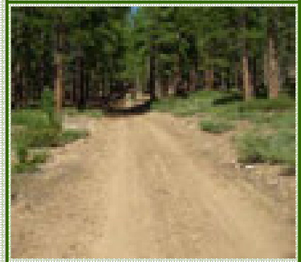
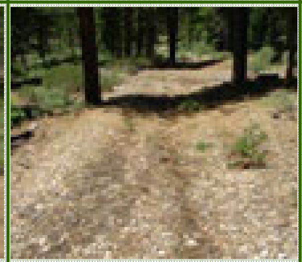
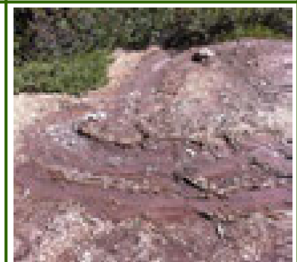
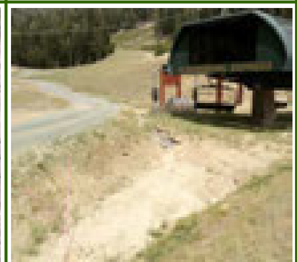
Table 7. Example criteria and rankings for SITE ATTRIBUTES. ***Note: slope ranges and road lengths should be adjusted to fit the range of features and conditions of the road network of interest.***

Attribute	Score = 1	Score = 2	Score = 3
Slope angle (%)	<20	20-40	>40
Length (ft)	0-100	100-1000	>1000

Table 8. Summary table combining assessment scores into an OVERALL EROSION RISK rating.

Site (Road Segment)	OBSERVED EROSION SCORE	SITE ATTRIBUTES SCORE	OVERALL EROSION RISK RATING
Segment 1	1	2	**1.5**
Segment 2	2.5	3	**2.75**
Segment 3	2	2.5	**2.25**

Table 9. Example field assessment criteria and rankings for OBSERVED EROSION. ***Note: attribute definitions for each score should be considered examples and be adjusted to fit the range of features and conditions in the watershed of interest.***

Attribute	Definition	Score = 1	Score = 2	Score = 3
Erosion	Observed rills, gullies or deposition along the length of the road section—either on the road or along its edge	Low erosion (little to no observed erosion)	Moderate erosion (e.g. small rills)	High erosion (e.g. large gully down center of road)
				
Deposition	Deposited sediment and/or forest litter at the flow break (or just off road)	Minor deposition (e.g. thin layer of sediment)	Moderate deposition (e.g. sediment covers mulch)	Heavy deposition (e.g. difficult to clean up)
				
Gullying	Gullying or evidence of concentrated flow beyond flow break. Check for connectivity to drainage ways	Minor gullying: extends 1-5 ft beyond flow break	Moderate gullying: extends 5-10 ft beyond flow break	Major gullying: extends 10+ ft beyond flow break
				

Tool 2.5 Road Erosion Risk Assessment Methodology

GIS-based Method (best for large road networks or watershed-scale assessments)

1 **Gather base data and create a base map.** Create a base map that shows the road network of interest and other features such as streams and key landforms. Using a base map that shows topographic relief (such as a USGS quad map) can be very helpful. Including elevation data in your GIS will also be helpful for later steps. See Tool 2.2 Characterizing your watershed for data sources.

2 **Locate flow breaks along roads.** Flow breaks include both natural grade changes where a road flattens out as well as structures installed to divert surface runoff—such as water bars or rolling dips. It is most accurate to identify flow breaks in the field using a GPS unit. However, preliminary slope-based flow breaks can be identified in the GIS prior to field work. Using a digital elevation model (DEM) a slope map can be created, and a GIS used to identify points where the road slope nears zero. In GIS, cut the roads into segments at each flow break and assign each road segment a unique ID. Additionally, some land managers have a GIS layer of waterbars, which can be used as flow break features in the GIS.

3 **Calculate the length and average slope of each road segment in GIS.** In general, the longer and steeper a section of road, the higher its propensity to generate runoff and erosion.

a. **Assign a relative score of 1-3 for each SITE ATTRIBUTE using table (Table 6).**

If field verification is not possible, skip to Step 5. However, GIS analysis is not an adequate replacement for field observations. Even limited (targeted) field verification of the GIS analysis results is likely to significantly improve the value and credibility of the assessment and the effectiveness of subsequent maintenance/treatment actions.

4 **In the field, observe and record actual erosion conditions for each road segment.** *Note: this portion of the assessment should be done as soon after rain or snowmelt as possible, as evidence of erosion can disappear quickly after even several days of dry weather.*

a. **Erosion** (of the road surface above the flow break)

b. **Deposition** (at the flow break)

c. **Gullying** (of runoff from the road at the flow break)

d. **Assign a relative score of 1-3 for each erosion attribute using the key in Table 6.**

Calculate an average **OBSERVED EROSION** value for each segment using the assigned scores. These attributes (and additional attributes, if desired) can be weighted differently based on site-specific conditions, results of testing, available data, anecdotal observations, etc. For instance, if a road segment is located near a stream channel, gullying might be weighted more heavily than other attributes if road runoff is more likely to be delivered to the stream. See Tool 2.4 Water flow/connectivity assessment for more information.

GIS-BASED METHOD

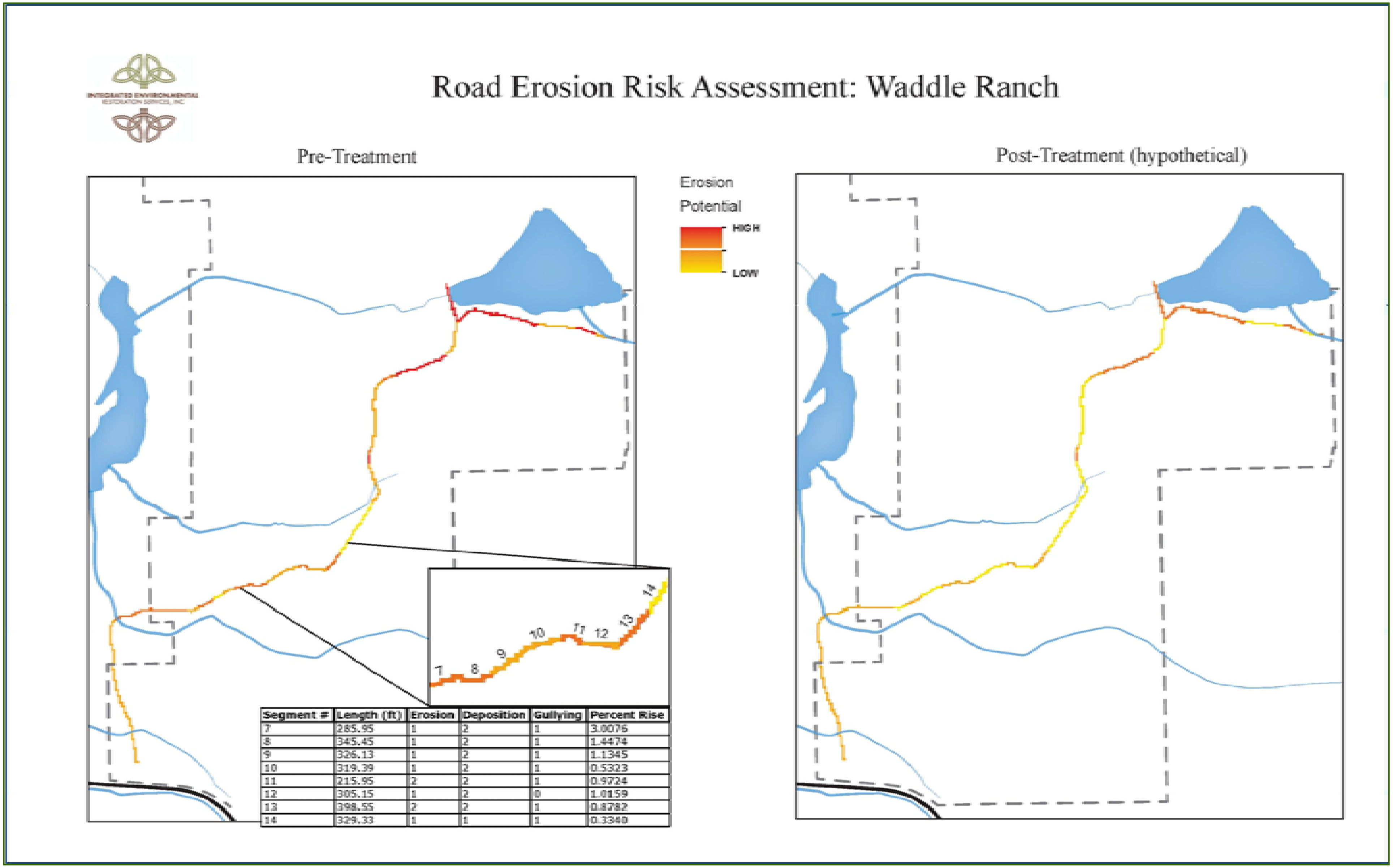
5 **Calculate an average EROSION RISK value for each road segment using the scores from Steps 3 and 4 (if applicable).** These attributes (and additional attributes, if desired) can be weighted differently based on site-specific conditions, results of testing, available data, anecdotal observations, etc.

6 **Create a map and/or table to display the EROSION RISK assessment results for the road network.**

a. Individual road segments can be displayed using a color ramp based on their relative erosion risk.

b. A table of road segments can be sorted by erosion risk to prioritize road maintenance and treatment efforts.

Tool 2.5 Road Erosion Risk Assessment Methodology



Segment #	Length (ft)	Erosion	Deposition	Gullying	Percent Rise
7	285.95	1	2	1	3.0076
8	345.45	1	2	1	1.4474
9	326.13	1	2	1	1.1345
10	319.39	1	2	1	0.5323
11	215.95	2	2	1	0.9724
12	305.15	1	2	0	1.0159
13	398.55	2	2	1	0.8782
14	329.33	1	1	1	0.3340

Figure 21. Road risk assessment output example from Waddle Ranch Watershed Assessment in Truckee, CA.

TOOL 2.6 TARGETED WATER QUALITY MONITORING

DEFINITION

Water quality is a term used to describe the physical and/or chemical characteristics of water. It follows that *water quality monitoring* is the process or activity of sampling and quantifying specific water quality parameters of interest. The term **water quality monitoring**, like other types of monitoring, takes many different forms and has multiple definitions (see Tool 4.1 – Developing a Monitoring Plan). For the purposes of this Guidebook, the term **load detection monitoring** is defined as the activities required to characterize event, daily, seasonal and annual changes in stream sediment loads.

PURPOSE

This tool is intended to provide useful guidance on using water quality monitoring to measure watershed-scale sediment loading and detect changes in sediment loading over time in order to support watershed management decisions and actions.

OVERVIEW

Streams and rivers integrate the conditions, functions and processes of entire watersheds or catchment areas. Water quality monitoring has been used for decades in an attempt to understand the effects of changes in land management. However, clear linkages between upland erosion control efforts and changes in stream water quality are elusive. These efforts are constrained by the inherent complexity and heterogeneity of watersheds and the need for long-term water quality monitoring datasets to distinguish natural variability from the effects of on-the-ground actions. This tool lays out an innovative sampling and analysis methodology that can be used in snowmelt-driven watersheds to **calculate defensible sediment loads and evaluate the watershed-scale sediment loading effects of on-the-ground management actions in a period of 3-5 years**.

Using a multi-parameter data logger to upload 15-minute turbidity data from a turbidity sensor.

TOOLKIT

Tool 2.6 Targeted Water Quality Monitoring

Beyond Compliance

Water quality monitoring is often required as part of proposed construction projects, implementation of Waste Discharge Permits and some restoration projects. The data is used to determine if these projects meet regulatory standards or to determine changes in water quality following activities such as construction or restoration. Most compliance-oriented water quality monitoring relies on routine weekly sampling, regardless of season or extreme weather events and associated changes in runoff and stream flow. In a commonly used approach, weekly collected stream water quality data is averaged over a month. That averaged monthly value is then used to determine an average annual concentration. This approach to water quality monitoring is often referred to as the 'mean of monthly means,' or MoMM, which is used for sediment and other pollutants, and helps determine compliance with water quality standards. MoMM-type sampling can be effective with point sources of pollution, such as wastewater treatment plant effluent streams that tend to be relatively consistent, but it may not be adequate for assessing about how watershed functions and conditions are impacted by management or development actions.

Mountainous watersheds, such as those in the Sierra Nevada, contain highly dynamic stream systems, where in-stream water quality is often defined by distributed, non-point sources of runoff. Therefore, pollutant loads can be highly variable throughout the season. The MoMM approach does not tend to accurately capture rapidly changing stream and pollutant conditions. Further, since stream flows and pollutant loads vary greatly with season and storm cycles, the MoMM process may not provide accurate information about how management actions might alter these patterns.

In contrast, when the same number of samples are targeted around periods of high stream flow (e.g. peak spring snowmelt, isolated rain events) when sediment and nutrient concentrations tend to be highest, the resulting data can be used to accurately compute sediment and nutrient loading. Further, targeting samples on the rising limbs of daily diurnals during peak flow periods and events improves the "signal" in often "noisy" water quality data. From this approach, sediment-discharge rating curves can be produced and used to reliably predict sediment and nutrient loads as a function of flow rate.


Stream flow and turbidity monitoring gauge installed in Homewood Creek.

Routine Sampling Approach

Routine sampling approaches (shown in top hydrograph) may miss spikes in stream flow and sediment concentration, limiting its usefulness for assessing daily and annual sediment loads.

Targeted Sampling Approach

By clustering samples around peak flow periods (shown in bottom hydrograph) and, most importantly, on the rising limb of daily diurnals during peak snowmelt and rain storms, sediment-discharge rating curves can be produced and used to reliably predict sediment and nutrient loads as a function of flow rate.

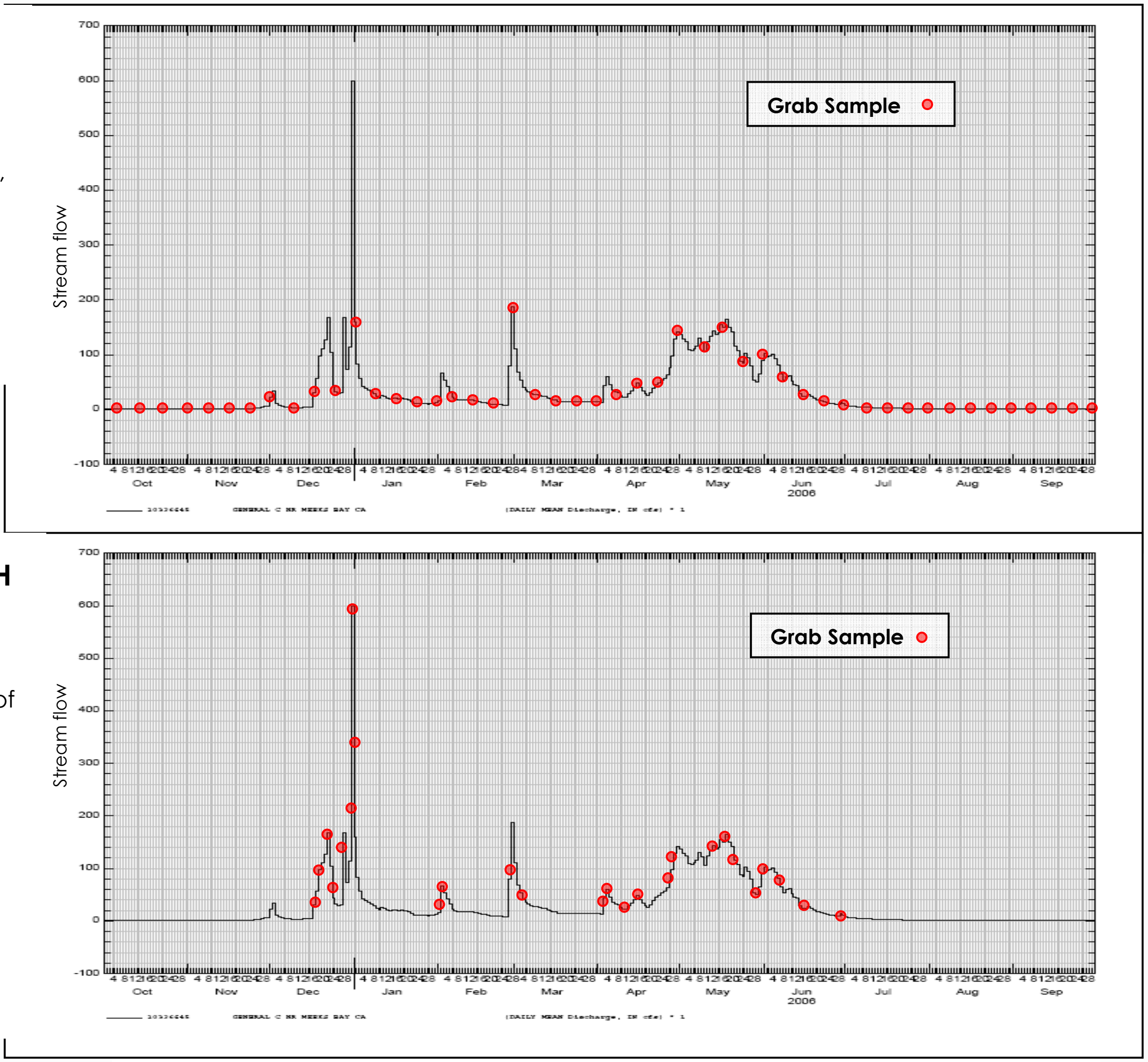


Figure 22. Example hydrographs illustrating routine (weekly) and targeted sampling approaches.

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TOOL 2.6 TARGETED WATER QUALITY MONTIORING

MONITORING FOR POLLUTANT LOAD DETECTION

Typically, pollutant loads are calculated from point-in-time pollutant concentrations from grab samples and associated flow rates at the time of sampling, then extrapolated across the time period of interest (e.g. hourly, daily). Even when near-continuous flow data is available, pollutant concentration data is sparse across the full range of the daily and seasonal hydrograph. Thus, hourly or daily loads are then based on estimated concentrations, or loads determined from averaging, ratio estimators, or statistical regressions such as rating or load-flow curves as discussed above. Significant errors can be introduced when grab samples are collected on a routine basis (e.g. weekly sampling on Monday mornings at 9am) and pollutants vary widely during the course of a day. Further, in snowmelt-driven watersheds, where >90% of the total flows and pollutant loads occur in a 4-month period, sampling during low-flow conditions provides little to no useful information for detecting changes in sediment loading.

The methodology offered in this tool is based on a targeted TMDL implementation pilot project conducted in the Homewood Creek watershed on the west shore of Lake Tahoe. This project was used to test the hypothesis that ***flow and sediment sampling targeted during the rising limbs of the daily hydrographs during the rising limb of the seasonal (spring snowmelt) hydrograph provides the nearest approximation of actual daily sediment loading from Tahoe west shore watersheds***.

Daily hydrograph rising limb sediment (TSS) yields (kg/ha) as they depend on rising limb average flow rate during the rising limb seasonal hydrograph were determined in an effort to reduce uncertainty in load-flow relationships associated with the known daily and seasonal hysteresis in TSS concentration-discharge relationships (Stubblefield et al., 2007). This approach relies on calculation of the sediment load during the afternoon periods (sum of 15-min flow-concentration products for 4-8 hours) of each day during the snowmelt season until the average daily flow peaks for the season. Such an approach removes the greater load variability associated with the recession limb of the daily and seasonal snowmelt hydrographs. See Figure 23 for graphical representation of this targeted, "rising limb"-based monitoring and analysis method.

LOAD DETECTION MONITORING METHODOLOGY

STEP-BY-STEP

1. **Install continuous stream stage monitoring equipment**, such as a pressure transducer. Develop stage-discharge rating curve during year 1 by taking discharge and stream cross-section measurements at about 10 different flow depths, particularly during spring runoff.
2. **Install continuous turbidity sensor** to enable calculation of a total suspended sediment (TSS)-turbidity rating curve.
3. **Determine timing of peak daily and seasonal flows** in order to target grab sampling. This can be done in the first season of through comparison of the new watershed area of interest to that of those already measured. Grab sampling and flow measurements between noon and 8pm during the spring snowmelt period should provide a starting point. Watersheds smaller than roughly 600 acres tend towards earlier day peak flows as compared to those greater in area than about 2,000 acres.
4. **Conduct targeted grab sampling** at different times/flow rates along the rising limb of the daily and seasonal hydrograph until the average daily flow peaks for the season. Recommend minimum of 15-20 samples during snowmelt period.
5. **Calculate the daily rising limb sediment load** by summing the 15-minute discharge-sediment concentration products for the daily rising limb period (approx. 4-8 hours, typically during the afternoon for smaller Alpine watersheds).
6. **Calculate annual rising limb sediment load** by summing the daily rising limb sediment loads for each day during the snowmelt season until average daily flow peaks.
7. **Repeat above steps for 3-4 water years**.
8. **Plot rising limb sediment-discharge relationship** to compare annual changes in sediment loading per unit discharge.

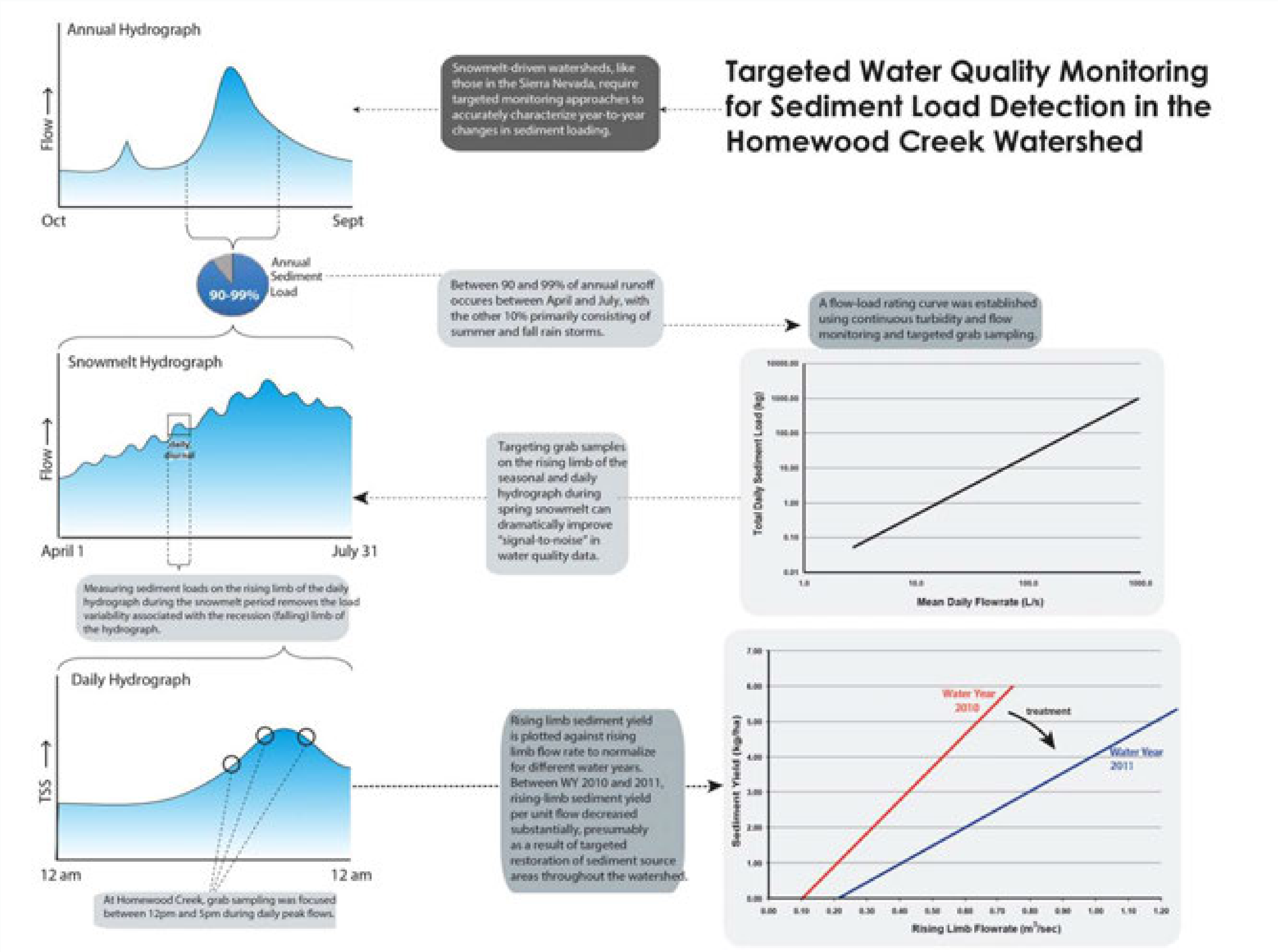

Figure 23. Targeted Water Quality Monitoring for Sediment Load Detection.

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Tool 2.6 Targeted Water Quality Montioring

Basic Requirements for Load Detection Monitoring

- Measurement of continuous (15-minute) stage and turbidity
- Discharge measurements to establish stage-discharge rating curve
- Minimum of 15 grab samples for TSS at various flow rates along the rising limb of the daily and seasonal hydrograph

Equipment Required

- **Pressure transducer**
- **Turbidity sensor**
- **Discharge measurement equipment widely known as pygmy or flow meters or simply streamflow meters**
- **Laptop or PDA for uploading data**

Relevant Publications

For additional technical information on how this methodology has been developed and applied, refer to the following publications:

- Grismer, M.E. 2012. Detecting Soil Disturbance/Restoration effects on Stream Sediment Loading in the Tahoe Basin – Modeling Predictions. Hydrological Processes. In-press.
- Grismer, M.E. 2012. Stream Sediment and Nutrient Loads in the Tahoe Basin – Estimated versus Monitored Loads for TMDL "Crediting". Environmental Monitoring & Assessment. Submitted.
- Grismer, M.E. 2012. Soil Disturbance/Restoration effects on Stream Sediment Loading in the Tahoe Basin – Detection Monitoring. Environmental Monitoring & Assessment. Submitted.
- Stubblefield, A.P., J.E. Reuter, R.A. Dahlgren and C.R. Goldman. 2007. Use of turbidometry to characterize suspended sediment and phosphorus fluxes in the Lake Tahoe basin, California, USA. *Hydrological Processes* 21: 281–291.
- Stubblefield, A. P., 2002. Spatial and Temporal Dynamics of Watershed Sediment Delivery, Lake Tahoe, California. PhD Dissertation. University of California at Davis, Davis, CA.

Useful Resources for Developing Water Quality Monitoring Plans

- EPA WQ Monitoring How-to Guide prepared by the Chehalis River Council: http://www.crcwater.org/Archive/public/wqmanual.html
- USGS National Field Manual for the Collection of Water-Quality Data: http://water.usgs.gov/owq/FieldManual/
- USGS Guidelines and Standard Procedures for Continuous Water-Quality Monitors: Station Operation, Record Computation, and Data Reporting: http://pubs.usgs.gov/tm/2006/tm1D3/
- U.S. Geological Survey, Water Supply Paper 2175 - Measurement and Computation of Streamflow: http://pubs.usgs.gov/wsp/wsp2175/
- EPA Monitoring and Assessing Water Quality - Volunteer Monitoring: http://water.epa.gov/type/rsl/monitoring/index.cfm

Suppliers of Water Quality Monitoring Equipment

- YSI - www.ysi.com
- Design Analysis - http://www.waterlog.com/
- Hach - www.hach.com
- Campbell Scientific - http://www.campbellsci.com/
- Stevens - http://www.stevenswater.com/

Tool 2.7 Erosion Modeling

Definition

Models are mental, visual, or mathematical representations of systems. For the purposes of this tool, the term "erosion model" refers to mathematical models used to predict erosion and sediment transport. Erosion models require the user to input a series of physical variables describing the area of interest and the model utilizes a mathematical equation (or series of equations) to predict the amount of erosion expected to occur.

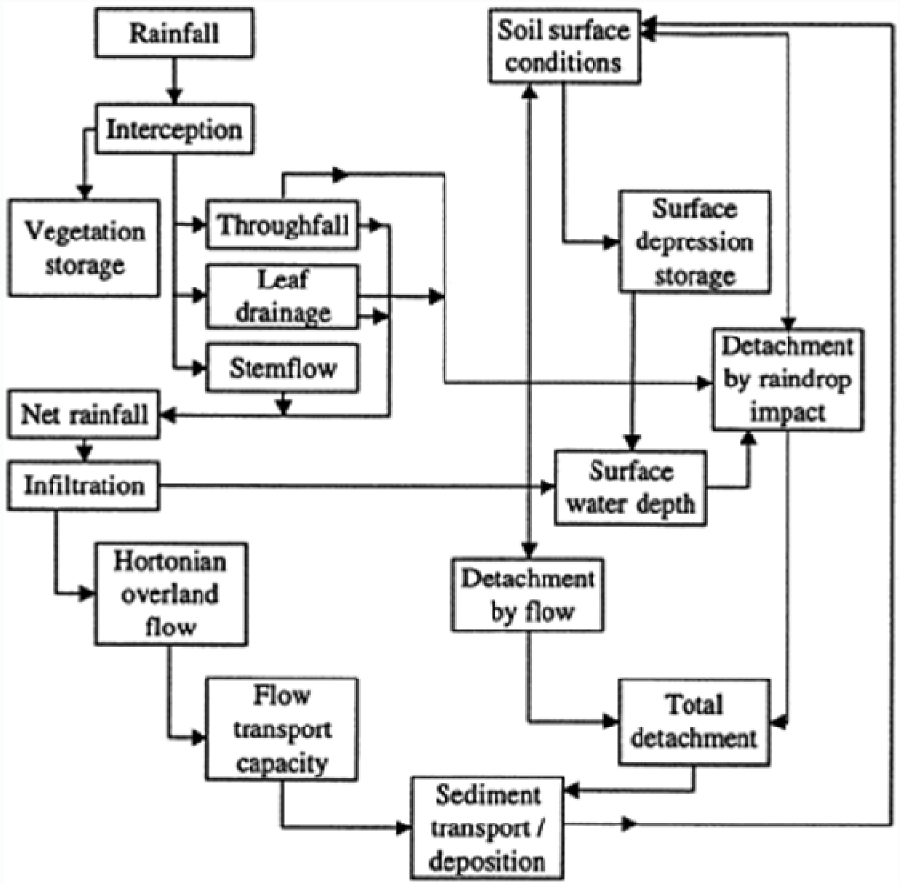
Purpose

The purpose of this tool is to equip the user with enough information to decide if erosion modeling would add value to their project or program and, if so, to understand the opportunities and limitations of using erosion modeling to improve the effectiveness of watershed management and restoration efforts.

Context: Modeling, Assessment & Outcome-Based Management

Models provide hypotheses about outcomes and as such, can be useful planning tools. Models alone cannot assure or predict achievement of actual outcomes. Direct assessment can be used to measure and understand actual outcomes. Addressing and managing actual outcomes is the theme of this Guidebook.

Modeling offers a quantitative predictive approach that has been applied for many years to environmental projects. This approach is attractive because the output is clear and quantitative, which can create an illusion of certainty or even accuracy. In fact, watershed and erosion model predictions can differ substantially from measured outcomes (Grismer 2012c ; Tiwari 2000). In order for a prediction to be accurate, the processes being modeled must be completely understood. All variables of any importance and feedbacks must be accounted for if the model is to have any usefulness (Pilkey and Pilkey-Jarvis 2007). Since we obviously do not understand all ecosystem variables or their interactions and feedbacks, interpretation of model predictions as actual outcomes can be misleading at best and costly at worst. Perhaps the greatest



Example of conceptual map of erosion processes common to many erosion models.

limitation of the predictive, model-based approach is that "front end" predictions are seldom checked against actual outcomes on the "back end" of the project, which could support both model improvements and, most importantly, on-the-ground adjustments to ensure that project goals are actually achieved.

TOOLKIT

TOOL 2.7 EROSION MODELING

An alternative and complementary approach to assuring that project goals are achieved is termed Adaptive Management or, for the purposes of this Guidebook, Outcome-Based Management. In this approach, clear goals are set and project plans are developed based on a first-hand, relatively complete understanding of field conditions and site variables. Any modeling predictions made at this point are treated as hypotheses for comparison with post-project assessment results. Adjustments to plans are sometimes made as new field information is gained during implementation. Actual project outcomes are assessed to determine if project goals were achieved. What distinguishes outcome-based management from the predictive approach is that it is focused directly on the physical reality of the project, not on hoped-for predictions. **Outcome-based management is not intended to replace modeling. Rather, it is designed to offer a process for distinguishing assumptions, honoring predictions as useful hypotheses, and delivering on the promises of more predictive approaches.**

TYPES OF EROSION MODELS

Erosion models can generally be classified as either process-based models or empirically based models.

Process-based (physically based) models mathematically describe erosion processes such as detachment, transport, and deposition. Equations describing those processes provide estimates of soil loss and sediment yields from specified land surface areas. All process-based models still include some empirical elements, since our understanding of erosion processes is not (and never will be) complete.

Empirical models relate management and environmental factors directly to soil loss and/or sediment yields through statistical relationships. Most current erosion modeling research is focused on developing process-based erosion models. However, the most widely-used model for erosion assessment and conservation planning is still the empirically-based Universal Soil Loss Equation (USLE) and its direct offshoots, the Revised USLE (RUSLE) and Modified USLE (MUSLE).

APPROPRIATE USES AND APPLICATIONS

- Forming and communicating hypotheses about watershed and erosion processes
- Estimating the erosion impacts of proposed projects (e.g. cumulative watershed effects (CWE) analysis for forest fuels project or ski resort expansion)
- Estimating the erosion reductions associated with different restoration and mitigation measures
- Evaluating the erosion impacts associated with changes in land use (e.g. conversion of meadow to camp ground)
- Evaluating the relative erosion rates of different watershed areas

LIMITATIONS OF EROSION MODELS

- Quality of model output is dependent on quality of input data and understanding of types and magnitudes of relationships.
- Models can be "black boxes" with implied or less-than-obvious assumptions built in by the creators and users of the model about various erosion processes that may reduce confidence in output information.
- Mathematical or numerical models are based on equations developed to approximate the magnitude and rates of various physical processes. Typically such equations (e.g. Manning's equations for channel hydraulics or Darcy equation for soil-water transport) were developed at smaller (human) scale than that at which they are applied in watershed analyses.
- Models are often scaled, meaning that the data used is representative of processes on one scale but then applied to a completely different scale, both temporarily and spatially.
- General lack of directly-measured erosion rates for different land conditions and management actions limits model calibration opportunities.
- Data requirements for process-based models can be extensive, often

resulting in reliance on generalized data (such as regional soil surveys) or empirical relationships rather than site-specific measurements.

- Models and their results may appear authoritative and definitive and are often confused with actual measured results, since they can be presented as clear graphs and enable quantification of output variables of interest, which can be misleading and lead to actions that fail to address the root causes of erosion problems in the watershed.
- Most erosion models do not address routing of surface flows and rely on empirically estimated soil "erodibility" factors
- Many erosion models were developed on and for relatively bare agricultural soils. Few erosion models have been specifically developed in or for snowmelt-driven, forested watersheds.

Using Models Effectively

Models are powerful tools that can be used to improve watershed management within an overall outcome-based framework. Building and using models can help groups of people articulate and communicate core assumptions about the way we think watersheds and erosion processes work. When tempered with a healthy dose of humility, these assumptions can be translated into hypotheses that can and should be field tested. Modeling different management scenarios can reveal many questions that can be used as the foundation for field monitoring and observation.

Modeling can be used in conjunction with field assessment as a means of organizing data in a logical framework. In cases where the watershed or project area is too large for complete field assessment, simple GIS-based models can be used to identify potential problem areas in order to target subsequent field assessment (see Tool 2.3 Hot Spot Identification and Tool 2.5 Road Erosion Risk Assessment). This can lead to more efficient use of field time, and support defensible monitoring practices, which are necessary to measure the effectiveness of restoration efforts. Likewise, feedback from monitoring data can support modeling calibration and improvement.

Models are, in the end, a prioritization approach to understanding that which cannot be fully understood. We base assumptions on what we 'know' or have observed. Since what we 'know' is incomplete, and since the mathematical foundations of models cannot fully replicate complexity in natural systems, models cannot be expected to be highly accurate. Occam's razor, a principle that has been used as a "rule of thumb" to guide scientific inquiry since the mid-1800's, states that among competing hypotheses, the one that makes the fewest assumptions should be selected. In accordance with this principle, and given the complexity of watersheds, erosion processes and ecosystems in general, it may be better to use fewer variables, more conceptual models, and field verification in order to manage to outcomes.

Erosion Modeling Resources

- Grismer, M.E. 2007. Soil Restoration and Erosion Control: Quantitative Assessment and Direction. Invited to ASABE Transactions Soil & Water Centennial Collection. 50(5):1619-1626.
- Merritt, W. S., R. A. Letcher, and A. J. Jakeman. 2003. A review of erosion and sediment transport models. Environ. Modelling and Software 18(8-9): 761-799.
- Tiwari, A. K., L. M. Risse, and M. A. Nearing. 2000. Evaluation of WEPP and its comparison with USLE and RUSLE. Trans. ASAE 43(5): 1129-1135
- Grismer, M.E. 2012. Erosion Modeling for Land Management in the Tahoe Basin, USA: scaling from plots to small forest catchments. Hydrological Sciences J. 57(5):878-900.
- Grismer, M.E. 2012. Detecting Soil Disturbance/Restoration effects on Stream Sediment Loading in the Tahoe Basin – Modeling Predictions. Hydrological Processes. In-press.

"Both experts and laypeople mistake more confident predictions for more accurate ones. But overconfidence is often the reason for failure. If our appreciation of uncertainty improves, our predictions can get better too. This is the 'prediction paradox': The more humility we have about our ability to make predictions, the more successful we can be in planning for the future."

Nate Silver

TOOLKIT

Tool 2.7 Erosion Modeling

- Grismer, M.E. 2012. Stream Sediment and Nutrient Loads in the Tahoe Basin – Estimated versus Monitored Loads for TMDL "Crediting". Environmental Monitoring & Assessment. Submitted.
- Morgan R. P. C. and M. A. Nearing. 2010. Handbook of Erosion Modeling. John Wiley & Sons, Ltd, Chichester, UK.
- Pilkey O.H. and L. Pilkey-Jarvis. 2007. Useless Arithmetic: Why Environmental Scientists Can't Predict the Future. Published by Columbia University Press, New York, New York.

Comparison of Erosion Models

There are many erosion modeling tools in use today. Some are being actively updated and are the focus of long-term research efforts. The table below is intended to provide a general overview of some of the more widely-used or newly-developed erosion models but is in no way an endorsement of any particular modeling tool or approach.

Table 10. General comparison of different erosion modeling tools

Model	Platform/Type	Spatial Scale	Time Scale	Strengths	Weaknesses	Level of Effort	Linkage to Monitoring
WEPP	Distributed model, process-based, erodibility factors from USLE database	Hillslope (watershed scale possible using GeoWEPP)	Event-based or annual	Fine-grained - capable of estimating spatial and temporal distribution of erosion Simulates snowmelt	Data intensive and complex to run	Moderate-High	Direct link to field monitoring
RUSLE (USLE– type models)	Empirical, field geometry and soil survey info required	Hillslope	Annual	Minimal field measurement required	Does not account for deposition (can over predict erosion) Does not simulate snowmelt	Low	Requires long-term monitoring of natural erosion events to calibrate
RCAT	Empirical, rainfall simulation data based	Small hillslopes (<4m)	Event-based or annual	Developed based on extensive field measurement in Tahoe area	Requires some site-specific field measurements Tahoe-specific	Low-Moderate	Direct link to field monitoring
SWAT	Empirical, field geometry & soil survey info required	Hillslope	Event-based or annual	Minimal field measurement required	Does not account for deposition (can over predict erosion) Does not simulate snowmelt	Moderate	Rarely calibrated for erosion prediction
TR-55	Empirical, flow generation and routing only. Can add particle information.	Small watershed	Event	Minimal field measurement required	Does not simulate snowmelt	Low	Rarely calibrated for erosion prediction

Section 3: DOING

Doing is the most obvious element of a project. Many of us tire at long planning processes and want to jump right into implementation. A key question embedded in all watershed management and restoration projects is: "Does the work we DO have the intended impact?" In other words, is the **DOING** getting us closer to what we are **AIMING** for?

This section offers tools for addressing specific treatment elements such as what types of mulch to use, how to set success criteria for soil loosening or options for determining appropriate soil amendment additions. It also provides tools for developing a site-specific treatment plan aimed at rebuilding resilience in disturbed sites. Perhaps most importantly we offer tools for protecting treatment areas from further disturbance and documenting treatments so that we can learn from our projects and improve the cost-effectiveness of future projects.

Tools:

Tool 3.1 Treatment Planning

Definition

Treatment planning is the process of developing a site-specific treatment plan to achieve specific project outcomes.

Purpose

In the context of this Guidebook, the purpose of treatment planning is to develop a treatment approach that integrates multiple treatment elements. These elements are intended to achieve specific outcomes, which are tied to project goals. The intention of this tool is to provide a holistic approach to selecting and blending treatment tools to address site-specific *functional* deficiencies and rebuild *resilience* in degraded sites.

Overview

Restoration plans and specifications are often driven by how we want a site to "look" rather than how we want a site to "work." That is, we focus on form instead of function, and assume that carefully implementing the plan will result in the desired level of function or performance. But when the treatment planning process is focused more on getting the right parts in place (e.g. vegetation, finished slope angle) than on rebuilding functions and processes (e.g. infiltration, nutrient cycling), project outcomes often fall short of our expectations, particularly in the long-term. So how do we bridge the gap between the *plan* and the *outcome*?

1. Define goals, projected outcomes and success criteria in functional terms. *See Tool 1.2 Setting Goals and Objectives and Tool 1.3 Developing Success Criteria.*
2. Assess treatment sites to determine what functions have been degraded or lost. *See Tool 4.2 Site Condition Assessment.*
3. Develop an integrated treatment plan/design that uses treatment elements to restore degraded functions. ***You are here!*** *See Toolkit Section 3.0 (Doing)*
4. Train implementation personnel, implement plan and document treatments. *See Tool 3.4 Documenting Treatments*
5. Measure project outcomes to determine if desired outcomes and success criteria were achieved. *See Toolkit Section 4.0 (Achieving)*
6. Make adjustments to treatments if necessary (if defined outcomes haven't been met) in order to achieve success criteria. *See Tool 4.13. Management Response*

Form and Function: Bridging the Gap

The graphic below depicts the issues that must be addressed to achieve functional outcomes. You must first start with defining the goal, and then follow the Integrated Treatment Plan until you are able to document treatments.

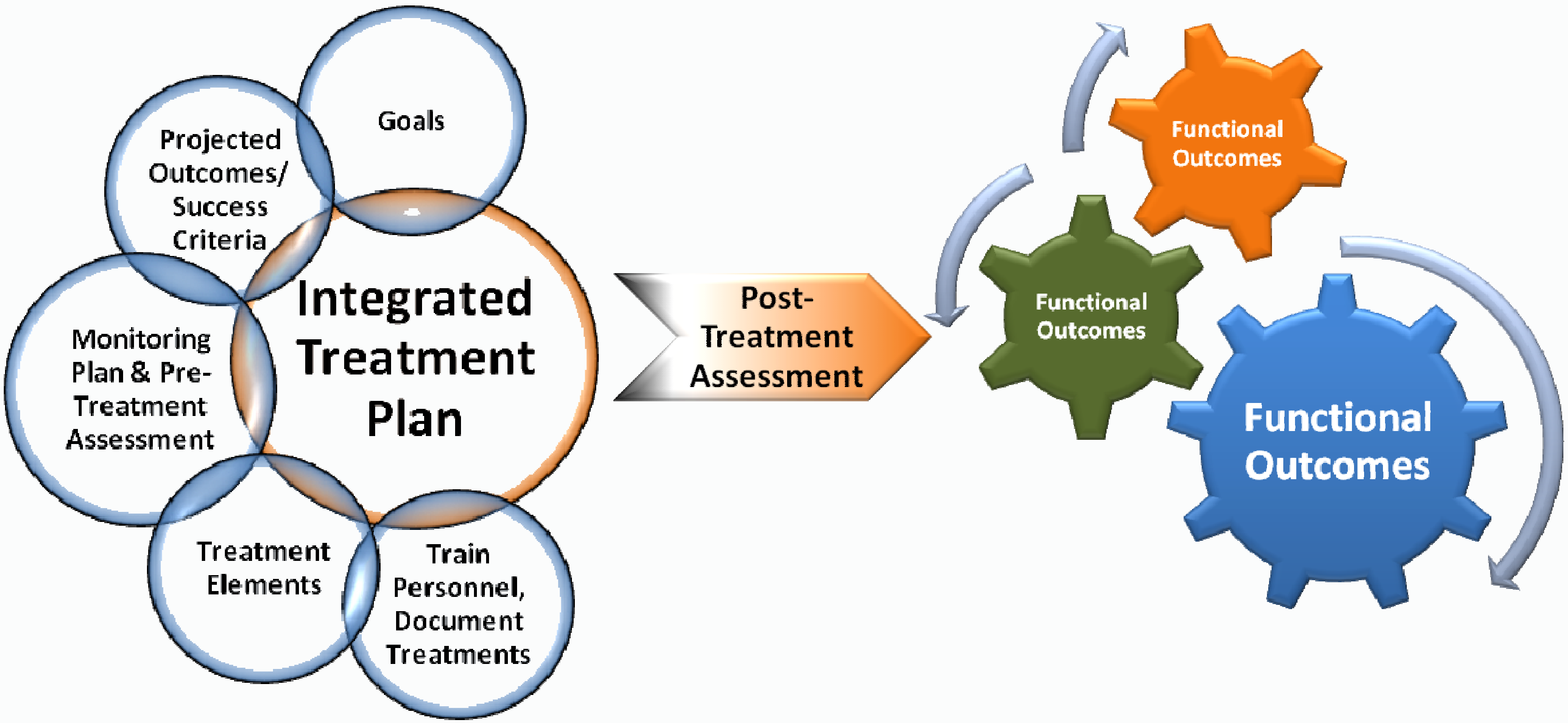


Figure 24. Bridging the gap between form and function.

Tool 3.1 Treatment Planning

Developing Integrated Treatment Plans to Rebuild Function

So what ecological functions and processes should we focus on when developing an integrated treatment plan? We are suggesting that the broad goal for restoration treatments should be *resilience* (see callout box). A simple framework for defining resilience in functional terms is presented in Figure 25 (adapted from Cummings 2003). Cummings suggests that these three key functional classes are the foundation of healthy ecosystems and when they are disturbed, treatment is required to restore function and thus rebuild long-term resilience in degraded sites. This simple framework can be used to define project goals and success criteria, assess disturbed sites to determine what functions are damaged or missing, and develop integrated treatment approaches that result in self-sustaining, or *resilient*, project sites.

Restoration project areas – whether a whole watershed or a small site – are dynamic, interconnected systems. Every treatment action will affect more than one functional class. Use the alternatives matrix below as a starting point to determine which treatment actions will result in the functional improvements you are aiming for.

> **Resilience**
>
> *In ecology, resilience is the capacity of an ecosystem to respond to a perturbation or disturbance by resisting damage and re-covering quickly.*
>
> (Source: Wikipedia- Resilience)

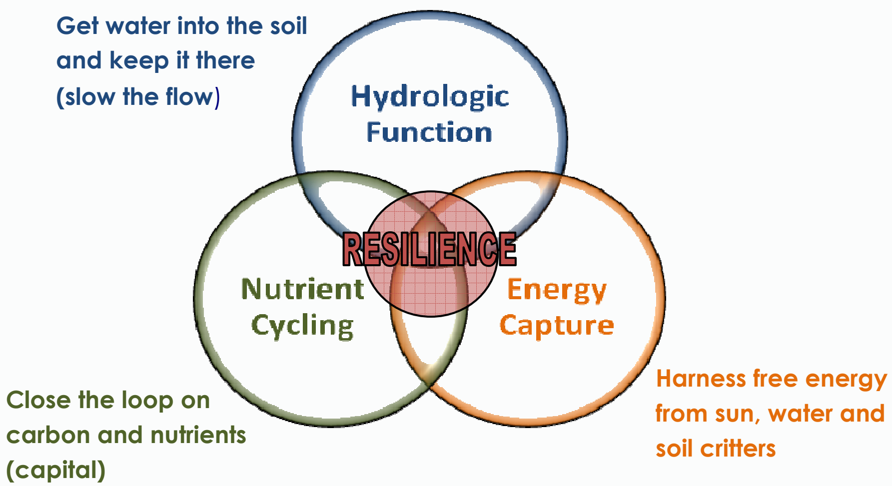


Figure 25. Integrating treatment plans to maximize resilience.

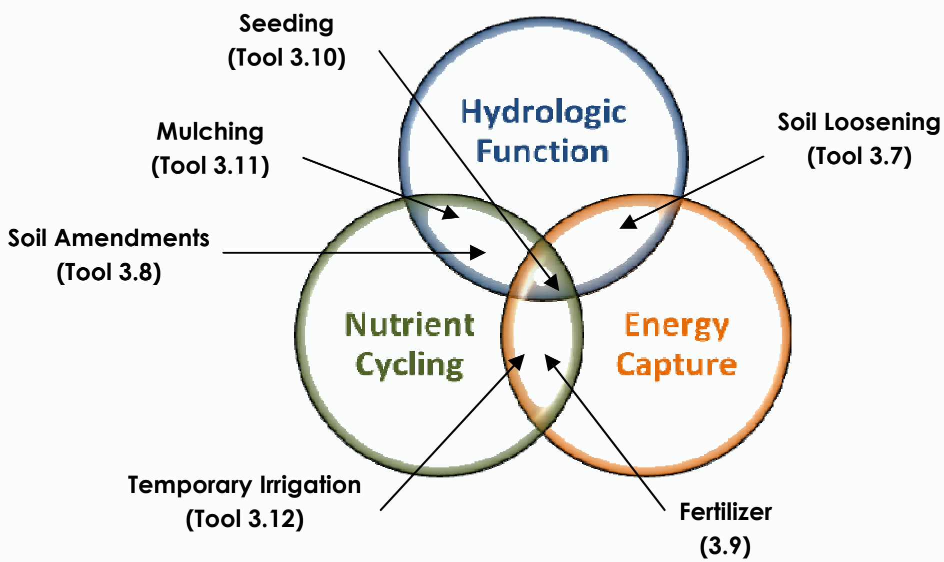


Figure 26. Linking treatment elements with functional impacts

Table 11. Linking treatment tools and functional impacts.

Treatment Tools	Functional Impacts	Hydrologic Function	Nutrient Cycling	Energy Capture	Depends on:
Soil Loosening (Tool 3.7)	**Increased infiltration and water storage** **Deeper plant roots, more drought-tolerant plants**	X		X	Having adequate soil organic matter to sustain loose soil over time
Soil Amendments (Tool 3.8)	**Increased infiltration and water storage** **Long-term source of C and N to support nutrient cycling** **Increased microbial activity (food for microbes)**	X	X	X	Linking appropriate types and amounts of amendments with site and soil conditions
Fertilizer (Tool 3.9)	**Expedites plant growth** **Immediate source of plant-available nutrients to support nutrient cycling**		X	X	Type, quantity and timing of fertilizer application
Seeding (Tool 3.10)	**Bootstraps nutrient cycling process** **Captures suns energy through photosynthesis** **Protects soil surface against erosion**	X	X	X	How well-adapted seeded species are to site Availability of water and nutrients
Mulching (Tool 3.11)	**Protects soil surface against erosion** **Provides long-term source of nutrients**	X	X		Mulch type and depth
Temporary Irrigation (Tool 3.12)	**Deeper plant roots, more drought-tolerant plants** **Expedites plant growth** **Increases decomposition of high-carbon amendments**		X	X	Using irrigation schedule that encourages deep root penetration

TOOLKIT

Tool 3.1 Treatment Planning

Integrated versus Reductionist Approach

The integrated treatment approaches supported by and advocated for in this Guidebook are a stark contrast to the more conventional, reductionist approaches to erosion control that have been developed and heavily promoted over the past 50 years. Most widely-used erosion control methods (such as hydroseeding and erosion control blankets) are based on addressing one or two components of the plant-soil system, such as vegetation or surface cover. These reductionist treatment approaches are largely an outgrowth of using mathematical models, such as the Universal Soil Loss Equation (USLE), to understand and address erosion one element at a time. In contrast, this Guidebook is based on the results of applied, field-based science aimed at understanding the whole system and measuring functional outcomes of various treatment approaches. The treatment tools in this Guidebook do not offer simple and prescriptive solutions, but rather present a range of integrated treatment alternatives and a process by which the user can determine which treatment approaches are likely offer the highest return on investment for their particular project.

Example: Form vs. Function

The graphic on the next page illustrates how two different erosion control treatment approaches at the same site led to very different outcomes.

Plan A (guess-based):

It is widely believed that vegetation alone controls erosion. Plan A was based on this assumption. In order to establish vegetation at this disturbed site, it was seeded with grass species not well-adapted to the project area, fertilized several times with a relatively fast-release nitrogen fertilizer, and irrigated every summer for 6 years. The outcome: ongoing runoff and erosion issues and struggling vegetation despite repeated treatments. This site is still functionally depleted. The small overlap between functions in the Venn diagram suggests very low resilience at this site.

Plan B (information-based):

After many years of Plan A not producing the desired outcomes, a more integrated treatment approach was used. Pre-treatment site assessment identified that all functional areas were heavily depleted due to topsoil removal, grading and compaction. A treatment approach was designed to rebuild resilience by restoring lost functions and "recapitalizing" the bankrupt soil-plant system. Soil tilling and incorporation of composted wood chips were used to improve infiltration and water storage (**hydrologic function**) and support deep plant root growth (**nutrient cycling** and **energy capture**). The combination of slow-release organic fertilizer and high-carbon composted wood chips provide food for soil microbes, which in turn provide nutrients for plants and keep the soil loose over time (**nutrient cycling** and **energy capture**). A site-appropriate seed mix reestablished native, deep-rooting perennial grasses and pine needle mulch provided surface protection (**hydrologic function**). This one-time treatment optimized each of the core functions (as suggested by the large overlap between functional elements), rebuilding resilient site conditions that resist erosion with no ongoing maintenance.

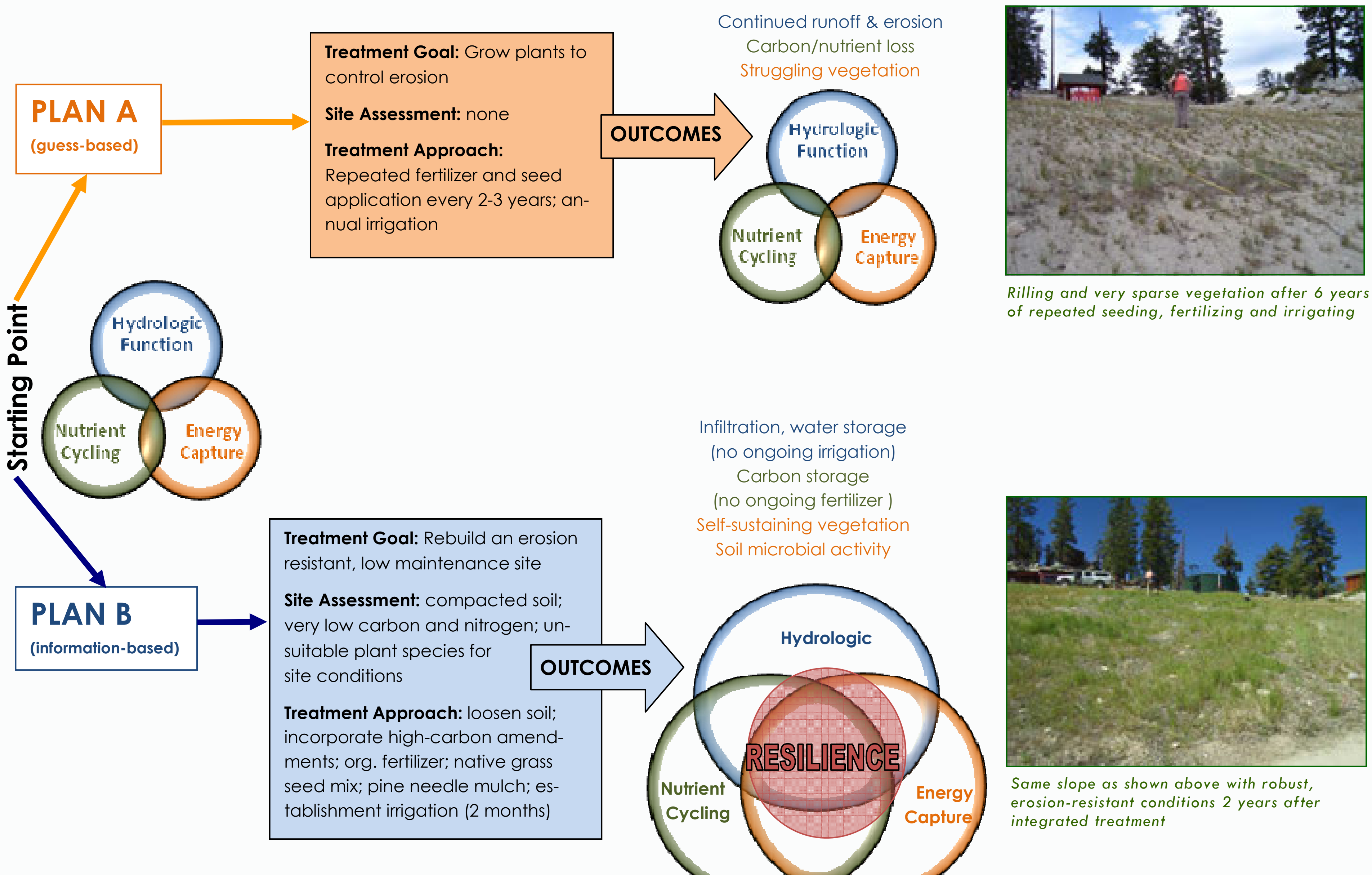


Figure 27. Form vs. Function of a poorly functioning eroding slope.

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.

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 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.

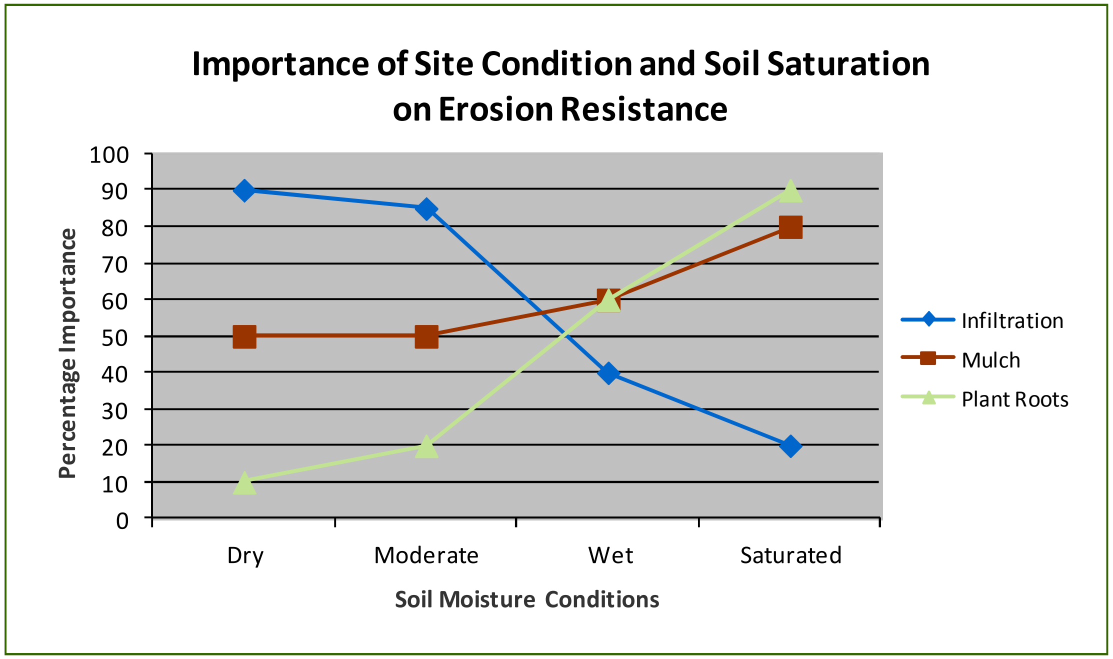


Figure 28. A graphical model of soil moisture levels: The influence of specific site conditions on erosion over a range of soil moisture conditions by approximate percentage of importance. For instance, when soil is dry, infiltration is the dominant process that minimizes erosion. However, when the soil 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.

A Conceptual Framework for Soil and Vegetation Treatments

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.

Tool 3.2 Test Plot Development

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 answer 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 a cost 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 cost effective treatment for the site
- 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

Fertilizer rate test plots at Heavenly

Road restoration test plots at Homewood

Tilling depth test plots at Northstar

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Tool 3.2 Test Plot Development

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 1.3 Developing 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. The more quantitative and repeatable the monitoring, the more defensible the results.

5. Conduct site condition assessment (pretreatment monitoring) at treatment area before construction of test plots (see Tool 4.2 Site Condition Assessment).

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. Photo taken one week after treatment.

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 3.5 Protecting Treatment Areas).

11. Complete as-built using information and data recorded during construction. An example as-built and template is provided in Tool 3.4 Documenting Treatments.

12. Conduct post-treatment monitoring during the following season (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.

Grow-out pots used to assess plant response to different soil treatments. The most effective treatments can then be tested at the project site or used to inform cost-effective full-scale implementation.

Improving Revegetation Success By Testing with Small "Grow-Out" Pots

Testing can take place on various scales. The intention of testing is to develop a cost-effective understanding of treatments or potential treatments prior to full-scale implementation. Testing can minimize the risks associated with application of treatments that are not yet proven or where previously successful treatments are intended to be used in new settings, soil types or terrain.

In cases where field test plots are not viable, such as where time or appropriate locations are limited, a very cost-effective method to test a range of treatments is through the use of grow-out pots. Grow-out pots can be built from many different materials and generally should be able to hold enough soil volume to allow at least 6 inches of root growth (12 inches is preferred). Actual soil can be obtained from the site, placed in the pots and mixed with specific soil amendments, fertilizers and seed mixes. Pots can be placed under inexpensive indoor grow lights to simulate summer light cycles. Various moisture regimes can be applied in order to test plant response to stress. Fertilizers or pollutants can be added to test plant response. Pots can also be used to test infiltration, water holding capacity, nutrient leaching rates, and pollutant adsorption (removal). Grow-out pots can be constructed during non-field months and field conditions can be recreated, thus developing information during a time period when field testing may be difficult or impossible.

Grow-out pots have been used successfully in research (**Hogan, 2003**) and in bench tests for Federal Highway Administration (Mt Hood, OR), private companies (CEMEX sand mine) and difficult highway sites (Mono Lake region).

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Case Study: Bonanza 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 Tahoe Basin. 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. 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 3.3 Project Grouping and Prioritization

Definition

Project Grouping and Prioritization is the process of grouping individual "hot spots" and other erosion problem areas into defined projects and creating a prioritization and phasing framework for implementation.

Purpose

The purpose of *Project Grouping and Prioritization* is to prioritize and implement watershed improvement efforts in an intentional and cost-efficient manner that maximizes watershed benefits and learning opportunities. This process integrates a range of operational, ecological and economic factors to create a custom tailored framework for implementation.

Value of a Phased Approach

Phasing implementation of watershed treatment efforts over several years can offer several key advantages over attempting to implement all projects in a single season.

Spread the Costs: First and perhaps most obvious, phasing projects over several years can lighten the financial burden by spreading capital expenditures out over different budget years.

Improve Effectiveness and Efficiency: Phasing projects over several years allows for testing of different treatment approaches, assessing results and incorporating effective and cost-efficient approaches as well as lessons learned into the next year's projects. This iterative process of learning and improvement is the foundation of outcome-based management.

Attractive to Funders: Creating a prioritized plan for watershed improvement based on a thorough understanding of the individual problems and interconnections within a watershed demonstrates to potential project funders that you are well-prepared to achieve real watershed improvements with their financial investment.

Linkage to EfRA

Project Grouping and Prioritizing is the last step in Erosion-focused Rapid Assessment (EfRA) process (see Tool 2.1 EfRA). It builds on the results of previous steps, such as identifying erosion hot spots (erosion problem areas) and understanding hydrologic connectivity and surface drainage patterns in the watershed of interest.

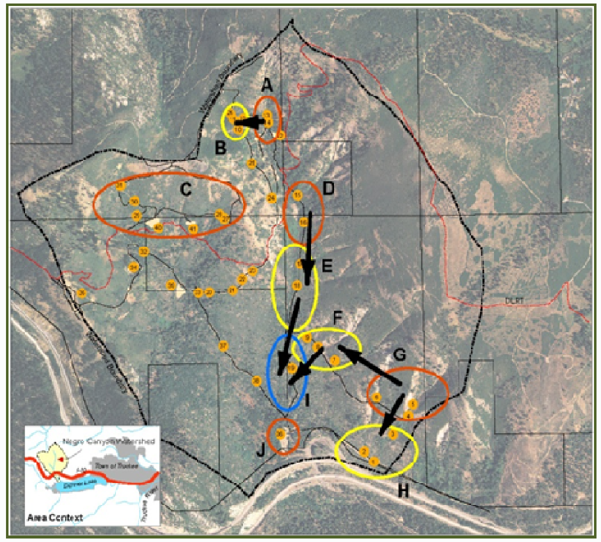

Figure 29. Project groupings and prioritization restoration plan for a watershed near Truckee, Ca.

Key Considerations for Defining and Phasing Projects

The first step in this tool is **grouping erosion hot spots into constructible projects**. This process of defining projects should take into account ecological considerations such as hydrologic connectivity to other hot spots and operational considerations such as proximity to other hot spots and grouping hot spots with similar problems and treatment approaches to maximize efficiency. The second step is **developing a prioritized and phased implementation plan**. The prioritization and phasing step should take into account ecological considerations such as sediment reduction potential and hydrologic connectivity between projects as well as operational considerations such as construction costs/budget and maintaining vehicle and equipment access where needed through proper sequencing. Each of these considerations is discussed in more detail below and summarized in Table 12.

Tool 3.3 Project Grouping and Prioritization

Ecological Considerations

Hydrologic Connectivity

Hydrologic Connectivity is a critical element in both grouping and prioritizing projects. Upslope/upstream problem areas should typically be treated before (or at the same time as) downslope/downstream projects that are hydrologically connected (e.g. by a drainage ditch along a road). This is to ensure that downslope projects can be completed without the risk of further disturbance/ input from upslope problem areas. This is especially true for riparian restoration projects, where addressing upslope erosion sources before or during riparian improvements should improve the chances of success for riparian projects. From a prioritization and phasing standpoint, problem areas that are known or likely to contribute surface runoff and erosion to streams or major drainage ways should be a higher priority for treatment than treating problem areas where erosion is less likely to reach a stream.

Same Catchment or Drainage Area

For most projects, grouping hot spots based on catchment or drainage area boundaries is a logical approach, especially where multiple hot spots are hydrologically connected. From a phasing standpoint, completing a series of restoration projects in single catchment or drainage area before moving on to the next one can provide a clear context for the people involved in the work and more obvious or immediate results in terms of watershed improvement.

Sediment Yield Potential

Sediment Yield Potential refers to how much sediment is likely to be eroded/eroding from the source/site itself. Sediment yield potential can be difficult to estimate in that it integrates many factors – infiltration capacity, surface cover, surface roughness, slope steepness, frequency/ intensity of ongoing disturbance, etc. However, using the direct assessment tools in this Guidebook (see Section 4.0 ACHIEVING), users can either directly measure sediment yield (using simulated rainfall or runoff) or develop a simple framework for ranking sites based on relative sediment yield potential (see Table 13for example).

Sediment Reduction Potential

Sediment Reduction Potential refers to how much sediment yield is likely to be reduced as a result of treatment. As described above in Sediment Yield Potential, this Guidebook provides tools to directly assess sediment yield and sediment reductions after treatment. The framework shown in Table 12 can be used as a starting point for estimating sediment reductions. However, we strongly encourage users to assess the outcomes of restoration efforts and compare those outcomes to predicted improvements.

Table 12. Key considerations for grouping and prioritizing watershed improvement projects.

Ecological Considerations	Project Definition Criteria	Project Phasing Criteria
Hydrologic connectivity (to other hot spots, projects or surface water)	X	X
Same catchment or drainage area	X	X
Sediment yield potential (estimated)		X
Sediment load reduction potential (estimated)		X
Operational and Economic Considerations	**Project Definition Criteria**	**Project Phasing Criteria**
Construction cost		X
Maintenance cost		X
Land ownership	X	X
Proximity (to other hot spots or projects)	X	X
Similar/same disturbance types and/or treatment approaches	X	X
Access requirements		X
Regulatory requirements and priorities		X

Operational and Economic Considerations

Construction Cost

Construction cost is an obvious and important factor to consider when prioritizing projects for implementation. Phasing implementation of treatment efforts over several years can not only spread capital expenditures out over different budget years but can allow for lessons learned in one year to be used to improve the efficiency and effectiveness of treatments in subsequent years. Alternatively, grouping multiple sites with similar treatments or several sites in close proximity may reduce mobilization costs and gain economies of scale on materials and other project expenses. Beyond construction costs, other costs that should be considered are planning, permitting and monitoring.

Maintenance Cost

Some watershed improvements will require periodic maintenance to function effectively over the long run. This is especially true for infiltration and conveyance features that collect runoff from unpaved roads such as drainage ditches and infiltration swales. Be sure to consider the frequency and resources required for monitoring and maintenance when phasing watershed improvements.

Land Ownership

Some watershed assessment and improvement plans include land owned and/or managed by multiple entities. Be sure to consider the implications of land ownership when defining and phasing projects, especially with regard to ongoing maintenance requirements.

Proximity

Physical proximity of hot spots and/or larger projects often allows construction to be completed much more cost-effectively than when they are spread out in different areas. This is a useful criterion for both grouping hot spots into projects, and for developing a phased implementation schedule.

Similar Disturbance Types and/or Treatment Approaches

Much like proximity, grouping individual sites or projects with similar impacts and/or treatment approaches can save time and money during implementation by creating economies of scale.

Access Requirements

Some projects will eliminate or modify road or trail access to other parts of a watershed. Short and long-term access requirements for different areas of the watershed, and how proposed projects will affect access, should be a key consideration in phasing projects.

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Table 13. Example ranking framework for estimating the relative sediment yield potential of different sites. Score of 1 is LOW. Score of 3 is HIGH. All scores should be linked to field assessment at each site.

Project Site or Hot Spot	Slope angle	Total surface cover	Vegetation cover	Soil density/ infiltration capacity	Soil organic matter	Active erosion	Ongoing disturbance	Sediment Yield Potential (avg)
Site A	2	1	1	3	3	3	1	2.0
Site B	1	1	2	1	2	1	3	1.6
Site C	3	3	2	1	1	3	3	2.3

Tool 3.3 Project Grouping and Prioritization

Regulatory Requirements and Priorities

Regulatory requirements and priorities will vary greatly from watershed to watershed but should be considered when prioritizing projects for implementation. Is the project in a 303(d)-listed watershed or identified in a TMDL? Is the project or maintenance activity required as an EIR mitigation measure or as part of a Waste Discharge Permit? Will the project support achievement of a specified beneficial use for a particular water body?

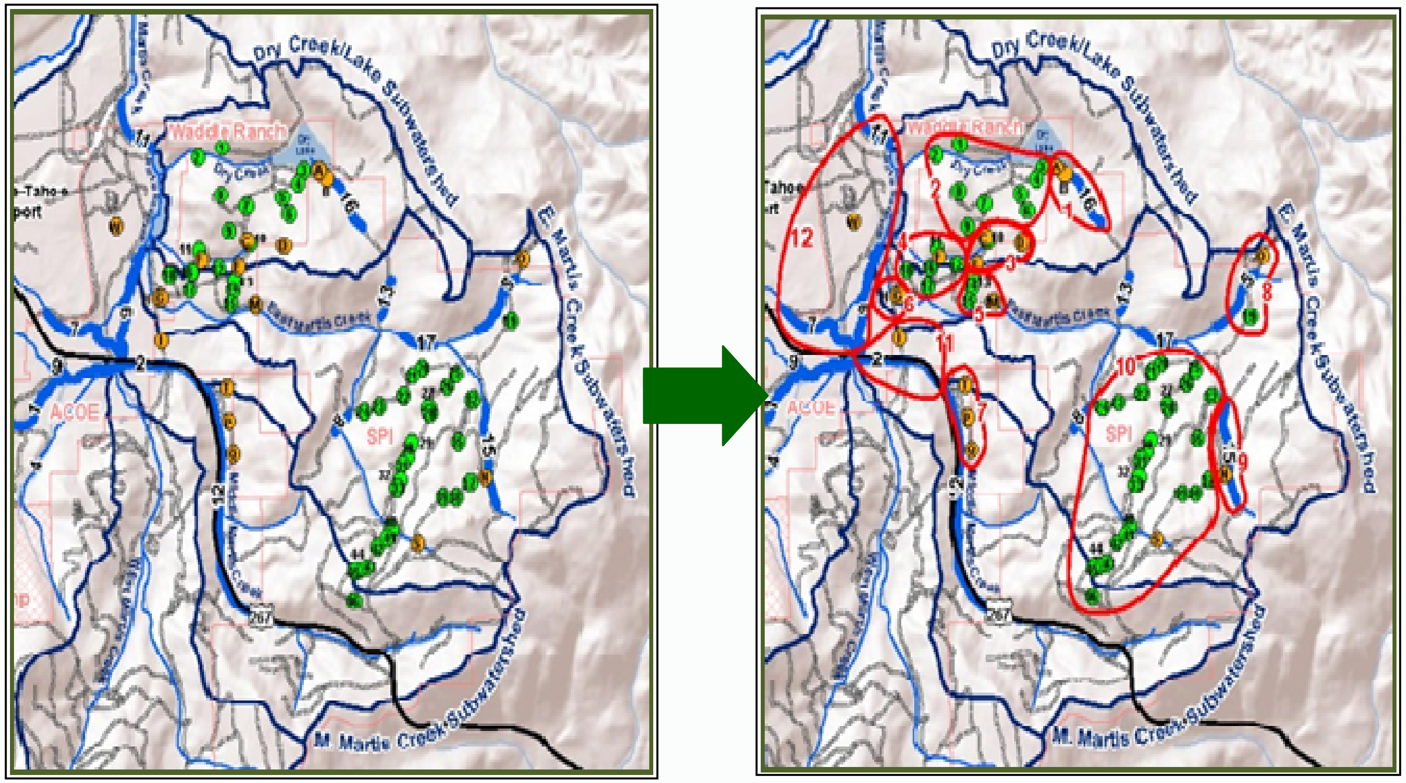


Figure 30. Example map showing hot spots grouped into projects following an erosion focused watershed assessment in the Martis Watershed. Truckee, CA.

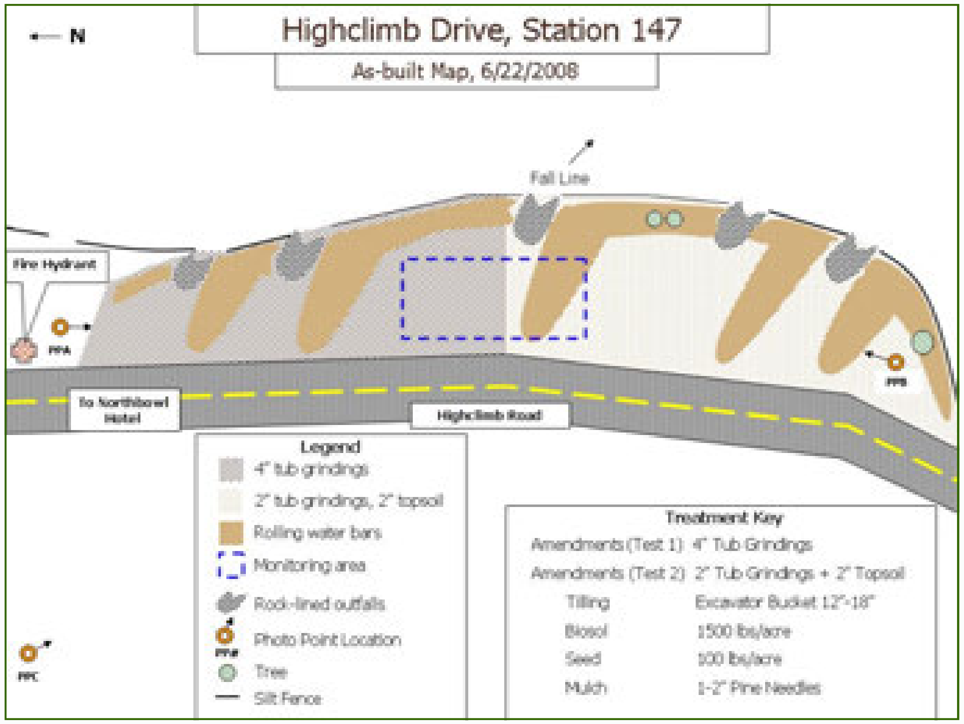
Partnership, Funding and Political Will

This tool offers suggestions and example frameworks for defining and prioritizing watershed projects to develop a phased implementation plan. Engaging in this process helps to build common language among partners and helps to clarify the intention of the watershed improvement effort. At the end of the day, the key factors that tend to determine the order in which projects get implemented are willingness of landowners to participate, availability of funding, and political priorities. We hope that this tool helps you develop an empowering framework in which to integrate the social, economic, ecological and political elements of watershed management.

Table 14. Example framework for prioritizing and phasing multiple projects. The evaluation criteria and rating metrics should be customized to reflect the priorities and interests of the partners involved in the watershed improvement effort.

	Ecological Considerations				Operational and Economic Considerations						
	Hydrologic connectivity (to surface water)	Same catchment or drainage area	Sediment yield potential (estimated)	Sediment load reduction potential (estimated)	Construction cost	Maintenance cost	Land ownership	Proximity (to other projects)	Similar disturbance types and/or treatment approaches	Access constraints	Regulatory requirements and priorities
Project 1	High	Yes	High	High	$$$$	none	Land Trust	Med	slope stabilization	none	303(d) listed watershed
Project 2	Med	Yes	Med	High	$$	$	Land Trust	Low	road and landing decom	maintain access to projects 3/4	required mitigation measure in EIR
Project 3	Low	Yes	High	Med	$$$	$$	Land Trust and Private	Low	road and landing decom	none	none
Project 4	Med	No	High	Med	$$$$	$	Forest Service	High	road-stream crossing; road decom	none	303(d) listed watershed
Project 5	High	Yes	Med	Low	$$$	$$$	Forest Service and Private	High	road-stream crossing; road decom	maintain access for future trail const.	none

Tool 3.4 Documenting Treatments



Example as-built map for restoration project.

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 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 and what they hope to achieve through documentation

2. Develop a standard as-built format/ template

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

7. Begin project implementation

8. Document treatments at appropriate intervals 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.

Tool 3.4 Documenting Treatments

As-Built Template

Project Name (ID)	
Location Description	
Project Foreman	
Project Staff	
Start Date	
Completion Date	
Treatment Area (ft2)	
Soil Loosening Method	
Soil Loosening Depth (in)	
Soil Amendment Type(s) & Source(s)	
Soil Amendment Depth (in)	
Fertilizer Type and Source	
Fertilizer Rate (lbs/acre)	
Seed Mix Name & Source	
Seed Rate (lbs/acre)	
Mulch Type and Source	
Mulch Depth (in)	
Mulch Surface Coverage (%)	
Irrigation Dates, Duration, & Frequency	
Irrigation Wetting Depth (in)	

As-Built Map

As-Built Map Checklist

- North Arrow
- Legend
- Project Name
- Treatment & 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.

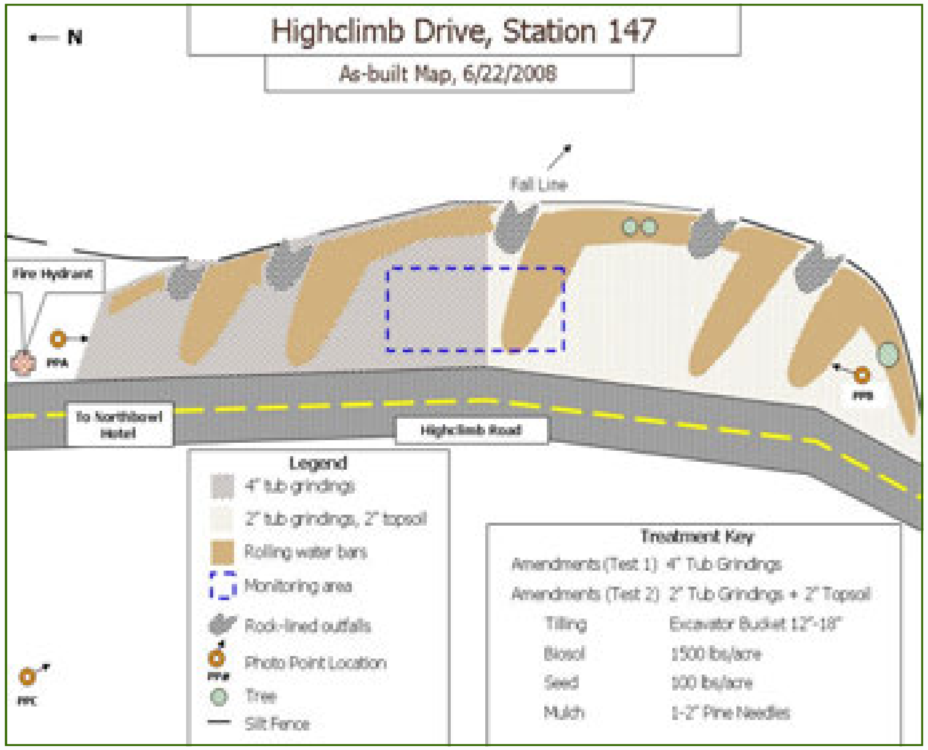
Include before and after Photo Points on another sheet (see page 126 For an example).

Tool 3.4 Documenting Treatments

As-Built Template EXAMPLE

Project Name (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 High way 267
Project Foreman	Lorenzo Muclhman
Project Staff	Dave Wattle, Jeremy Lovestoseed
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) & Source(s)	Topsoil (salvaged from Northbowl Hotel Construction site) & Tub grindings (On site)
Soil Amendment Depth (in)	Top soil- 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 & Source	upland grass shrub seed mix- Comstock seed (photo copy of seed tag attached)
Seed Rate (lbs/acre)	100 lb/acre
Mulch Type and Source	Pine needles, Incline Village GID
Mulch Depth (in)	1-2"
Mulch Surface Coverage (%)	98% coverage
Irrigation Dates, Duration, & Frequency	6/22/08—4 hrs, 6/30/08—6 hrs, 7/3/08—6hrs, 7/10/09—4hrs
Irrigation Wetting Depth (in)	8", 12", 10", 9"

As-Built Map



As-Built Map Checklist

- North Arrow
- Legend
- Project Name
- Treatment & 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 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 long 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 hand spreading of seed and raking. The entire treatment area 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.

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Tool 3.4 Documenting Treatments

Photo Points

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

Photo Point B (PPA) - 6/1/08, before treatment

Photo Point C (PPA) - 6/1/08, before treatment

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

Photo Point B (PPA) - 8/29/08, after treatment

Photo Point C (PPA) - 8/29/08, after treatment

Lessons from the field

"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 the 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.

-Michael Hogan, Soil Scientist, Restoration Specialist

Tool 3.5 Protecting Treatment Areas

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.

Overview

There are many methods that can be employed to protect treatment areas from disturbance (see Table 15, 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 re-compact soil that has recently been loosened, rendering the treatment ineffective, or at least less effective.

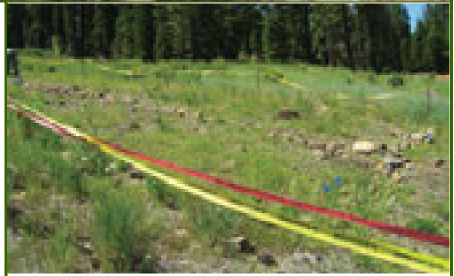
Treatment areas must also be protected from concentrated surface water that may flow onto the project area. This may require upslope diversion of water flow paths or treatment of upslope runoff source areas prior to implementing the intended project.

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

Physically excluding vehicle traffic with large boulders and logs is typically the most effective approach for protecting treatment areas.

Table 15. Treatment area protection options 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	Use of fences, bollards, and other manufactured barriers to exclude traffic from treatment area	• 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 treatment areas	• 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	

Tool 3.5 Protecting Treatment Areas

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)

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 treatments
- Over-communicate importance of protecting treatment areas to staff and other appropriate parties through trainings, tailgate meetings, and contractor coordination meetings

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
- Visual observation, Cone penetrometer (to assess recompaction), and Photo points will be used to measure success

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 redisturbance. Trainings, tailgate meetings, and contractor coordination meetings can be great venues for communicating importance of treatment area protection.

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.

Tool 3.6 Topsoil Salvage and Reuse

Definition

Topsoil is the top 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. 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 additional planning, topsoil salvage and reuse can lead to great cost savings on projects where sustainable sediment source control is the goal.

Well-aggregated native topsoil (left); disturbed, non-cohesive soil after topsoil had been removed (right).

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.

Tool 3.6 Topsoil Salvage and Reuse

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 individual1 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 shown to be detrimental to soil organic matter quality (Smith et al. 1987). Topsoil should never be compacted or used as temporary fill. Topsoil needs to be protected from weed infestation.

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 135-136). Once applied, topsoil should be mixed with the upper 6-12 inches of subsoil 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 3.11, Mulches), as this nutrient-rich material is easily transported by wind and water and can contribute to water quality degradation.

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

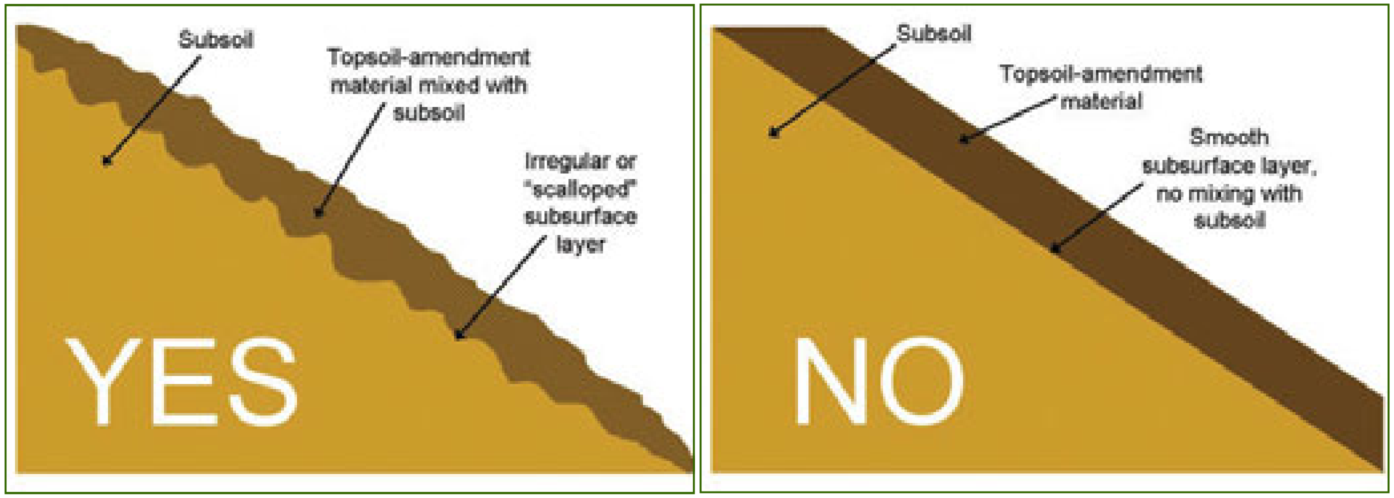


Figure 31. Topsoil amendment applied and mixed with subsoil, creating a "scalloped" subsurface layer (left). Typical topsoil-amendment application without mixing with subsoil (right).

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
- 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 and analysis

Management Response to Lack of Success

- Topsoil contaminated with undesirable materials such as weed infestations or chemicals may be unusable and off-site amendments my need to be imported to meet treatment goals

Tool 3.6 Topsoil Salvage and Reuse

- 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 (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 surpassed the soil amendment needs of this large development project.

Highlands View Road at Northstar. Topsoil was salvaged and re-applied along 4 miles of cut-and-fill slopes and was a key to cost-effective slope stabilization and successful revegetation.

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, three 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.

Topsoil Endnote

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.

Tool 3.6 Topsoil Salvage and Reuse

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 16. His calculations indicated that 2 inches of topsoil would not provide enough OM to achieve the target of 8% OM (See Figure 32) 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.

Scenario 2

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 17) 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.

Table 16. Scenario 1 calculations indicating inadequate amount of topsoil.

	Material Depth (in)	% of Tilling Depth (12 in)	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 17. Scenario 2 calculations indicating adequate amount of topsoil.

	Material Depth (in)	% of Tilling Depth (12 in)	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%

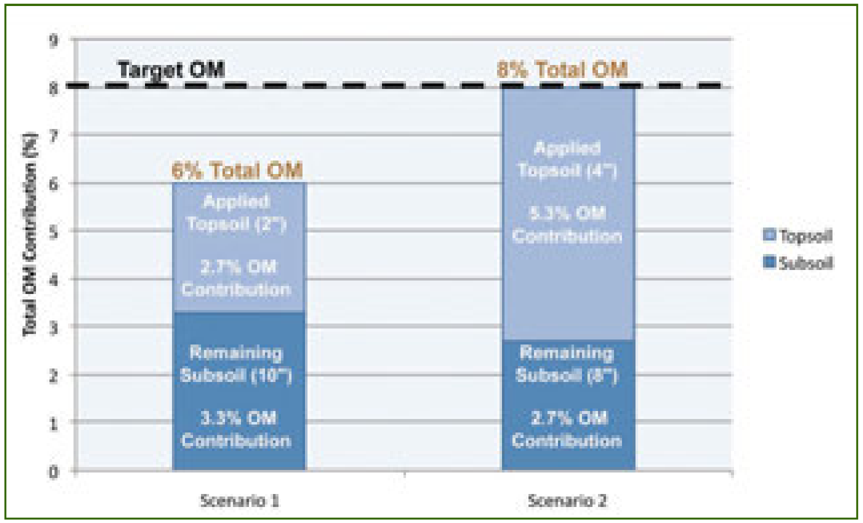


Figure 32. Graph showing OM contributions of different amounts of topsoil and resulting in total soil OM compared to target soil OM.

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.

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

Buried topsoil layer revealed by an erosion gully on Sierra ski run.

Tool 3.7 Soil Physical Treatment

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

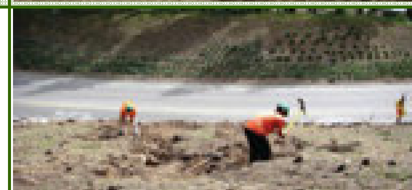
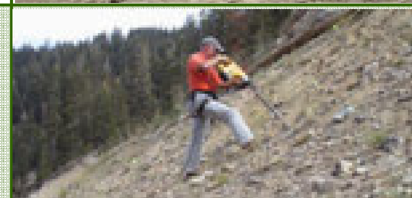
Compaction, or high soil density, is one of the main limiting factors for a large range of soil functions. Root penetration, water infiltration, runoff, oxygen exchange, microbial activity, and nutrient cycling are all affected by soil density/compaction. Soil physical structure, including soil density, 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 selection 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 18 on the next page provides a more detailed comparison of soil physical treatment types.

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.

Table 18. 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 subsurface 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, decompact, 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	
Targeted Loosening	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	
Auguring/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	

Tool 3.7 Soil Physical Treatment

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 4.3, Types of 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 19, provides some general guidelines for selecting treatment methods for different site conditions and project types.

Table 19. Site Suitability Matrix.

	Machine Tilling	Ripping/ Subsoiling	Targeted Loosening	Hand Tilling	Auguring/ Drilling	Rototilling
Steep slopes	X		X		X	
Ski runs	X		X			
Road decommissioning	X	X	X			
Road cut and fill slopes	X		X			
Shallow bedrock			X		X	
Well-vegetated areas			X	X		
Landscaping			X	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/ recompaction. 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 3.5, 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 4.3, Types of Monitoring, for more information).
- **Surface roughness:** measurement using straightedge or visual 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

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 per acre. A site that has been tilled to 12 inches may hold up to 130,340 gallons per acre, an increase of 800 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.

Maintenance and Inspections

- Check treatment areas regularly for evidence of re-disturbance/re-compaction
- Recently loosened soil is extremely sensitive to re-disturbance 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

Tool 3.7 Soil Physical Treatment

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)
- 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

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 more expensive 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.

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 road-bed 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 stability/sediment source control when compared to most other treatment types.

Tool 3.7 Soil Physical Treatment: Machine Tilling

Definition

Machine tilling is 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 subsurface 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)

Constructing test plots on ski run at Heavenly Mountain Resort.

- Till soil in a manner that achieves high subsurface roughness, leaving the subsoil "scalloped" (as shown in Figure 33 on the next page). 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

Tool 3.7 Soil Physical Treatment: Machine Tilling

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 (Grismer et al, 2009)
- **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

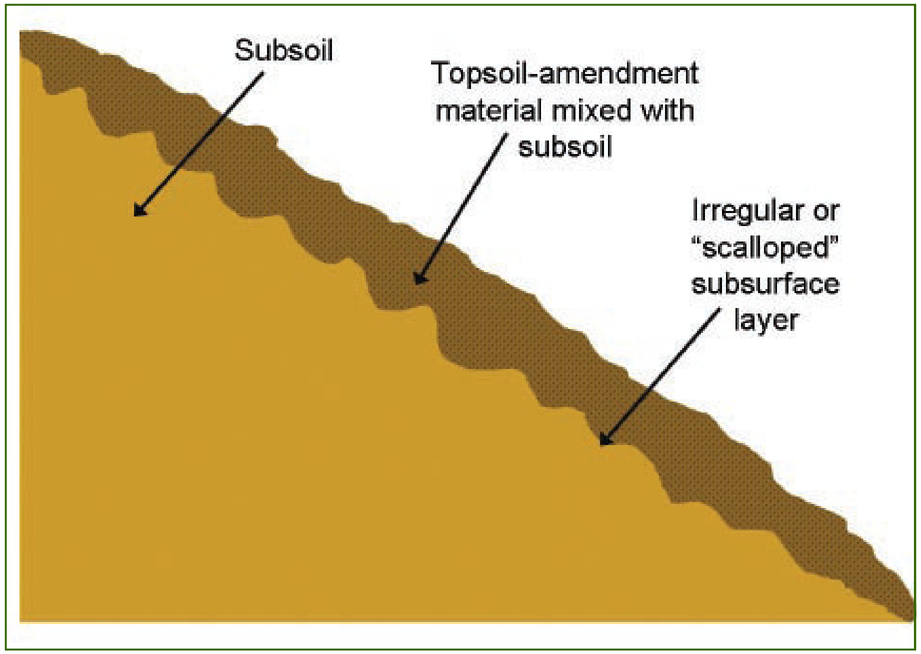


Figure 33. Topsoil-amendment material applied and mixed with subsoil using bucket tilling, creating a roughened or "scalloped" subsurface layer which helps prevent slumping until deep plant roots are established.

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 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.

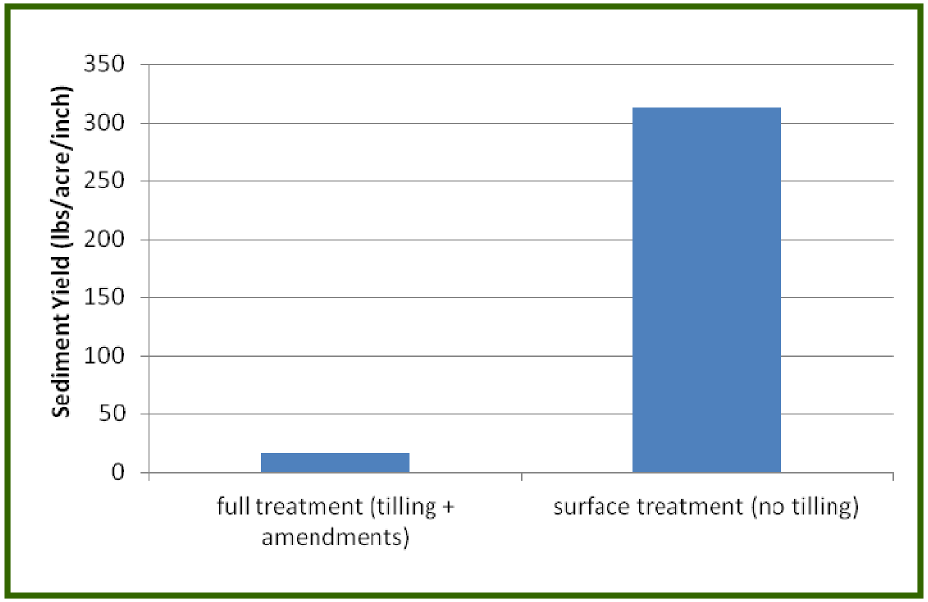


Figure 34. Heavenly Gunbarrel test plots. Sediment yield was 20 times higher at the 'surface treatment' plot (313 lbs/acre/in) than at a 'full treatment' plot (16lbs/acre/in). 'Full treatment' included 4 inches of wood chips tilled to a depth of 18 inches, 2,000 lbs/acre Biosol fertilizer, upland seed 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).

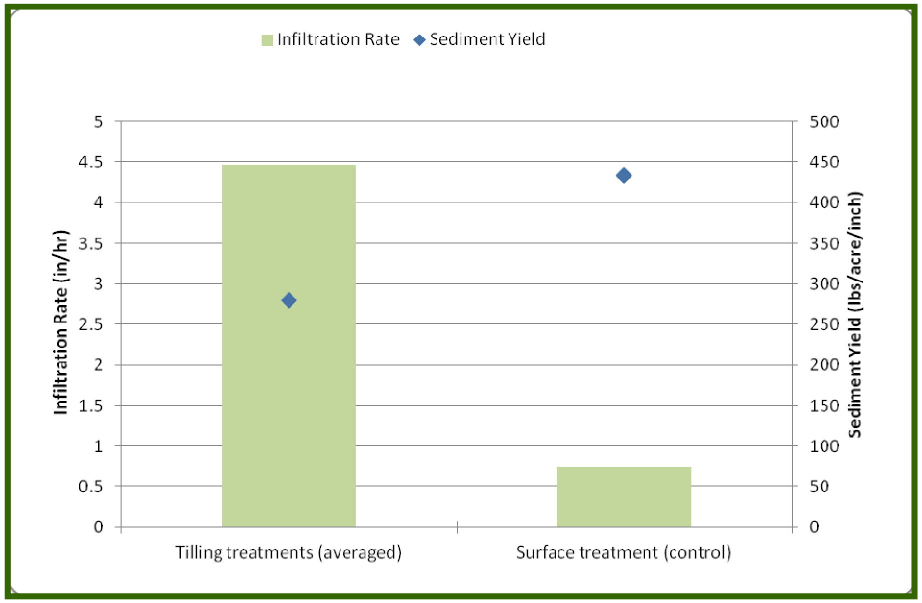


Figure 35. Mammoth Mountain Stump Alley test plots. Tilling treatments with incorporated amendments exhibited infiltration rates more than 5 times greater than the adjacent surface treatment. On average, sediment yield from the tilled test plots was 1.4 times lower than the surface treatment plots—280 lbs/acre/inch compared to 433 lbs/acre/inch.

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Tool 3.7 Soil Physical Treatment: Targeted Loosening

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.

Case Study: Homewood Smooth Cruise Road

Targeted Loosening Can Be Efficient and Effective

How do different soil loosening techniques affect soil density? At Homewood's Smooth Cruise Road test plots, Tier 2 treatments (targeted loosening) using bucket-mounted infiltration tines achieved deeper soil loosening depth (as measured with a cone penetrometer) than full tilling with a mini excavator bucket. This is due in part to the rocky soils at the site, where infiltration tines are more effective at getting between the rocks to loosen dense soil. Targeted loosening with infiltration tines proved to be more efficient (faster) and more effective (deeper soil loosening) compared to bucket tilling at this site.

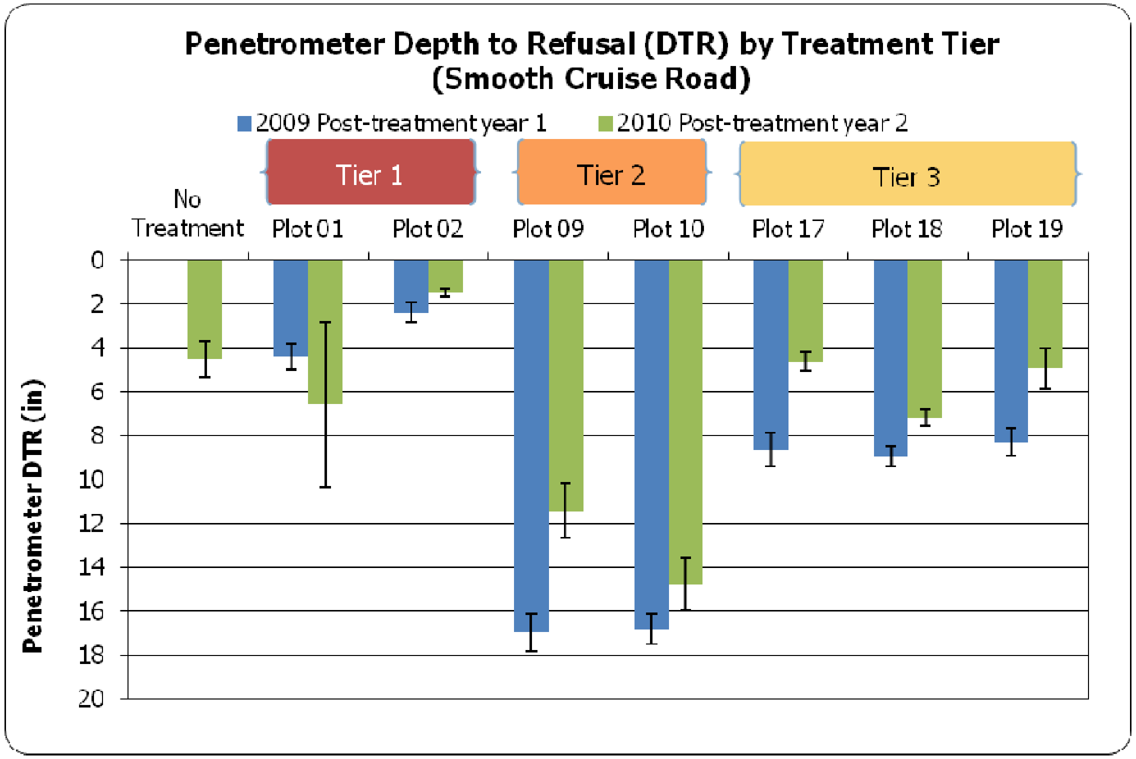

Figure 36. Penetrometer Depth to Refusal (DTR) by Treatment Tier at Smooth Cruise Road test plots. Tier 1 is a mulch-only treatment, Tier 2 is targeted loosening, Tier 3 is bucket tilling.

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Tool 3.8 Soil Amendments

Wood chips and compost are two types of organic materials that are rich in carbon and can be used as soil amendments for depleted sites.

Definition

A *soil amendment* is a material that is used to change or enhance soil physical, chemical, and 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, and 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 3.6 Topsoil Salvage and Reuse, for more information.

Table 20. 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	• 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 3.9 Fertilizers 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 out-plantings • Inexpensive to purchase • Can be collected from native areas	• Questionable long-term benefits • Can reduce growth of plants in soils with adequate or high phosphorous • May introduce non-indigenous strains of fungi into soil community
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/	• 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
Biochar	Products burned at low to high temperatures in an oxygen deficient environment	• Low soil organic matter • Low carbon or water holding capacity	• Are thought to retain water, nutrients and pollutants	• Substantive research is lacking so many claims are not supported • Biochar responses tend to vary

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Tool 3.8 Soil Amendments

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 20. Soil Amendments Alternatives Matrix).

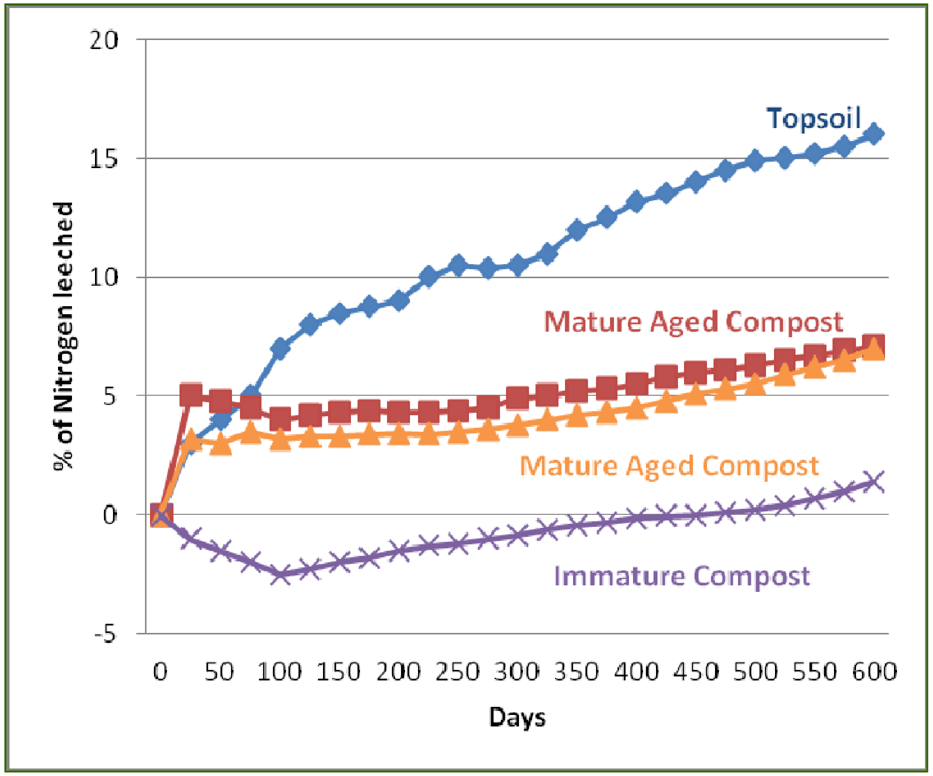


Figure 37. shows the differences in compost nitrogen (N) release over time. This chart indicates the importance of matching the appropriate compost or soil amendment to a specific site condition. For instance, immature compost actually removed or "locked up" nitrogen, and would tend to reduce or eliminate 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.

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)

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 yard of material per acre per inch of application depth desired.

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.

Tool 3.8 Soil Amendments: Compost

Definition

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

In general terms, compost essentially consists of materials derived from the breakdown of organic matter that have the unique ability to improve the chemical, physical, and biological characteristics of soils or growing media.

However, the type of compost and breakdown process can affect project outcome and should be carefully considered, especially if construction specifications are being prepared.

Description

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

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

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

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

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

Site Suitability/Indicators for Use

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

Advantages

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

Disadvantages

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

Suggested Material Specifications

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

Observed or Measured Results

- Incorporation of compost has been shown to increase plant cover, soil OM and TKN, microbial activity, and infiltration rates.
- Compost texture (percent woody versus fine material) can affect soil and plant response to treatment. Fine-textured compost tends to result in high plant growth but can also encourage the growth of weeds when a seed source is present (see Figure 38 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 Lookout Mountain, long-term test plots: Several types and textures of compost were tested. Four years after treatment, test plots amended with coarse-textured compost (75% coarse overs) years later, treatments with the 6-inch exhibited lower soil density than plots compost application had higher plant cover amended with fine-textured compost and soil TKN. (100% fines).

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.

Tool 3.8 Soil Amendments: Compost

- **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% fine) 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.

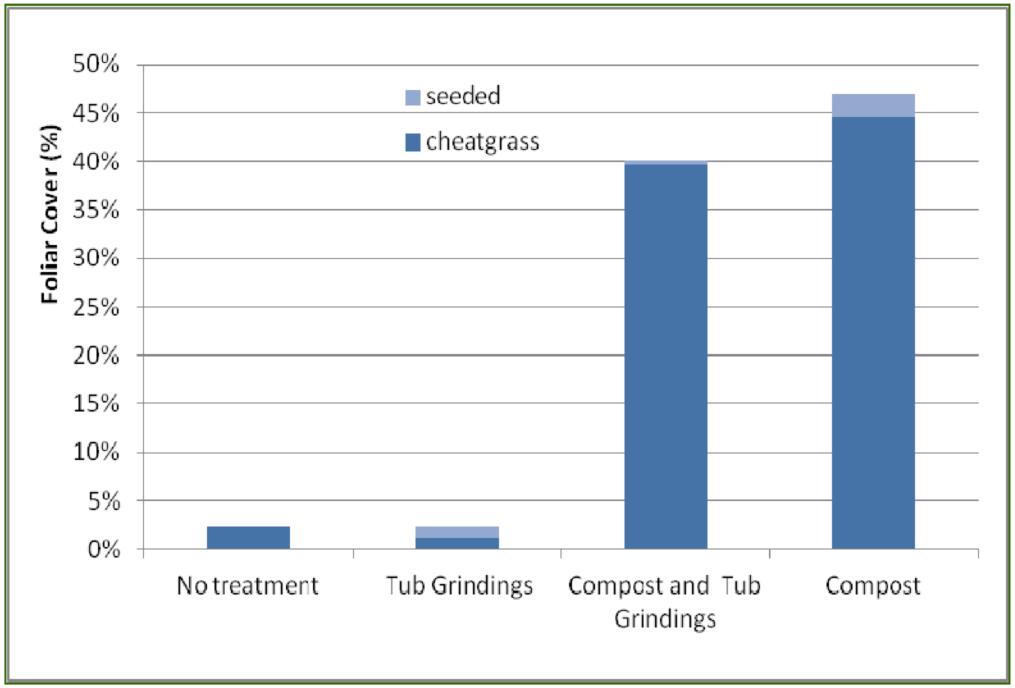


Figure 38. Compost is known to encourage the establishment of weedy and undesirable plant species, especially where weed seed is present in the seed bank. At Brockway Summit, cheatgrass outcompeted the native (seeded) species on all plots where a fine-textured compost blend was used as a soil amendment.

Tool 3.8 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 when incorporating into soil
- 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

Tool 3.8 Soil Amendments: Wood Chips

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, temperature, 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.

Older is Better

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.

Wood chips produced from branches and slash often have a high concentration of pine/fir needles. This material is better used as a surface mulch than as a soil amendment.

Tool 3.8 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

Tool 3.8 Soil Amendments: Wood Shreds

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).

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.

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.

Tool 3.9 Fertilizers

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 3.8 Soil Amendments, for more information.

Mineral Nitrogen Fertilizers

Mineral nitrogen fertilizers are largely synthesized from atmospheric nitrogen using the energy-intensive Haber-Bosch process. 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

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

rates can vary depending on temperature, moisture, and other environmental factors.

Organic Fertilizers

Organic fertilizers are 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.

Tool 3.9 Fertilizers

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 and various compost-type materials. 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 fertilizer 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 4.2 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.

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.

Table 21. Fertilizer Alternatives Matrix

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 Does not build soil Production is energy-intensive
Slow-release Mineral Fertilizers	Mineral-coated material (some organic fertilizers are also considered slow-release)	More predictable release rate Relatively inexpensive	Actual release rates can very Moderate leaching potential

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.

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 3.10 Vegetative Treatments.
- Species composition (presence of desired and undesired species) – Weed growth and excessive annuals can be an indication of excess available nitrogen.

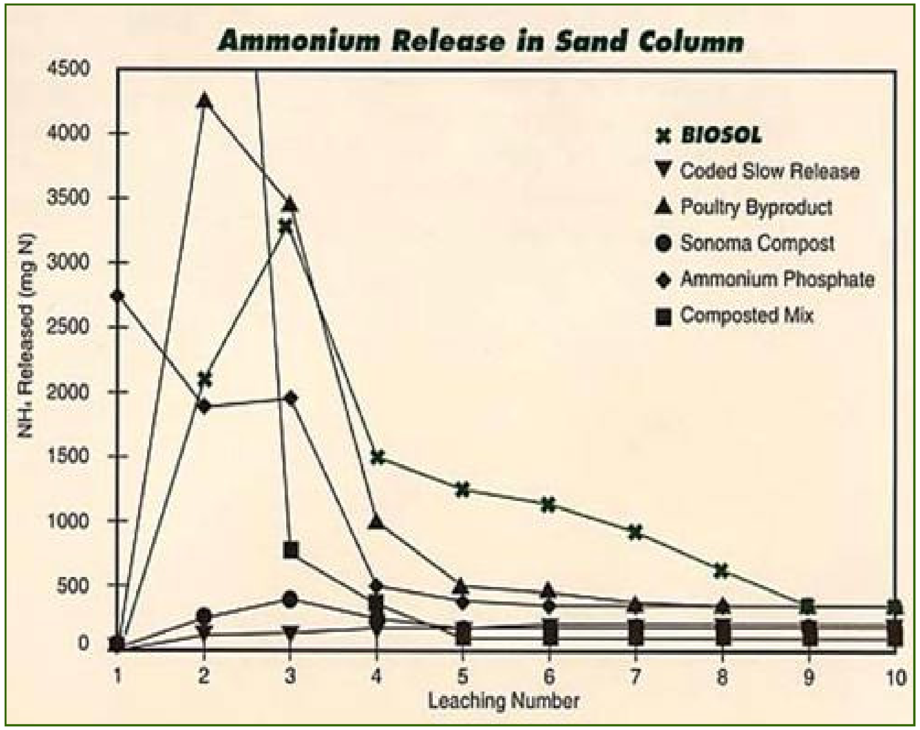


Figure 39. Leaching data for a number of mineral and organic fertilizers. The horizontal (X) axis represents leaching events (water leached through a sand column containing one form of fertilizer or soil amendment). The vertical (Y) axis represents the amount of plant-available nitrogen (N) leached from 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 ammonium phosphate, may present a runoff and pollution threat if not absorbed by plants immediately. From Claassen and Hogan (1998).

Tool 3.9 Fertilizers

Measurement Methods for Success

- Soil nutrient sampling and analysis
- Cover point monitoring or ocular estimates to determine percent plant cover
- Plant count (census) to determine plant density, seedling survival rate, species diversity, and presence of weeds

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.

Table 22. Fertilizer Information Resources

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

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'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

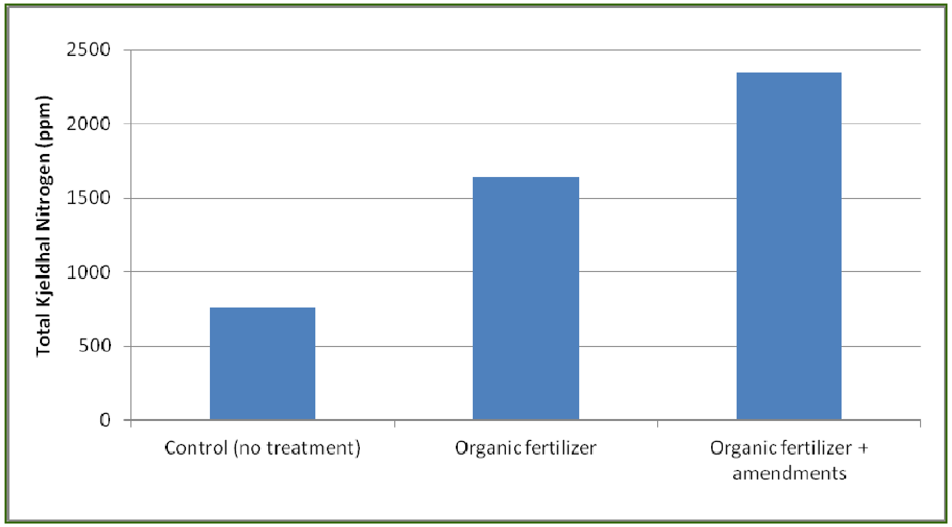


Figure 40. The graph shows soil total Kjeldhal nitrogen (TKN) levels for a treatment test area at Northstar. Three years after treatment, soil TKN levels were highest where a combination of organic fertilizer and amendments were used, as compared to application of fertilizer alone and an untreated area. Similar results have been measured at other test sites as well, indicating that a combination of fertilizer and long-last amendments may be the most useful treatment approach for establishing and sustaining adequate soil nutrients over time.

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 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 40).

- 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.

- As shown in Figure 41, plots at Truckee Bypass 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 undesirable species.

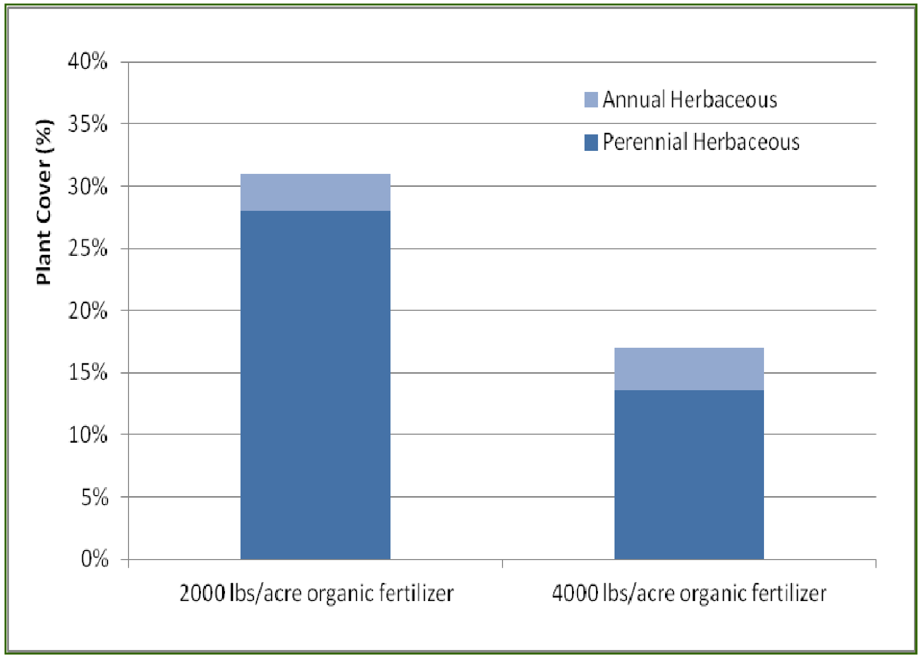


Figure 41. Truckee Bypass test plots. On average, plots treated with the lower fertilizer rate (2,000 lbs/acre) exhibited higher cover by seeded perennial species than those plots treated with the higher fertilizer rate (4,000 lbs/acre). This site-specific assessment helped save the landowner money by reducing fertilizer application rates on future restoration projects.

Tool 3.10 Vegetative Treatments

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 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. Therefore, strict attention must be paid to soil conditions if a desired plant community is to be successfully established and sustained over time.

Seed mix of Sierra native perennial grasses and shrubs.

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 Guidebook 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.

Planning Considerations

- Temporary irrigation can be used to encourage seed germination and deep root penetration, which can increase slope stability (see Tool 3.12 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 first two growing seasons. 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 3.11 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 23) 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.

Tool 3.10 Vegetative Treatments

Table 23. Vegetative Treatment Alternatives Matrix.

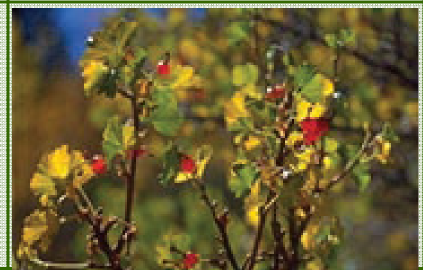
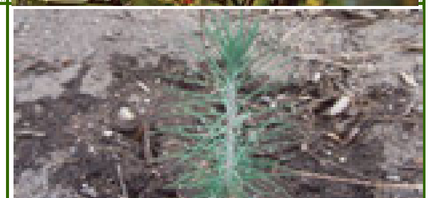
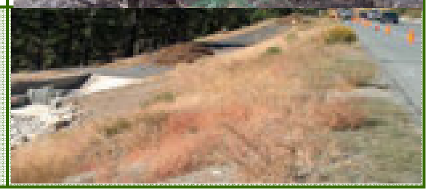
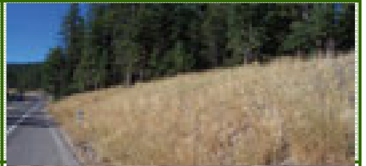
Seed/Planting Type	Definition	Advantages	Disadvantages	Photos
Native Perennial Grasses	Any perennial grass that is native to the local area	• Native plants are an essential component of the local ecosystem • Most native perennial grasses are deeply rooted and add strength to the soil • Native grasses 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 • Provide shade and create wildlife habitat	• 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 24. Vegetative Treatment Seeding or Planting Matrix

Application Method	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	

- 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.

Pure Live Seed (PLS)

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

Tool 3.10 Vegetative Treatments

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.

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 25), 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.*
- 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.

Table 25. Favorable site conditions for selected northern and central Sierra grass species that have been successfully used in revegetation and erosion control projects.

	Mountain brome (Bromus carinatus)	Blue wild rye (Elymus glaucus)	Squirreltail (Elymus elymoides)	Western 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

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.

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 rootbound.
- 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 3.7, 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 root ball or otherwise handle seedling roots.

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

Tool 3.10 Vegetative Treatments

- 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.

Suggested Success Criteria

As with any restoration project, it is important to determine vegetation success criteria during the planning phase (see Tool 1.3 Developing 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 4.9 Foliar and Surface Cover Point Monitoring and 4.10 Foliar and Surface Cover Ocular Estimation).

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 25 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.

Photo A– well vegetated, high sediment yield

Photo B– poorly vegetated, high sediment yield

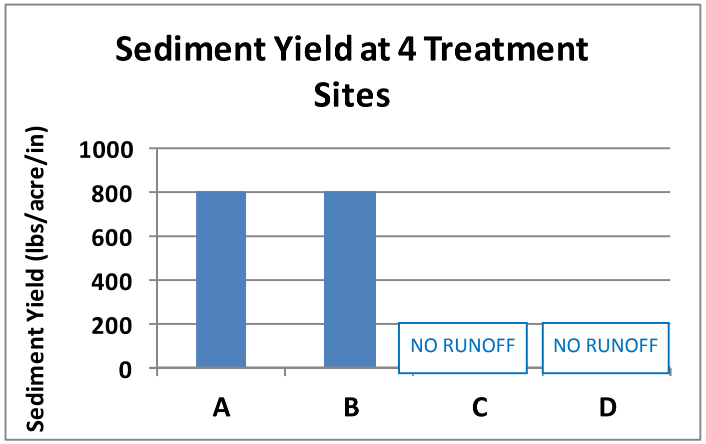


Figure 42. Sediment Yield for Sites A-D treatments.

Photo C– poorly vegetated, low sediment yield

Photo D– well vegetated, low sediment yield

The above photos show four sites with different treatments. Figure 42 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.

Tool 3.11 Mulches

A bitterbrush seeding emerges through pine needle mulch.

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 ecosystem 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
- Minimizing 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.

Tool 3.11 Mulches

Case Study: Mulch Cover and Sediment Yield

Mulch has a direct effect on how much sediment leaves or remains in place at a site. The photos below show three different research plots with similar slopes in close proximity to one another at a project site at North Lake Tahoe.

Mulch cover varied greatly between the plots, and the graph below shows the amount of sediment present in the runoff from each plot during simulated rainfall. Sediment yield was an order of magnitude (ten times) higher from the plot with the lowest mulch cover (10%) than the plot with the highest mulch cover (95%). The bottom line: adequate mulch cover is a critical element of preventing erosion and sediment yield.

95% mulch cover

60% mulch cover

10% mulch cover

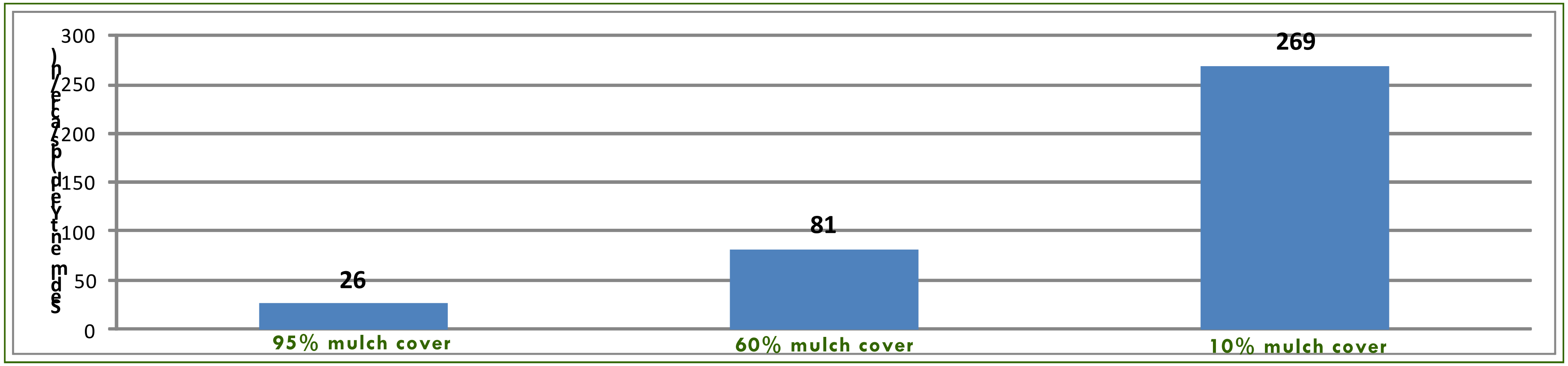
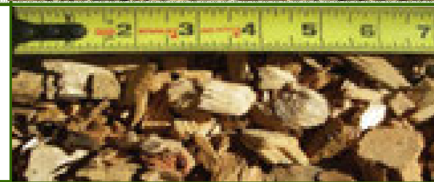
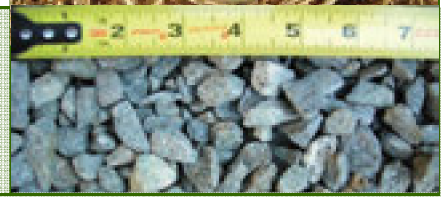


Figure 43. Mulch cover and sediment yield. Sediment in runoff increased as mulch cover decreased, as measured using rainfall simulation at an erosion control project at North Lake Tahoe, CA.

Table 26. 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 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	

Tool 3.11 Mulches

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 26 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 testing of their erosion control effectiveness in alpine watersheds is limited (see Foltz 2012).

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 reapplied 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 3.8 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:

Clear evidence of significant erosion occurring underneath erosion control 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).
- 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.

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 reapplication, 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 27, identifies the recommended uses for each type of mulch.

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.

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.

Table 27. Mulch Site Suitability Matrix

	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

Tool 3.11 Mulches

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 reapply 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.

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, and 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

Spreading pine needles.

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.

TOOL 3.11 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.

Pine needle mulch is now widely available in the Lake Tahoe region and in many other communities thanks to the success of pine needle recycling programs.

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 project costs if salvaged and reused on site
- May contain native seed if collected locally

DISADVANTAGES

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

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.

Tool 3.11 Mulches: Pine Needles

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 at depths of 1", 3" and 5" to dirt roads in a west shore Lake Tahoe watershed reduced sediment yields by 72% to 86% (measured with rainfall simulation), with larger sediment reductions associated with deeper mulch depths (Drake et al. 2012).
- 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 any-thing, 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 over-stocked, closed-canopy forests where light cannot penetrate. But where an open stand exists, you may sometimes find under-story vegetation so thick you cannot see the pine needles.

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.

Tool 3.11 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

- Wood chips applied at depths of 1", 2" and 4" to dirt roads in a west shore Lake Tahoe watershed reduced sediment yields by 92% to 96% (measured with rainfall simulation) (Drake et al. 2012).
- 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.

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Tool 3.11 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 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

- 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.
- Foltz (2012) measured sediment reductions of 42% from sparse (approx. 50% cover) applications of wood shreds on decommissioned forest roads in the Rocky Mountains. Further, none of the wood-based mulches tested inhibited plant growth.

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.

Tool 3.11 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

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.

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. Evenly distribute straw by hand or blower until at least 98% of the soil surface is covered (approximately 1 inch in depth).
3. Anchor straw using an acceptable method (crimping/track packing, tackifying, or covering with netting).

Observed or Measured Results

- Foltz (2012) found that wood shreds were equally effective at mitigating erosion in first year as straw and did not inhibit plant growth.
- Even when properly applied and anchored, straw mulch rarely maintains

Tool 3.12 Temporary Irrigation

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.

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:

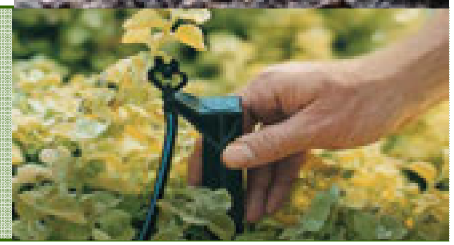
1. To assist with initial germination of seeds
2. To encourage deep root penetration

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 during the growing season.

Tool 3.12 Temporary Irrigation

Table 28. Temporary Irrigation Alternatives Matrix

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

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.
- 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.

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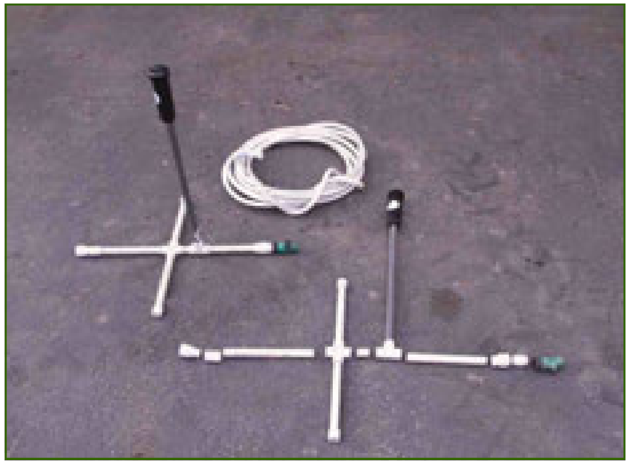

Examples of reusable, modular irrigation systems. Yellowmine pipe (left), is easy to assemble and disassemble, which can reduce material waste and save money. At 2-inch diameter, it is ideal for larger sites. Another option is to construct sprinkler stands out of ¾-inch PVC pipe (center and right) and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

Tool 3.12 Temporary Irrigation

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.

Highly adjustable fire hose nozzles (left) 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 (bottom).

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.

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 3.7 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 3.7 Soil Physical Treatment).

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

Poor irrigation system design can lead to uneven water application. Photo at right shows poor water distribution due to inadequate water pressure and sprinkler head spacing.

Tool 3.12 Temporary Irrigation

Observed or Measured Results

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.

Northstar 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. See photos below.

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.

Northstar Superpipe – failure caused by over-irrigation (left); repaired slopes with proper irrigation (center); stabilized slopes two years after treatment (right).

Tool 3.13 Road Management and Decomissioning

The Problem with Roads

Unpaved roads are a common feature in most watersheds. They are often necessary to provide access for recreation and land management activities but even the most well designed and maintained roads fundamentally alter watershed processes. Roads change the "plumbing" of watersheds by intercepting and concentrating runoff, altering the amount and timing of water delivery to streams (Beechie et al. 2005, Madej 2001) and increasing sediment transport by 1-3 orders of magnitude compared to undisturbed forested areas (Drake et al. 2012). The good news is that there are many field-tested road management and decommissioning treatments that can reduce (and in some cases eliminate) the hydrologic and sediment impacts of roads. Many of these treatment approaches also reduce ongoing maintenance costs.

Purpose and Goals

The purpose of this tool is to provide options for managing a road network to achieve the following goals: **minimizing sediment yield, maximizing hydrologic function, and minimizing ongoing maintenance costs**. Before choosing a specific treatment approach, consider the current and future level(s) of use within your road network. High-use roads will require more active management whereas low-use or unused roads may be good opportunities for decommissioning or low-maintenance stabilization treatments.

Treatment Tiers

The concept of "treatment tiers" was used during the planning phase of the Lake Tahoe TMDL to evaluate potential sediment reductions from disturbed soil areas by applying different levels (or "tiers") of treatment, representing different levels of effort. The three treatment tiers developed for forested uplands areas of the Tahoe Basin ranged from applying surface mulch/ protection (Tier 1) to targeted loosening restoration treatments (Tier 2) to full hydrologic reconnection/recontouring and soil restoration treatments (Tier 3). These different "tiers" of treatment have been extensively tested in the Lake Tahoe area over the past few years, and some of the results are included in this tool. Tier 1 is generally covered in the Road Management section and Tiers 2 and 3 are covered in the Road Decommissioning section.

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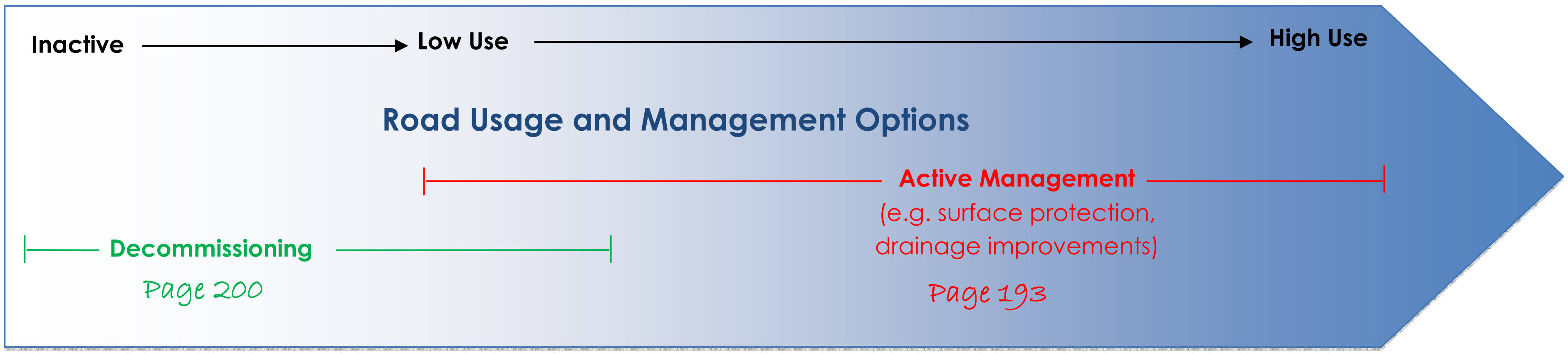


Figure 44. Graphical depiction of road use levels and management options.

Tool 3.13 Road Management and Decomissioning

Developing a Road System Management Plan

Below are recommended steps for developing a cost-effective management plan for unpaved road systems:

1. **Inventory your road network and create a base map.** At a minimum, a road management base map should show road segments, streams and wetland/riparian areas. Other useful map features are topography/slope contours, culverts, water bars, and seasonal/ephemeral drainage features. See Tool. 2.2 Characterizing your Watershed
2. **Determine use levels for each road segment.** For example: low use = less than 1 trip per month; moderate use = 1-5 trips per week; high use = 1-5 trips per day.
3. **Assess road surface condition and erosion risk**. See Tool 2.5 Road Erosion Risk Assessment
4. **Assess runoff connectivity to drainages and surface waters**. Also identify sources of concentrated run-on that direct runoff onto the road network. See Tool 2.4 Water Flow/Connectivity Assessment
5. **Prioritize road segments and create road management plan based on the above steps.** Your plan should address both ongoing management requirements (e.g. fall/spring road maintenance) and, when applicable, a phased plan for decommissioning unneeded and/or high-risk road segments. See Tool 3.3 Project Grouping and Prioritization.

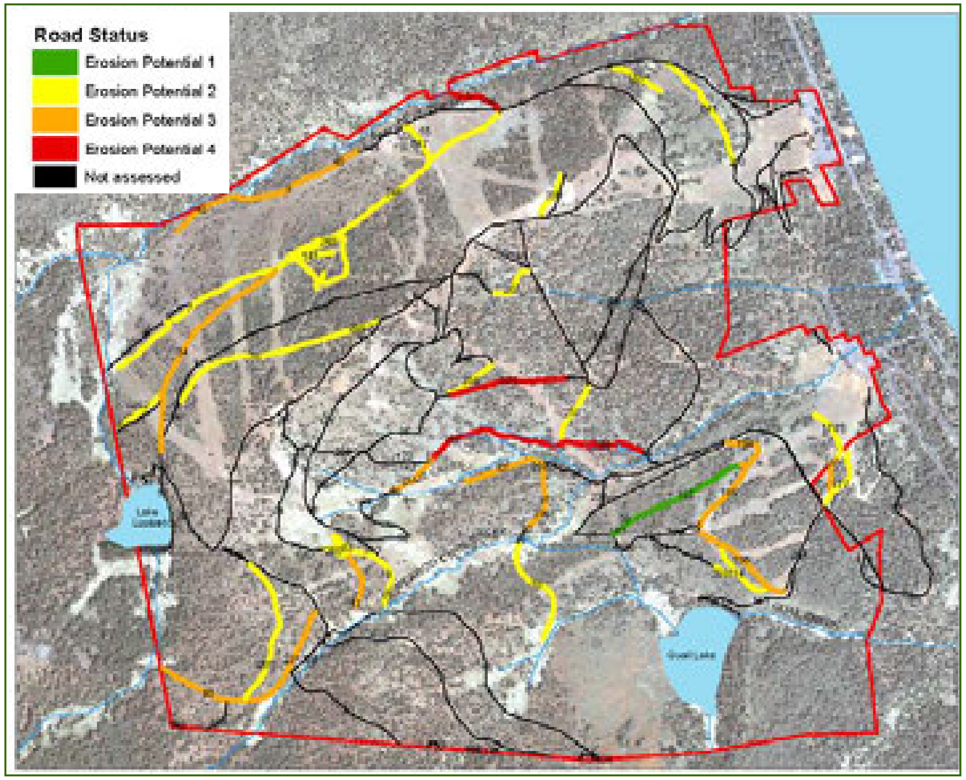
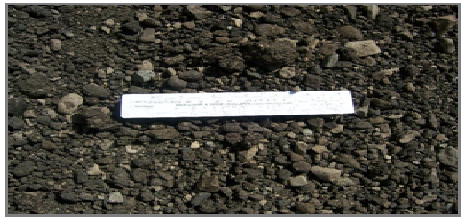


Figure 45. Example map showing road segments prioritized for active decommissioning based on field assessment of erosion potential.

Road Management Tools for Active Roads

Unpaved roads are a necessary feature in most watersheds, as they provide emergency access for fighting fires, repairing utilities and support multi-use recreation opportunities. Actively used roads tend to be very compacted with little to no infiltration capacity, which creates conditions where runoff from the road surface must be actively managed. Management options range from protecting the road surface with various materials to changing the road surface configuration to manage drainage patterns. A range of management options are summarized and compared below.

Table 29. Tools for Managing Active Roads – Alternatives Matrix

Treatment Option	Advantages	Disadvantages	Photo
Paving	• Durable, long-lasting surface • No erosion of road surface	• Impervious-higher runoff volumes to manage, even in small storms	
Asphalt Concrete (AC) Grindings	• Durable, even with high use • No erosion of road surface • Low cost when sourced from local road construction projects	• Must be compacted to be effective • Not recommended near streams (may leach hydrocarbons)	
Gravel	• Effective for med-high use roads • Easy to apply • Inert material suitable near streams	• Must be replaced more frequently than AC grindings	

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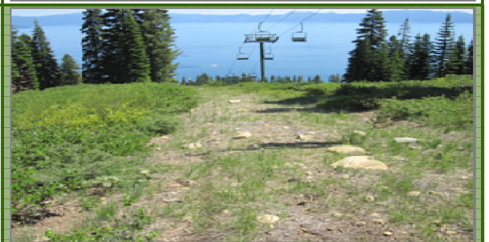
Tool 3.13 Road Management and Decomissioning

Table 29 continued. Tools for Managing Active Roads – Alternative Matrix

Treatment Option	Advantages	Disadvantages	Photo
Wood Chips	• Effective surface protection for low-med use roads • Low cost or free when produce onsite (e.g. fuels thinning) • Builds soil as it decomposes	• Easily displaced by runoff on steeper slopes (tub-ground wood chips more effective) • Must be occasionally maintained to remove tire ruts/bare areas on med-high use roads	
Pine Needles	• Effective surface protection for low-med use roads • Effective at reducing erosion	• Breaks down quickly with frequent vehicle traffic (requires replacement) • Resists displacement by runoff • Potential fire hazard if vehicle traffic is expected during summer months	
Vegetate	• Helps stabilize/protect road surface • Certain types of vegetation can survive infrequent vehicle disturbance • Aesthetically pleasing	• Only appropriate on infrequently used roads • Compaction from vehicle traffic can stress vegetation • Potential fire hazard if vehicle traffic is expected during summer months	
Surface Grading	• Creates roads suitable for low-clearance vehicles • Can change slope of road drainage to suit site-specific needs	• Dramatically increases sediment transport following grading (including wind erosion) • "Erases" evidence of erosion that can help identify problem areas • Must be repeated on ongoing basis	
No Management	• Inexpensive (free)	• Erosion likely to increase over time unless actively managed or decommissioned	

Observed or Measured Results

Asphalt-Concrete (AC) Grindings

- Applying a layer of compacted asphalt grindings (1.5" depth) to an unpaved haul road reduced turbidity in runoff by approximately 10 times with no measurable change in infiltration rate (see Figure 46).

Gravel

- Applying 1 inch of gravel to high-use unpaved road segments on the west shore of Lake Tahoe reduced sediment yield by 94 times (from 138,947 to 1,484 lbs/acre/in) on a graded road and by 10 times (from 4,227 to 408 lbs/acre/in) at an ungraded road (Drake et al. 2012). See case study below for additional details.

Wood Chips

- Applying a layer of wood chips (3" depth) to an unpaved, recently used road reduced turbidity in runoff by approximately 10 times with no measurable change in infiltration rate (see Figure 46).
- Wood chip mulch was applied to an inactive dirt road in the Homewood Creek watershed (west shore Lake Tahoe) at several depths (1", 2", 4"). Rainfall simulation showed wood chip mulch reduced sediment yield by an average of 17 times compared to bare soil conditions (from 868 lbs/acre/in to 51 lbs/acre/in). Deeper mulch depths (2-4") resulted in the greatest sediment reductions of 21-22 times (Drake et al. 2012).
- Lab studies by Foltz and Copeland (2008) measured sediment yield reductions greater than 60% compared to bare soil conditions and that sediment reductions generally increased as wood chip percent cover increased.

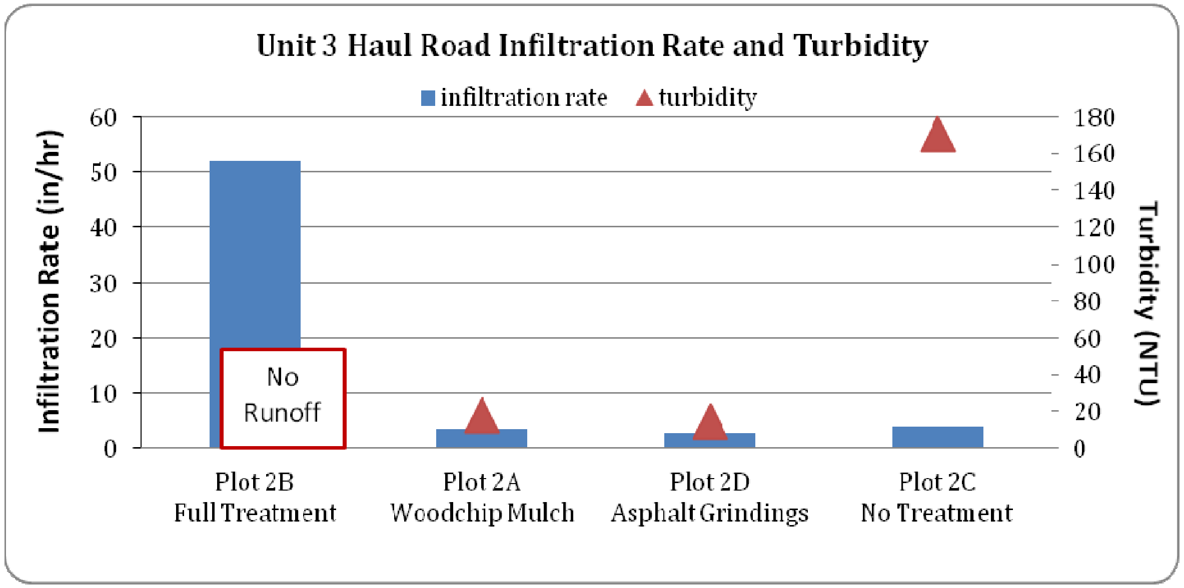


Figure 46. Infiltration rate and turbidity for different road treatment techniques measured using a runoff simulator two years after treatment at Waddle Ranch (Truckee, CA). Note: "full treatment" refers to Tier 2 targeted loosening treatment.

Pine Needles

- Pine needle mulch was applied to an inactive dirt road in the Homewood Creek watershed (west shore Lake Tahoe) at several depths (1", 3", 5"). Rainfall simulation showed that pine needle mulch reduced sediment yield by an average of 5 times compared to bare soil conditions (from 868 lbs/acre/in to 176 lbs/acre/in). The 5" mulch depth resulted in the greatest sediment reduction of nearly 7 times (Drake et al. 2012).
- Pine needle mulch depths of at least 51cm (~2") was associated with the highest average sediment reductions in a multi-year Tahoe Basin study (Grismer et al. 2008).

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Tool 3.13 Road Management and Decomissioning

Vegetate

- A three-year study of restoration treatments on disturbed sites throughout the Tahoe Basin indicated that test plots with greater than 60% foliar cover by native perennial species had the lowest average sediment yields. Most of the plots with greater than 60% foliar cover by native perennial species also received soil loosening and amendment treatments, which appeared to be an important factor in supporting robust native vegetation and low sediment yields over the long-run (Grismer et al. 2008; Grismer and Hogan 2005).
- Vegetative treatments that do not improve soil physical structure (e.g. hydroseeding) have been shown to temporarily reduce sediment yield by reducing raindrop impacts (Montoro et al. 2000); however, long-lasting sediment reductions tend to be associated with treatments that improve soil infiltration rates through loosening and soil amendment incorporation, which also tend to support robust native vegetation (Grismer et al. 2008).
- Road decommissioning treatments – including soil loosening and wood chip incorporation, fertilizing, seeding, mulching – tested in the Homewood Creek watershed (Lake Tahoe basin) resulted in sediment reductions of more than 100 times (compared to untreated dirt roads) and foliar plant covers ranging from 3-18%. Three roads treated using these techniques resulted in NO RUNOFF and therefore no sediment yield, even at rainfall rates of 4.7 inches per hour (Drake et al. 2012).

Surface Grading

- Runoff simulation conducted on a graded section of road directly adjacent to an ungraded section indicated that grading increased sediment yields by 33 times (Drake et al. 2012). Where road grading is necessary, application of gravel road base can substantially reduce sediment yield in runoff (see case study on the next page).

No Management

- **Active vs. Inactive Roads**: Rainfall and runoff simulation studies on a variety of road types in the Homewood Creek watershed (Lake Tahoe) revealed that actively used roads (>1 vehicle trips per day) produced sediment yields 20-2000 times higher than inactive roads (<1 vehicle trip per year). Active road sediment yields ranged from 20,780 to 208,421 lbs/acre/in, while inactive road sediment yields ranged from 96 lbs/acre/in to 6,344 lbs/acre/in. Fine sediment particle content in runoff sediment ranged from 12% to 43% for inactive roads and from 45% to 52% for active roads. These results underscore the importance of understanding the relative erosion potential and fine sediment particle contribution of road segments with different use levels when prioritizing watershed management and restoration efforts (Drake et al. 2012).

Case Study: Managing Active Roads for Sediment Reduction

Grading unpaved roads is a common management practice to maintain the road surface for vehicle traffic. The question is, does this practice have an impact on sediment yield and, if so, what can be done about it? At Homewood Mountain Resort, runoff simulation conducted on a graded section of road directly adjacent to an ungraded section indicated that grading increased sediment yields by 33 times (see Figure 47). However, after applying 1 inch of gravel to the road surface (Tier 1 treatment), sediment yields decreased by 94 times (from 138,947 to 1,484 lbs/acre/in) at the graded road and by 10 times (from 4,227 to 408 lbs/acre/in) at the ungraded road. Road surfacing helps disperse water and prevent erosion from occurring, which may reduce the need for grading in the first place. Where road grading is necessary, application of gravel road base can substantially reduce sediment yield in runoff.

Photos from the top-down show 1) Runoff simulation conducted on graded (left side of fork) and ungraded (right side of fork) roads, 2) Graded road (no treatment) during runoff simulation. Deep rill formation is visible, 3) Ungraded road with 1 inch gravel. Water is dispersed and not able to erode the road.

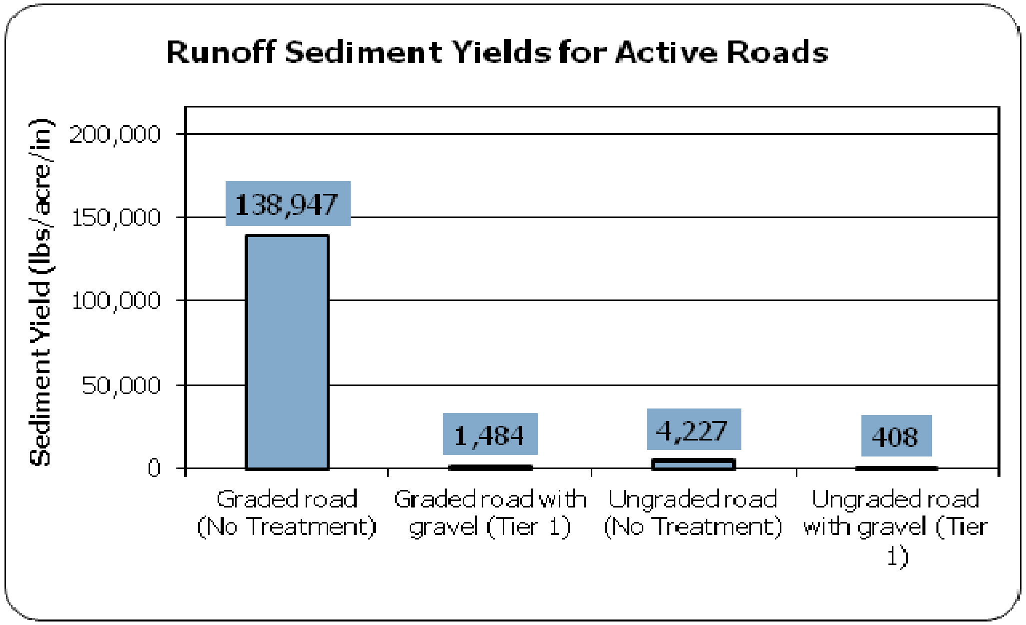


Figure 47. Runoff sediment yields for active roads

TOOLKIT

Tool 3.13 Road Management and Decomissioning

Drainage Management Considerations for Active Roads

Road construction and maintenance tends to be more complex that it seems at first glance. A primary contributing factor is water. Water is generally an ephemeral variable in a road or road network. Thus, the forces at work are not easy to address, especially when they are generally unseen. Since there are many very good publications that directly address construction and maintenance of dirt and gravel roads, we do not provide a complete overview of road drainage management here. Instead, we address some commonly overlooked hydrologic aspects of road design and drainage management that we have repeatedly observed to cause road-associated failures and water quality degradation issues. These issues are worth consideration in both construction and maintenance of dirt and gravel roads, particularly in mountain settings.

Insloping/Outsloping

Insloping and outsloping are road design techniques that refer to the cross-sectional angle of the road surface. Insloping was popular for many years and involves directing road runoff toward the cut slope to contain the water in a ditch or other conveyance with exits installed where needed. Typical issues associated with insloped roads and their conveyances include ditch clogging, culvert clogging, concentration of flows, down-cutting of ditches, etc. Outsloping has become a popular technique to (theoretically) encourage runoff water to "sheet" off the road surface in an even and distributed manner and disperse that water over a stable, vegetated fill slope.

The issues and maintenance requirements of insloped roads are fairly well understood. Outsloped roads present some poorly understood challenges which arise from the difference between the concept (promise) and the application. Three primary issues with outsloping roads are:

1. Water tends to concentrate rather than "sheet" at the edge of the road, often resulting in rills and gullies. This condition should be monitored and addressed as it occurs.
2. Outslope angles must be significantly greater than the linear road angle. That is, if the travel direction road angle is 10% and the outslope angle is

The road is insloped, yet water has formed a rill down the center of the road and is down-cutting at the rolling dip.

5%, runoff will follow the steeper of the two angles. Thus, on even moderately steep roads, outsloping may be of limited actual effectiveness. Where outsloping is used, it should be assessed during and immediately following runoff events in order to assure effectiveness or if not functioning properly, to adjust road surface angles.

3. Wheel tracks on the road surface tend to capture and concentrate runoff and thus can overtake and cancel out the advantages expected from more dispersed surface runoff.

In all cases, the field outcomes of design assumptions should be assessed during actual runoff events in order to either verify effectiveness or to make adjustments so that road management goals are achieved.

Water Diversion Structures

Water bars and rolling dips installed along dirt or gravel roads are designed to remove water running downslope along the road surface. An often overlooked element of water diversion structures is the fate of the concentrated runoff from those structures (see Tool 2.4 Water Flow/ Connectivity Assessment). Once water is captured, it is critical that this concentrated drainage is accommodated through the watershed until it is either effectively spread or conveyed to a stable flow path. Well-built conveyances should not add any sediment to the water flow. Low Impact Design or "LID" treatments – such as swales designed to maximize infiltration – are increasingly being used to reduce surface runoff volumes while providing stable conveyances through the watershed for large runoff events. Features that effectively infiltrate surface runoff can be a potentially cost-effective alternative to traditional rock-lined conveyances.

Additional Resources for Road Construction, Maintenance and Drainage Management

There are many useful publications that focus specifically on dirt and gravel roads. The following is a very incomplete listing of some of these publications:

- UC Agriculture and Natural Resources: http://anrcatalog.ucdavis.edu/pdf/8262.pdf
- Handbook of Forest and Ranch Roads: http://www.krisweb.com/biblio/gen_mcrcd_weaveretal_1994_handbook.pdf
- USFS Northeast: http://www.na.fs.fed.us/spfo/pubs/stewardship/accessroads/accessroads.htm
- Utah State: http://extension.usu.edu/files/publications/factsheet/NR_FF_010.pdf
- Penn State Center for Dirt and Gravel Road Studies: http://www.dirtandgravel.psu.edu/Resources/Documents/crown_cs.pdf
- http://www.dirtandgravel.psu.edu/Resources/Documents/crown_cs.pdf
- EPA: http://www.epa.gov/owow/NPS/sensitive/sensitive.html
- Massachusetts Department of Environmental Protection: http://www.mass.gov/dep/water/resources/dirtroad.pdf

Tool 3.13 Road Management and Decommissioning

Road Decommissioning Tools

Decommissioning forest roads is defined in many ways, ranging from simply closing a road to vehicle traffic to treatments that restore hydrologic and ecological functionality. For the purposes of this tool, we use the term decommissioning to mean eliminating both a road's human function (vehicle travel) and physically treating the roadbed (and associated cut and fill slopes) to restore the ecological and hydrologic functions that have been degraded or lost as a result of human activities. This level of treatment has been shown to be necessary to fully eliminate the impacts of roads on watershed function.

The road decommissioning treatment approaches and results offered below have been developed through extensive testing of a wide variety of materials and techniques over the past 10 years. Our aim has been to demonstrate that rebuilding ecologic function in even the most disturbed sites can be done in a cost-efficient manner. We hope that the examples below help to support and improve the practice of functional road decommissioning and expand its use as an important tool for watershed managers.

Steps for Successful Road Decommissioning

1. Identify and address surface drainages and sources of run-on. Are there any roads or drainage features that could direct concentrated flow onto the decommissioned road segment? *See Tool 2.4 Water Flow/Connectivity Assessment*
2. Assess decommissioning sites to determine what functions have been degraded or lost. *See Tool 4.2 Site Condition Assessment*
3. Develop an integrated treatment plan/design that uses specific treatment elements to restore degraded functions. *See Tool 3.1 Treatment Planning and Toolkit Section 3.0 (Doing)*
4. Protect decommissioned road segments from further disturbance and exclude vehicle traffic. *See Tool 3.5 Protecting Treatment Areas*

Lessons Learned in Road Decommissioning

Treatment Tiers: Are More Expensive Treatments More Effective?

The concept of "treatment tiers" was used during the planning phase of the Lake Tahoe TMDL to evaluate potential sediment reductions from different levels (or "tiers") of treatment intensity and effort/cost. The three treatment tiers developed for forested uplands areas of the Tahoe Basin ranged from applying surface mulch (Tier 1) to targeted loosening restoration treatments (Tier 2) to full hydrologic reconnection/recontouring and soil restoration treatments (Tier 3). Below is brief comparison of cost and sediment reduction effectiveness of different treatment tiers.

Tier 1 treatments consist of applying mulch (wood chips, pine needles, etc) to disturbed soil areas. This is a very low cost treatment, particularly when wood chips are acquired at no cost from nearby fire districts and forest fuels reduction projects. While this level of treatment does not recreate hydrologic function or support vegetation reestablishment in the short run, it can dramatically reduce erosion for at least several years. Applying 2-4 inches of wood chips (100% surface cover) on a compacted dirt road has been shown to reduce sediment yield by 90-96% (Drake et al. 2012; see Road Management section for discussion). Foltz (2012) measured sediment reductions of 42-76% on forest roads with much lighter applications of wood chips/shreds (40% surface cover).

Tier 2 is an intermediate level of treatment effort that uses targeted loosening (see Tool 3.7 Soil Physical Treatment) to increase infiltration and support plant establishment while minimizing disturbance to established vegetation and the soil profile. Tier 2 treatments typically include wood chip incorporation, fertilizer, seeding and mulch.

Tier 3 is the highest level of treatment effort. It typically includes all soil restoration treatments in Tier 2 but also includes full hydrologic reconnection – recontouring the roadbed to match surrounding contours. This level of treatment is especially important for decommissioning on-contour roads with significant cut and fill. Tier 2, which uses targeted loosening rather than full bucket tilling/recontouring (Tier 3), can be much more efficient to implement, especially for loosening up rocky soils, and has been shown to result in similar or better performance than Tier 3 treatments when tested side by side. For instance:

- **Soil Density**: Tier 2 treatments (targeted loosening) using bucket-mounted infiltration tines achieved and sustained (2 years after treatment) deeper soil loosening (50% deeper, on average, measured with a cone penetrometer) than full tilling with a mini excavator bucket (Tier 3), largely due to the rocky soils at the Smooth Cruise Road site (Drake et al. 2012).
- **Plant Cover**: Tier 2 treatments (targeted loosening) resulted in slightly high plant cover 2 years after treatment compared to Tier 3 treatments (full tilling with mini excavator bucket). This is largely due to Tier 2's ability to loosen soil while minimizing disturbance to already established vegetation (Drake et al. 2012).
- **Sediment Reduction**: across many test sites, Tier 2 treatments resulted in comparable sediment reductions to Tier 3 treatments, ranging from 15-100%. Reductions were 80-100% at most sites, except a few sites where pre-treatment sediment yields were unusually low (Drake et al. 2012).

Integrating Surface Drainage Patterns into Road Decommissioning: Creek Road Case Study

Unpaved road networks alter the "plumbing" of watersheds in many ways. When planning to decommission a road segment, it is critical to understand the "natural" and altered surface drainage patterns within the drainage area.

Erosion-focused rapid assessment in the Homewood Creek watershed on the west shore of Lake Tahoe revealed many eroding road segments that were contributing sediment directly to Homewood Creek. One of these was "Creek Road", where gully erosion was so severe (up to 3 feet deep) that the road was impassable by large trucks. Where was the water coming from? Aside from runoff generated from the roadbed itself, the first obvious source was a water bar routing surface runoff from a ski run upslope onto Creek Road. Further field assessment revealed that runoff from an adjoining road segment upslope (Smooth Cruise Road) was also directing concentrated flow across the ski run to Creek Road. Smooth Cruise Road had captured flow from several small ephemeral drainages, causing severe erosion of the roadbed and dewatering a larger ephemeral adjacent to the road.

Once we had an understanding of the complex road/drainage interactions in the area, road decommissioning and drainage improvements were implemented over two years. The first phase aimed to hydrologically disconnect Creek Road from Homewood Creek. First, a berm was built at the top of the road to route ski run drainage away from the road and into a stable channel. Fill material was brought in to fill the large gullies along the road and match surrounding grades. Then full (Tier 3) soil restoration treatments were implemented, including tilling wood chips (from local forestry operations) into the soil. Creek Road decommissioning treatments were assessed the following spring during runoff to determine the stability of both re-routed drainages and restoration treatments. Phase 2 focused on addressing the upslope drainage issues on and around Smooth Cruise Road. A rock-armored channel (with a subtle berm downslope) was constructed to reconnect several smaller drainages above the road with the natural drainage below, and prevent run-on to the road alignment. The roadbed was then functionally decommissioned using a combination of targeted loosening (Tier 2), where we wanted to minimize disturbance to well-established vegetation, and full soil restoration/recontouring (Tier 3). Successfully disconnecting these problem road segments from the Creek would not have been possible without first gaining a complete understanding of road-drainage interactions and developing a phased, systematic treatment approach based on this information.


Creek Rd with large gully before treatment (left) and after decommissioning (right).


Smooth Cruise Rd with erosion before treatment (left) and after decommissioning (right).

TOOLKIT

Tool 3.13 Road Management and Decommissioning

Do Abandoned Roads "Naturally" Recover?

Over time, vegetation tends to recolonize dirt roads, especially if vehicle traffic is low or excluded altogether. Dominant vegetation on compacted roads tends to be trees and shrubs, as grasses and forbs are unable to invest enough energy to get their roots down into the heavily compacted soil. This vegetation can make old roads difficult to see, but the compacted roadbeds can affect hydrology and runoff patterns for many years to come. At Homewood Mountain Resort, Road 31 had not been used by vehicles for 10-15 years. Chest-high shrubs were well-established along the road. Because of the presence of robust vegetation, a local regulatory agency was not willing to offer the resort restoration "credit" for decommissioning the road, as they believed the road had naturally recovered. We used cone penetrometer (see Tool 4.7. Cone Penetrometer), we did a quick assessment of compaction and infiltration potential. The penetrometer depth to refusal was 1-2 inches on the road bed and 12-15 inches in an adjacent native area, clearly indicating that the old roadbed had little to no infiltration potential and was still a threat to water quality. The road was later functionally decommissioned using Tier 3 treatments and the resort received restoration "credit" from the regulatory agency. This example (and several others like it) has reminded us that the effectiveness of road decommissioning should be defined and assessed based on how it *functions* rather than how it *looks*.

Slowing the Flow – Transforming Roads into Reservoirs

Many watersheds in the Sierra and throughout the west have a long history of disturbance, including mining exploration, ranching and logging. Perhaps the most lasting landscape changes are related to the roads that were created to support these activities. Individually, each road may not seem to have a substantial impact on watershed hydrology and erosion. However, the cumulative effect of active and historic/legacy roads on altering the amount and timing of water (and sediment) delivered to streams is well established (Beechie et al. 2005, Madej 2001). Compacted soils (such as roads) have the potential to hold 50-90% less water than a well-functioning, native soil. Thus, decommissioning of roads to a higher level of hydrologic function has the potential to attenuate or "stretch out" runoff in watersheds over a longer period of time. Cost-effective treatments, such as tilling/ripping wood chips into compacted soil, can functionally transform unneeded roads into temporary water storage reservoirs, thus attenuating runoff and reducing erosion.

Road 31 with well-established shrubs and a very compacted roadbed.

Here is an example of the impact that a ***roads-to-reservoirs treatment program*** could have. Let's take a road that is 1 mile long and 15 feet wide. Based on more than a decade of testing and monitoring, compacted soil on a dirt road can store approximately 8% water by volume, or 12,672 cubic feet of water for this example road. Functionally decommissioned roads (tilled to 24" with wood chips), can store approximately 40% water by volume, or 63,360 cubic feet of water for this example road. Based on this research, functional decommissioning of a 1 mile long road could increase reservoir (water storage) capacity in a watershed by 50,688 cubic feet.

Climate change projections suggest that an increasing amount of precipitation in alpine watersheds is going to come in the form of rain instead of snow, which will likely increase surface runoff, increase peak stream flows and decrease the amount of water stored in the watershed and slowly released throughout the late spring and summer months. Given the high density of roads in many watersheds, transforming unpaved roads into reservoirs offers a very cost-effective strategy for attenuating water flow, providing more steady and sustained water supplies, and adapting to the many effects of a rapidly changing climate.

SECTION 4: ACHIEVING

The **ACHIEVING** step is integral to the outcome-based management cycle. While we have presented tools for the planning and implementation phases of watershed projects, the most vital step in this approach is what comes after implementation.

Far too often, watershed management practices end with the **DOING** step. It is assumed that Best Management Practices (BMPs) and mandated activities will work, and thus the actual outcome is seldom checked. The assumption that the proposed project will inevitably be successful is often based on model predictions, which are at best educated guesses. While models generate clean numbers that are easy to understand, they are inherently incomplete, and cannot accurately represent what happens on the ground. If you are managing for outcomes, and taking ownership of the results of your work, checking the outcome is imperative. Nobody fully understands the complex systems within a watershed. If data is not collected to check the outcome of a project, you will never know if the work you did met the project goal of even had a positive effect.

Collecting post-treatment data to monitor for outcomes is a paradigm shift. It requires project managers to feel ownership over the work they do, and fully invest in achieving a valuable and verifiable outcome. It also requires project managers to build the cost of post-treatment monitoring into the budget from the planning stage—a step that is rarely taken due to the perception of high cost.

Humility is perhaps the most important aspect of **ACHIEVING** in the context of outcome-based management. We all prefer to believe, and prefer others to believe, that we are knowledgeable of the systems we work within. Training is extremely important, but being able to acknowledge that you did not achieve the outcome you hoped to or expected to is the only way to make progress. If we continue to implement activities without checking outcomes, we will continue to spend money on activities that may or may not be working. To make forward progress we must accept project "successes" and "failures", and learn from them, applying our newfound knowledge and experience to future projects.

TOOLS:

Tool 4.1 Developing a Monitoring Plan

Definition

An monitoring plan or assessment process is defined as procedures used to enhance understanding of a range of conditions required to manage and improve a watershed or watershed project. An alternative or parallel definition is found in Elzinga, Salzar and Willoughby: "Monitoring is making observations or measurements over time to detect changes or to determine the current state of the elements being monitored." For this Guidebook, the assessment process is defined within the context of outcome-based management. That is, an assessment plan is not just gathering data and information but in fact is rooted in the use of that information to determine effectiveness. Monitoring can include terrestrial (plant, soil, or other physiochemical elements) or water (quality, quantity).

Purpose

The purpose of a monitoring plan or assessment process is to help users develop a useful, and cost effective process for understanding a range of issues related to watershed management including baseline conditions, pre-project site assessments, implementation processes and project performance.

Overview

Assessment and monitoring are the primary mechanisms that supports true outcome-based management. While outcome-based management may have many faces, it cannot exist without a robust and targeted monitoring component. This section describes the development of a monitoring plan.

Current or common practices

Many projects are not monitored. Projects are constructed with the assumption that a decent plan will produce a decent project. Monitoring is considered expensive and not of great use. At the same time, there is a belief that we *must* monitor. The question becomes: 'What do we monitor and to what end?'

Investing Capital

This situation can be likened to investing in a recommended investment fund where no fund history is provided and no earnings report is produced. The investor would have absolutely no idea of how their capital investment is performing or whether their money is even available. While laws and regulations prohibit this type of hollow investment scheme, we may find parallels in environmental improvement practices when we implement without monitoring. Most individuals would not invest capital in a non-monitored investment and the same may hold true for future environmental investors or grant funding.

Future practices

This Guidebook supports the mentality that projects without monitoring represent a high probability of squandering capital. As funding for watershed projects and development becomes scarcer, monitoring will become more important. The reason is that when capital is overly plentiful, failed or partially successful, projects can be redone. However, when capital is scarce, re-treatment may not be possible and the job will need to be done correctly the first time. If problems do arise, they need to be addressed when they are small. Monitoring and assessment provides the needed support to assure proper implementation and function in projects and highlight problem areas.

Monitoring and assessment confusion

Monitoring and assessment can be extremely complex and confusing. There are many types of monitoring and many applications of monitoring. The goal of this Guidebook is to provide monitoring tools that are USEFUL and relatively inexpensive.

DEVELOPING A MONITORING PLAN

Monitoring and assessment activities vary widely depending on the project or need. The primary considerations in developing a monitoring plan are:

- **What is it that you would like to know?** That is, are you trying to understand existing conditions, change over time, whether a project is being implemented successfully or other bits of information?
- **What are the goals of the project or procedure?** Useful monitoring will always be clearly linked to project goals and objectives. The process of identifying goals and procedures may be more difficult than it seems but is well worth the effort.
- **How important is the monitoring information?** The answer to this question will help answer the next question. Can information gathered now help with future projects?
- **What level of information or understanding do you need to produce?** This is a critical question in that monitoring and assessment can range from visual observation to research level investigation. The level of effort needs to be linked to the needed outcome so that money and time are not spent needlessly but also so that important information is not left uninvestigated. If a project may be challenged or end in court, statistically defensible information may be required. If obvious performance parameters for internal project management need to be assessed, visual observations may be adequate.
- **What is your proposed monitoring budget?** This question is not as straightforward as is may seem. Monitoring funding and implementation funding can often be shifted and adjusted. Answering the previous and following questions will help suggest the level of effort and related funding that is appropriate.
- **How much do you really know about the expected project outcome?** This may be the most difficult question to answer. We implement projects with an extraordinary number of embedded assumptions. While we assume, for instance, that a commonly used practice or Best Management Practices (BMPs) will produce the desired results, can you say with certainty that this is always or even commonly the case? Many breakthrough research projects have been based on testing commonly held assumptions about project outcome.

Using a laptop is often the most efficient and accurate way to collect field data, as it reduces the potential for transcription errors and can support real-time quality control.

Once these questions are addressed, a monitoring plan can begin to be created.

TOOLKIT

Tool 4.1 Developing a Monitoring Plan

Steps in developing a monitoring plan

1) Identify project goals
2) Identify needed outcomes (measurable results)
3) Identify the level of information required or needed
4) Consider a range of assessment and monitoring options that will provide that information
5) Choose assessment tools
6) Develop measurable or defensible success criteria that can be assessed by that monitoring
7) Revisit assessment tools to make sure that the correct ones have been chosen that can provide defensible assessment of success criteria
8) Describe this process in a monitoring plan
9) Conduct monitoring
10) Timing is critical when monitoring, and should be addressed in the monitoring plan. For instance, baseline monitoring is implemented prior to a project. Implementation monitoring is performed during and just following a project. Performance monitoring is done during some time period after a project is implemented. Trend monitoring may occur through all of these periods.
11) Produce monitoring output and link to success criteria
12) If criteria are met, the project or project elements are deemed successful
13) If criteria are not met, interpretation and potential reasons are provided. If adjustments can be made, they are made (true outcome-based management requires the ability to make adjustments). If adjustment cannot be made, information is tracked and shared for future projects in order to be able to plan and implement those projects in a way that benefits from the lessons learned from this project. In this way, the entire process can be adaptive in the long term and cost effective.

Monitoring 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 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 4.2 Site Condition Assessment

Definition

Site Condition Assessment is a combination of measurements and observations collected at a specific site to develop an understanding of the erosion potential and/or limiting factors needed to develop an effective treatment plan.

Purpose

The purpose of conducting a Site Condition Assessment is to understand as much about the site as possible prior to taking action so that treatment actions are targeted, cost-effective and likely to achieve the project goals. This assessment framework is also used to evaluate treatment effectiveness after project implementation.

Overview

Projects are often planned and implemented without an adequate understanding of 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.

Measuring surface cover using a laser pointer along randomized transects (cover-point method).

Elements of a Robust Site Condition Assessment

The more robust 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 on the next page.

Tool 4.2 Site Condition Assessment

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.

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)

Rainfall simulation is a powerful tool for directly assessing soil hydrologic conditions.

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 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.

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.

Reference Site

A *reference site* is a site that represents the ideal conditions. 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 project site. The conditions of the reference site are monitored and defined to help identify specific conditions for the project 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, treatment may include addition of 4.5% organic matter and full soil tilling treatment to restore impaired functions at the treatment site.

TOOLKIT

Table 30. 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)				

Tool 4.2 Site Condition Assessment

Reference site conditions can also be compared with measured project site conditions following treatment to determine treatment success (see Tool 1.3 Developing 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 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 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.

Table 31. 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 & 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)				

"RESTORATION OF A DISTURBED ECOSYSTEM IS AN *ACID TEST* OF OUR UNDERSTANDING OF THAT ECOSYSTEM."

A.D. BRADSHAW

4.3 Types of Monitoring

Definition

Monitoring has a number of definitions. For the purposes of this Guidebook, 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.

Purposes

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. It is often an untreated area located next to the treatment site. Measurements may include soil and vegetation monitoring and other measurements that reflect site functional conditions.

Overview

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. In order to determine the true cost effectiveness of a project, *monitoring is essential.*

It is 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.

Implementation Monitoring

Conducted during and/or immediately following treatment. It serves to verify that project specifications are properly implemented. 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 are particularly important for future interpretation of project results. Documentation includes maps and drawings, as-built reports, and photos showing preconstruction conditions and the implementation process.

Performance Monitoring

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

Often a subset of, performance monitoring. It is used to determine if changes in particular parameters exhibit a trend over time.

Compliance monitoring

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 always the case.

Importance

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 includes 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.

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.

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.

Measuring soil resistance to force (surrogate for soil density) with a cone penetrometer.

TOOLKIT

4.3 Types of Monitoring

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.

Project Monitoring and Assessment Equipment/ Processes

The following pages summarize project monitoring tools that support the watershed assessment, project implementation and overall watershed improvement process.

The featured tools include:

- Rainfall Simulator
- Runoff Simulator
- Constant Head Permeameter
- Cone Penetrometer
- Soil Sampling
- Foliar and Surface Cover Point Monitoring
- Foliar and Surface Cover Ocular Estimation
- Photo Point Documentation
- Visual Erosion Assessment

Clockwise, the photos show various monitoring tools, including rainfall simulator, runoff simulator, cone penetrometer, soil sampling, and foliar and surface cover point monitoring.

"There is something fascinating about science. One gets such wholesale returns of conjecture out of such a trifling investment of fact."

Mark Twain

Tool 4.4 Rainfall Simulator

	Definition	Purpose	Output Data	How to Use it
	Produces rain storm of a known precipitation rate (water volume) to directly measure infiltration, sediment yield, and other pollutant concentrations in runoff	Used to simulate rain storms of different intensities and directly measure soil physical processes and erosion parameters	1. Infiltration rate 2. Runoff rate 3. Particle size distribution 4. Pollutant concentrations and mass measurements can be made for: • Total sediment yield • Fine sediment yield (with particle size distribution) • Organic matter in runoff	1. Install a collector frame in the ground 2. Set up simulator over the frame and connect to water source 3. Run water through the simulator at the desired rate and start timer 4. Record the time it takes to fill each sample bottle with runoff collected from the rainfall frame 5. Keep collecting sample bottles until you reach steady state runoff
	Input	Output	Source	
	$$$	☆ ☆ ☆	Must be custom built—no known commercial sources	

Input

$ = low, $$$ = high

Combination of required training, equipment cost and personnel time

Output

☆ = low, ☆ ☆ ☆ = high

Combination of applicability/usefulness and robustness/defensibility of output data and information

Data Interpretation Example

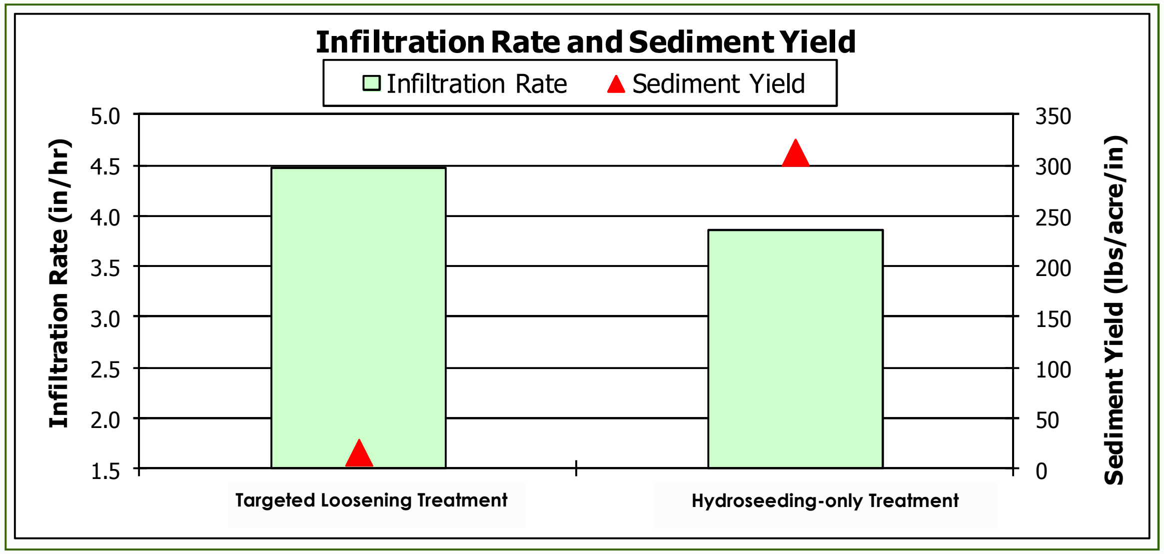


Figure 48. Example infiltration rate and sediment yield data graph.

Note: "Targeted loosening treatment" refers to loosening soil with infiltration tines mounted on an excavator bucket, incorporating wood chips into the soil, then applying fertilizer, seed and mulch. "Hydroseeding-only treatment" refers to application of seed and fertilizer only.

What does the data suggest?

This rainfall simulation example data portrays infiltration rate and sediment yield for two different erosion control treatments on a compacted ski run. **Infiltration rate** is the rate at which water infiltrated into the soil in inches per hour. The average steady state infiltration rate is typically calculated from multiple rainfall simulations. The collected runoff samples are then analyzed for **sediment yield**, which is normalized as "pounds of sediment per acre per inch of rainfall", or lbs/ac/in. Sediment yield is the amount of sediment collected in runoff water.

The data suggests that the targeted loosening treatment ("Tier 2") created soil conditions that supported a higher infiltration rate and dramatically lower sediment yield compared to the hydroseeding-only treatment.

TOOL 4.5 RUNOFF SIMULATOR

	Definition	Purpose	Output Data	How to Use it
	Produces runoff to measure infiltration, sediment yield, and nutrient content of runoff quantitatively	Used to simulate overland flow (e.g. snowmelt) at different flow rates to measure and visually assess soil physical processes and erosion parameters	1. Surface runoff rate 2. Erosion behavior; paths, parameters, etc. 3. Pollutant concentrations and mass measurements can be made for: • Total sediment yield • Fine sediment yield (with particle size distribution) • Organic matter in runoff	1. Set up simulator and water source 2. Set a collector frame downhill of the simulator 3. Run water through the simulator at the desired flow rate and start timer 4. Record the time it takes to fill each sample bottle with runoff collected from the runoff frame 5. Alternative: Record surface runoff distance in one minute increments to assess surface runoff rate (and rilling) for different sites/ treatments
	Input	Output	Source	
	$$	☆☆☆	Must be custom built—no known commercial sources	

Input

$ = low, $$$ = high

Combination of required training, equipment cost and personnel time

Output

☆ = low, ☆☆☆ = high

Combination of applicability/usefulness and robustness/defensibility of output data and information

Data Interpretation Example

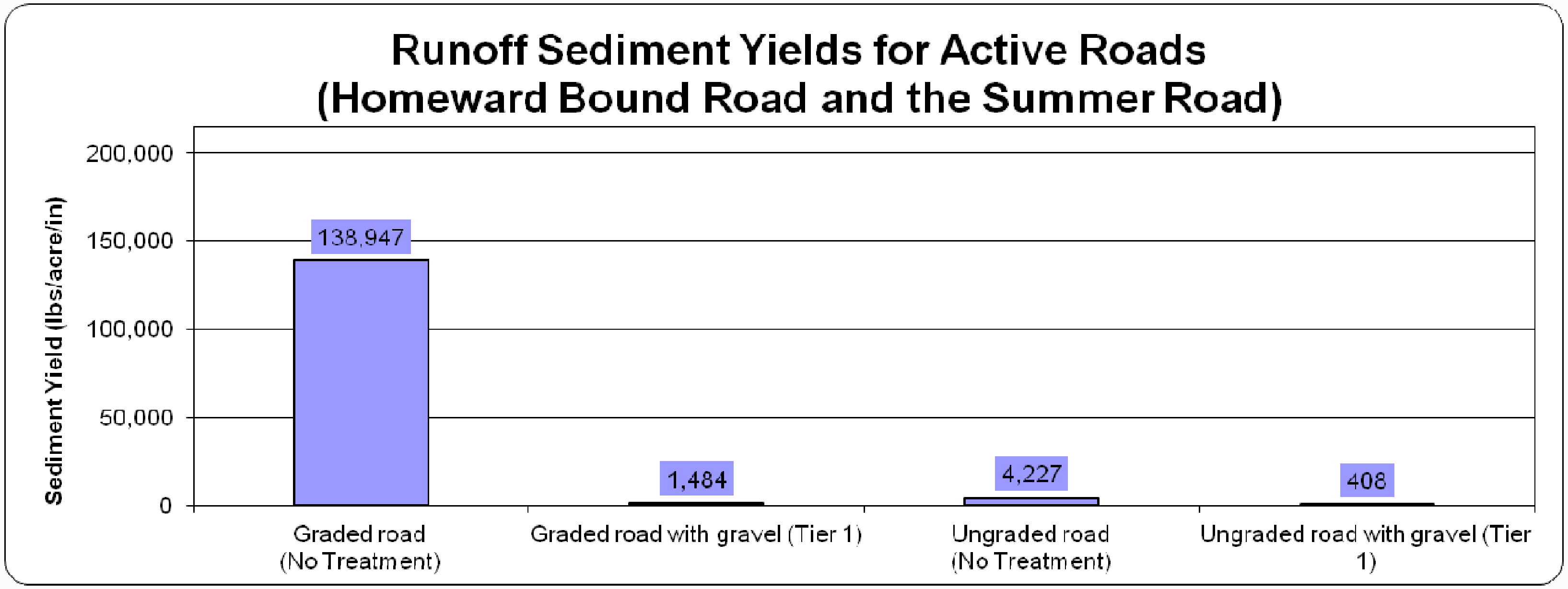


Figure 49. Example runoff sediment yield graph from active dirt roads with different management and mitigation treatments.

Note: A graded road is created by smoothing a dirt road surface with a grader or bull dozer, typically to allow for travel by low-clearance vehicles.

What does the data suggest?

This runoff simulator example graph depicts sediment yield from four different management treatments on two adjacent active roads at Homewood Mountain Resort. **Sediment yield** is the amount of sediment collected in runoff from the plot area over a 10 minute long runoff simulation. Sediment yield is normalized as "pounds of sediment per acre per inch of rainfall", or lbs/acre/in, in the graph. Runoff sediment yield measurements suggest that road grading increased sediment yields by 33 times compared to ungraded conditions. Most importantly, runoff monitoring suggests that applying 1 inch of gravel to the graded road surface can reduce sediment yield by 94 times (nearly an order of magnitude). Applying 1 inch of gravel to the ungraded road reduced sediment yield by 10 times compared to the unprotected road surface.

Management Recommendation: minimize road grading and protect the road surface with gravel (or other durable materials) to minimize sediment yield.

TOOLKIT

Tool 4.6 Constant-Head Permeameter

<table>
<tr><th></th><th>Definition</th><th>Purpose</th><th>Output Data</th><th>How to Use it</th></tr>
<tr><td rowspan="3"></td><td>Measures the saturated hydraulic conductivity of soils, or the permeability of soils</td><td>To measure soil permeability (i.e. saturated hydraulic conductivity)</td><td>Permeability, which is the Saturated Hydraulic Conductivity (Ksat) or long term constant infiltration rate when the soil is saturated.</td><td rowspan="3">1. Hammer a bore hole tool into the ground to 12 inches and remove
2. Fill the Constant Head Permeameter (CHP) with water and place in the hole through a wooden spacer
3. Open the water valve and start timer
4. Record water level at one minute intervals until steady state is reached</td></tr>
<tr><th>Input</th><th>Output</th><th>Source</th></tr>
<tr><td>$</td><td>★ ★</td><td>Build from pvc piping, ball valve and water gauge.</td></tr>
</table>

Input

$ = low, $$$ = high

Combination of required training, equipment cost and personnel time

Output

★ = low, ★ ★ ★ = high

Combination of applicability/usefulness and robustness/defensibility of output data and information

DATA INTERPRETATION EXAMPLE

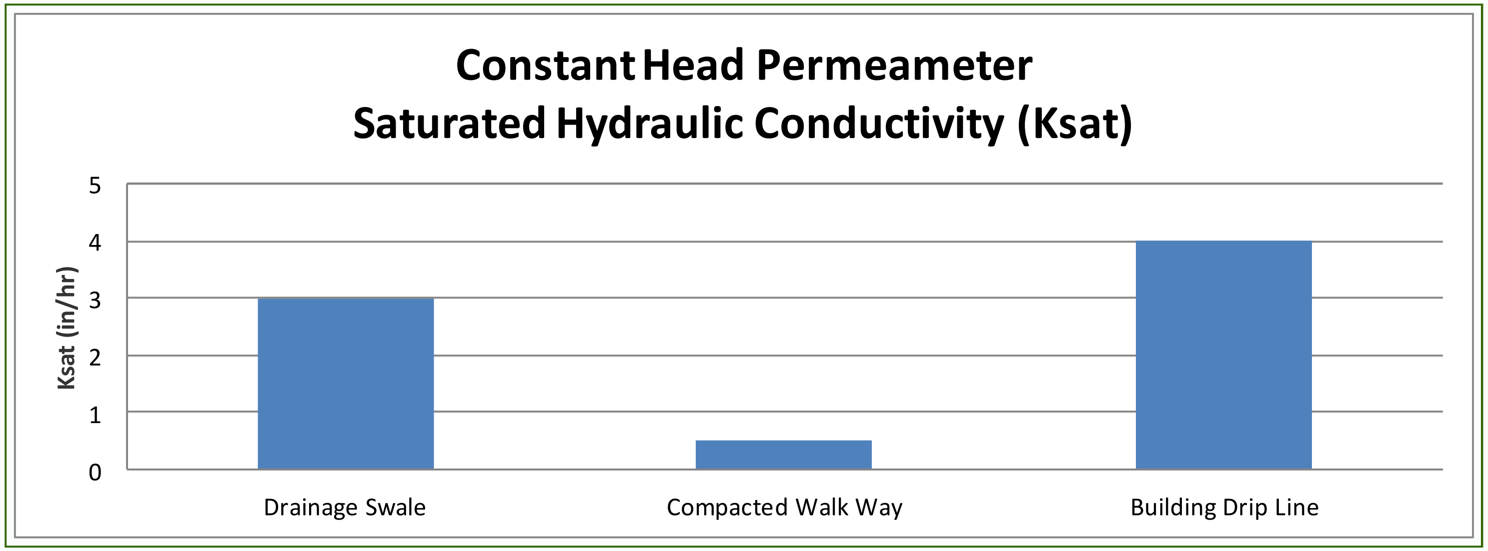
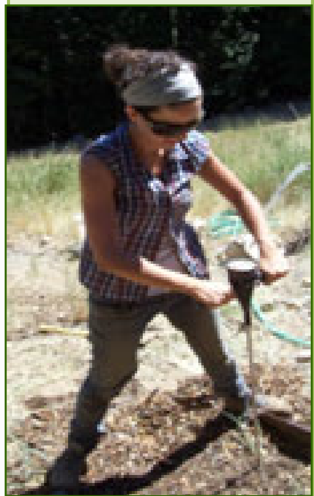


Figure 50. Example saturated hydraulic conductivity (infiltration in inches/hour) data graph.

What does the data suggest?

The constant-head permeameter (CHP) tests the constant rate of infiltration into soils, which is also referred to as the saturated hydraulic conductivity (K_{sat}) or permeability. Results are typically presented in inches per hour. In the example above, the CHP was used to assess infiltration capacity of BMPs around a school site. Results indicate that the building drip lines, and the drainage swale (where wood chips were tilled into the soil) exhibited infiltration rates 6-8 times greater than a nearby compacted walkway. CHP tests can be performed each year to directly assess the effectiveness of infiltration BMPs and to determine if/when maintenance needs to be performed.

Tool 4.7 Cone Penetrometer

	Definition	Purpose	Output Data	How to Use it
	Measures a soil's resistance to force, which can be used as a surrogate for soil density and infiltration potential	Cone penetrometer measurements can be used to assess compaction and infiltration potential, identify restricting soil layers, check soil loosening depth during treatment implementation, and many other uses	1. Soil depth-to-refusal at specified pressure, which can be used as surrogate for soil density and infiltration potential 2. Depth of root-restricting soil layers 3. Soil loosening depth	1. Position the penetrometer vertically so that the dial faces you and the pointed tip is touching the ground. Use the bubble on the dial to level the penetrometer 2. Grip the two handles and push the cone tip into the ground until you reach the desired pressure (350 PSI is a good starting point) on the dial (this is the depth to refusal, or DTR) 3. Place finger on point of penetrometer at ground surface, and pull road out of ground 4. While keeping finger in place, read the depth to refusal by utilizing the line markings spaced out in increments of 3 inches, (e.g. 11" DTR)
	Input	Output	Source	
	$	☆ ☆	Order from Spectrum Technologies: www.Specmeters.com	

Input

$ = low, $$$ = high

Combination of required training, equipment cost and personnel time

Output

☆ = low, ☆ ☆ ☆ = high

Combination of applicability/usefulness and robustness/defensibility of output data and information

DATA INTERPRETATION EXAMPLE

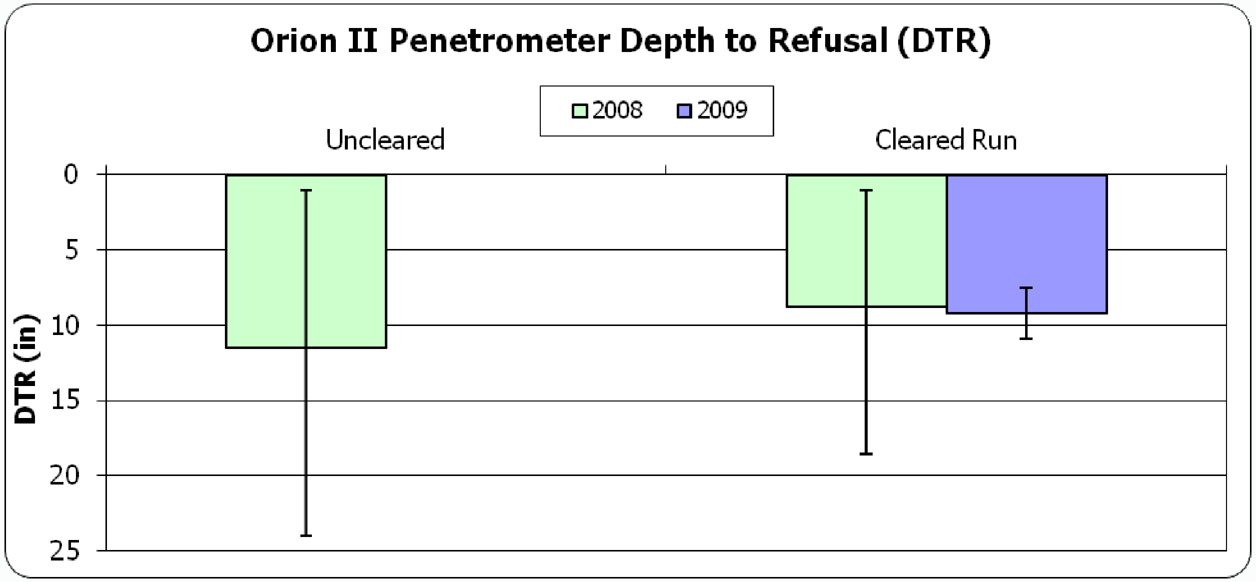


Figure 51. Average penetrometer depth to refusal graph. The error bars denote one standard deviation above and below the mean.

What does the data suggest?

Cone penetrometer monitoring was used to assess whether soil compaction occurred as a result of clearing (tree removal) for a new ski run at a Tahoe area ski resort. Measurements taken at the cleared run were compared to measurements at an adjacent uncleared run. Error bars are displayed for each site (one standard deviation from the mean) to show the variability in cone penetrometer depths at each site, and the large error bars indicate very high variability (i.e. a wide range of depths). When error bars overlap, measurements cannot be considered statistically different. Therefore, cone penetrometer monitoring results suggest that ski run clearing did not have a measurable effect on soil compaction, as measured with depth to refusal.

Note: Penetrometer DTRs should only be compared at similar soil moisture levels, since penetrometer resistance to force tends to decrease (which is typically associated with deeper DTRs) as soil moisture increases.

Tool 4.8 Soil Sampling

<table>
<tr><th></th><th>Definition</th><th>Purpose</th><th>Output Data</th><th>How to Use it</th></tr>
<tr><td rowspan="3"></td><td>The collection of soil samples, for subsequent lab analysis, to measure specific nutrient and physical parameters</td><td>Soil organic matter and nutrient levels can be used to develop appropriate restoration treatments and assess site resilience (e.g. ability to support vegetation, infiltrate and store water, etc.)</td><td>1. Nutrient content
2. Organic matter content
3. Physical properties
4. Chemical properties</td><td rowspan="3">1. Dig at least three, 12 inch deep holes
2. Using a trowel, collect soil from a hole by scraping the soil off the walls of the hole. Try to collect an equal amount of soil from the entire range of the pit wall
3. Repeat for the other two holes
4. If a 2mm sieve is available, sieve the sample
5. Send sample to a soil lab for analysis</td></tr>
<tr><th>Input</th><th>Output</th><th>Equipment Needed</th></tr>
<tr><td>$</td><td>★ ★</td><td>Buy a trowel, soil sieve, and Ziploc bags</td></tr>
</table>

Input

$ = low, $$$ = high

Combination of required training, equipment cost and personnel time

Output

★ = low, ★ ★ ★ = high

Combination of applicability/usefulness and robustness/defensibility of output data and information

Data Interpretation Example

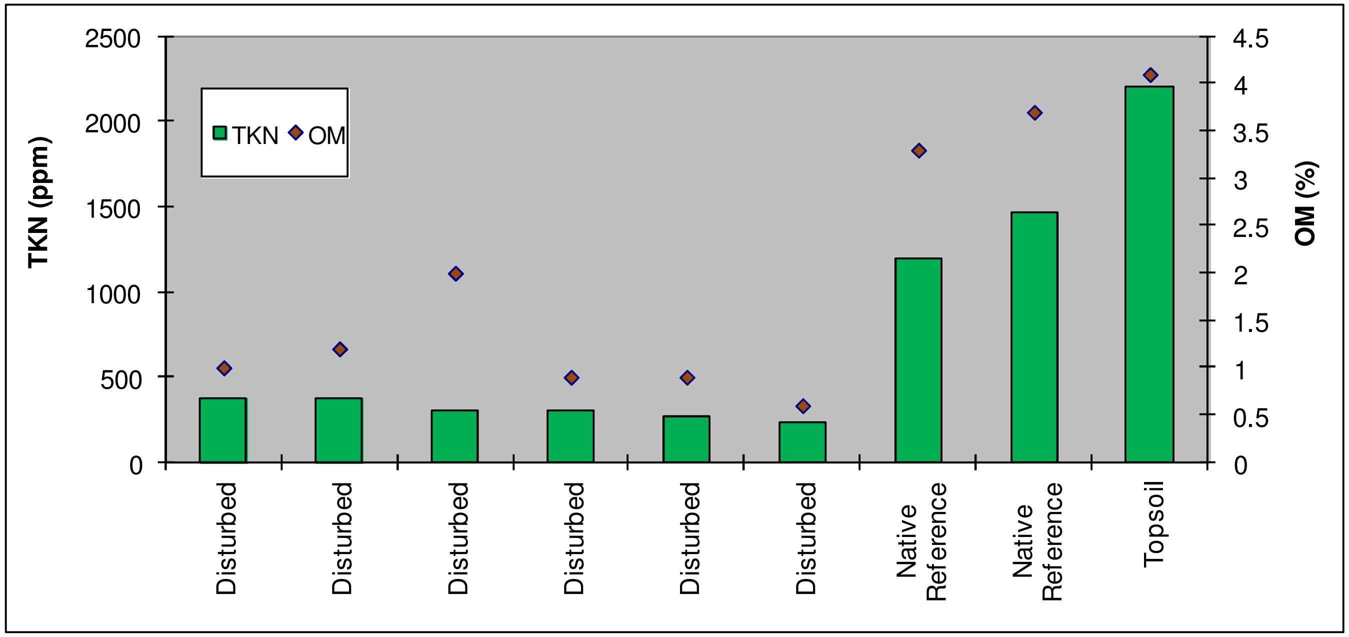


Figure 52. Soil organic matter (OM) and total Kjeldhal nitrogen (TKN) levels.

What does the data suggest?

In this example, soil sampling and analysis was conducted for an erosion control project to determine soil nutrient and organic matter levels for and appropriate types and amounts of soil amendments to be added. Samples were taken in disturbed areas (where topsoil had been removed and grading occurred), in a nearby native reference area, and of the topsoil salvage from the site the previous week. Samples were analyzed for percent soil organic matter (OM) and total Kjeldhal nitrogen (ppm) to determine how much "capital" was in the soil.

Results suggest that disturbed areas are lacking in both OM and TKN compared to reference levels. More importantly, the salvaged topsoil material is rich in both OM and TKN. Doing some simple calculations (see Tool 3.6. Topsoil Salvage and Reuse), the project revegetation specialist was able to determine an appropriate application rate for reapplying topsoil to disturbed areas to increase both OM and TKN to levels similar to the native reference site. Soil testing and topsoil salvage saved the project money by avoiding the need to bring in soil amendments from offsite.

Note: Soil nutrient and OM levels vary widely across even small areas. Several sub-samples can be composited to average out some of this variability. Soil testing can be a very cost-effective way to determine appropriate, site-specific amendment and fertilizer additions and set restoration projects up for long-term success.

Tool 4.9 Foliar and Surface Cover Point Monitoring

	Definition	Purpose	Output Data	How to Use it
	A quantitative method of measuring cover	To assess the amount and type of plant and surface cover	1. Plant cover 2. Ground cover 3. Bare ground 4. Verifying success criteria	1. Lay out one or multiple measuring tapes to be used as a transect 2. Determine intervals to take measurements 3. Hold the cover pointer vertically, adjacent to the pre determined spot on the transect tape 4. Press the button on the laser pointer and record what the laser pointer hits (i.e. rock, plant, bare dirt) 5. Repeat measurements along each transect
	Input	Output	Equipment Needed	
	$$	☆ ☆ ☆	Construct a cover pointer with a laser pointer taped to a vertical, easy to maneuver, straight object; 100 ft. measuring tapes can be found at any hardware store.	

Input

$ = low, $$$ = high

Combination of required training, equipment cost and personnel time

Output

☆ = low, ☆ ☆ ☆ = high

Combination of applicability/usefulness and robustness/defensibility of output data and information

Alternative Methods of Foliar and Surface Cover Point Monitoring:

- Step-point
- Right-angle laser device with bubble level
- Plumb bob or metal rod held vertically by its weight
- Daubenmire frame

Data Interpretation Example

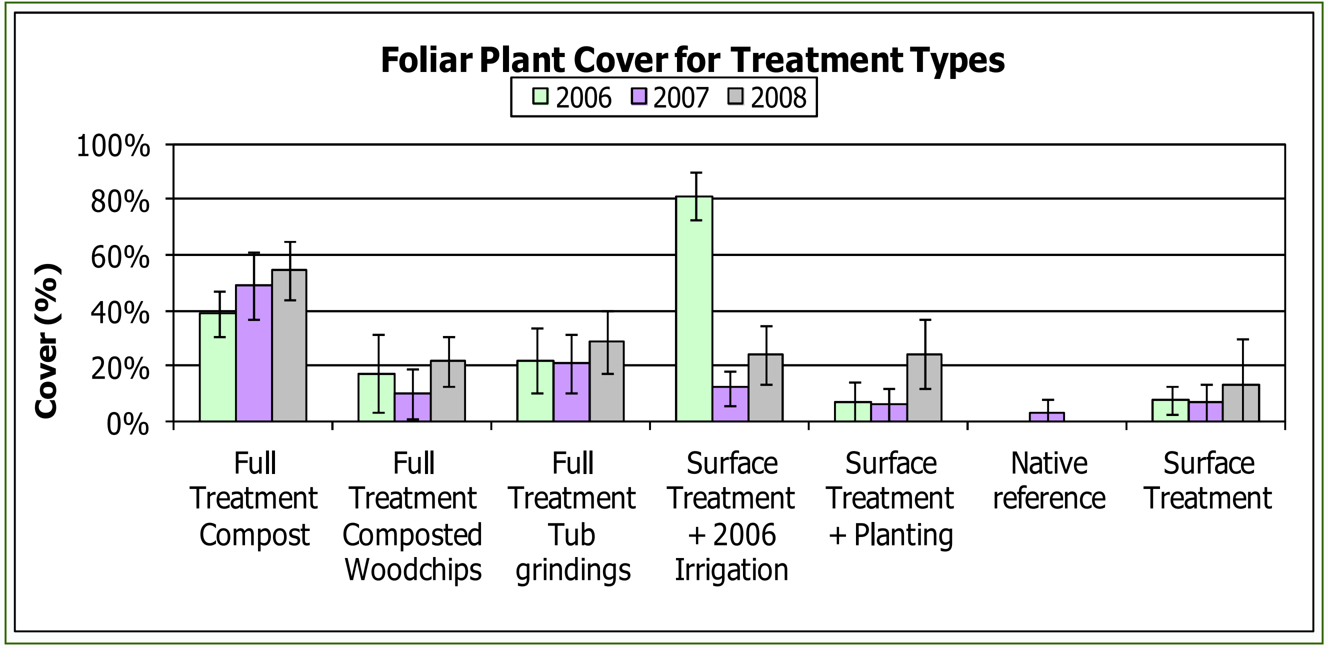


Figure 53. Example foliar plant cover percentage graph. The error bars denote one standard deviation above and below the mean.

What does the data suggest?

Surface cover was measured using the statistically-defensible cover point method along randomized transects. This example data portrays the foliar cover by plants at several different treatment plots over a three year period. **Foliar cover** is the cover by plants (leaves and stems). Foliar data can be analyzed by total cover (as in the graph above) or broken down by species. Cover point monitoring can also be used to measure total ground cover (plants, mulch, rocks etc.) and total bare ground.

In this example (Tahoe-area road cut reveg test plots), the plot with the highest sustained plant growth was the full treatment (tilling, soil amendments, fertilizer, seed, mulch) plot with compost. All treatments exhibited an overall increase in vegetation cover between years 1 and 3, with the exception of the surface treatment plots (hydroseeding-only, no soil treatments). At this site, irrigation was used in year 1 only, which supported robust plant growth for 1 year , but vegetation cover decreased by more than 80% in year 2.

TOOLKIT

Tool 4.10 Foliar and Surface Cover Ocular Estimation

Definition	Purpose	Output Data	How to Use it
A relative or subjective method of assessing cover	To assess the amount and type of plant and surface cover	1. Plant cover percent 2. Ground cover percent 3. Verifying success criteria	1. Define the area of interest. 2. Compare a reference guide, such as a photo of an area where cover has been measured, to the cover in the area of interest. 3. Either assign a discrete value to the estimated cover (e.g. 15%) **OR** create cover classes such as 0-25%, 26-50%, etc., and assign a class to the estimated cover. As a rule, rounding to the nearest 5 or 10% is useful since the eye cannot discern small differences.

Input	Output	Equipment Needed
$	★ — ★★	Camera for reference photo where cover is estimated

Input

$ = low, $$$ = high

Combination of required training, equipment cost and personnel time

Output

★ = low, ★ ★ ★ = high

Combination of applicability/usefulness and robustness/defensibility of output data and information

Ocular or visual estimates vary between observers and even within a single observer. Visual estimates are quick and therefore useful in a very general way. Accuracy even for highly trained individuals is low. When visual estimates are used, the method should always be disclaimed when the data is presented.

Ocular or visual estimates can take many forms. Use of a grid, as is used in Daubenmier plots, can increase accuracy. Photos of measured plant or ground cover used in the field as comparison can be helpful. Direct measurement of cover following a visual estimate can help calibrate the observer's eye. Accuracy of visual estimates are always subject to challenge and should not be presented as 'fact'. Statistical analysis cannot be defensibly performed on visual estimates since observer error is nearly impossible to determine. Ocular estimates are better suited for finding rare plants, those that make up a very small portion of the plant population, compared to statistically-valid cover monitoring methods, which are less accurate at either very low or very high cover levels. For more information, see: http://wiki.landscapetoolbox.org/doku.php/field_methods:ocular_cover_estimate

Alternative Methods of Foliar and Surface Cover Ocular Estimation:

- Gridded frames
- Cover patch diagrams
- Braun-Blanquet cover classes

Data Interpretation Example

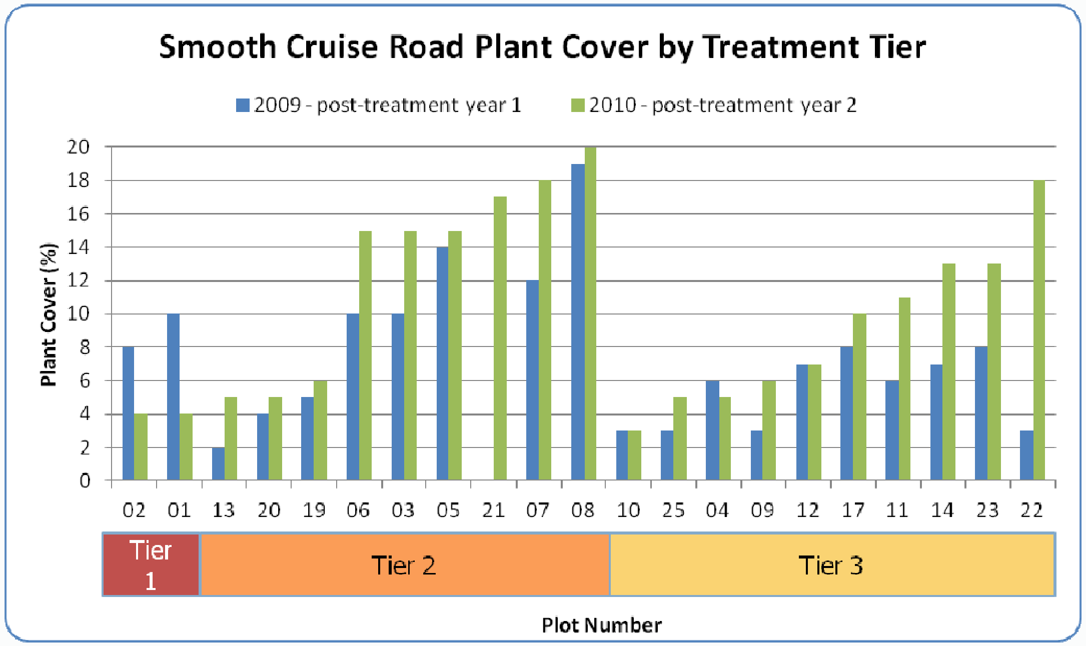


Figure 54. Ocular estimates of plant cover following different "tiers" of treatment on a forest road. Tier 1 is mulch-only treatment; Tier 2 is targeted loosening; Tier 3 is bucket tilling.

What does the data suggest?

At the Smooth Cruise Road test plots, we asked the question: How do different soil loosening methods affect plant cover? Our hypothesis was that targeted loosening can be used to loosen compacted soil with less disturbance to existing vegetation and less disruption of the soil structure than bucket tilling. As illustrated in the graph above, percent plant cover at Tier 2 (targeted loosening) plots was, on average, slightly higher than Tier 3 plots (bucket tilling). All plots were seeded with the same seed mix and rate, but the higher plant cover in Tier 2 treatment plots is presumed to be the result of less disturbance to both vegetation and soil during the targeted loosening process. The upshot is that targeted loosening can be a bit faster to implement than bucket tilling and can achieve similar or better outcomes in terms of vegetation protection and establishment. This is an important finding as we work to develop cost-effective treatments for sediment source control.

Note: Ocular estimates can be a rapid way to asses the vegetation and other types of surface cover. However, estimates can vary from person to person and calibrating your eye for accurate ocular estimates can take many years of practice. Ocular estimates are generally more useful for assessing relative differences in cover between different areas than for determining absolute cover.

Tool 4.11 Photo Point Documentation

<table>
<tr><td rowspan="4">
</td><th>Definition</th><th>Purpose</th><th>Output Data</th><th>How to Use it</th></tr>
<tr><td>Taking photographs at fixed locations over time utilizing GIS technology to mark locations and photo points</td><td>To document visual changes over time</td><td>1. "Before" and "After" photos of treatment area
2. Success criteria indicators
3. Visual documentation</td><td rowspan="3">1. Establish a photo point by taking a photo and then label the location and direction the photo was taken on a site map. Record GIS points of each photo location if necessary and/or install permanent landmarks such as t-stakes, flags, and record identifying features
2. Be sure to note specifics of where the photo was taken, such as "10 feet uphill from the road or standing on the large stump"
3. Repeat the photo point at given intervals making sure to match the new photo exactly with the original</td></tr>
<tr><th>Input</th><th>Output</th><th>Equipment Needed</th></tr>
<tr><td>$</td><td>★ ★</td><td>Digital camera and a tracking spreadsheet</td></tr>
</table>

Input

$ = low, $$$ = high

Combination of required training, equipment cost and personnel time

Output

★ = low, ★ ★ ★ = high

Combination of applicability/usefulness and robustness/defensibility of output data and information

Data Interpretation Example

Before Treatment

After Treatment

Example photo point documentation.

The photo points at left clearly show the differences between pre-treatment conditions and the same site 4 years after road decommissioning treatment. When presented with performance data, photo points help to tell the story of a restoration or erosion control project. The example as-built map, below, shows the location and direction of project photo points, which enables anyone to return to the site to retake photo points years after the project is completed.

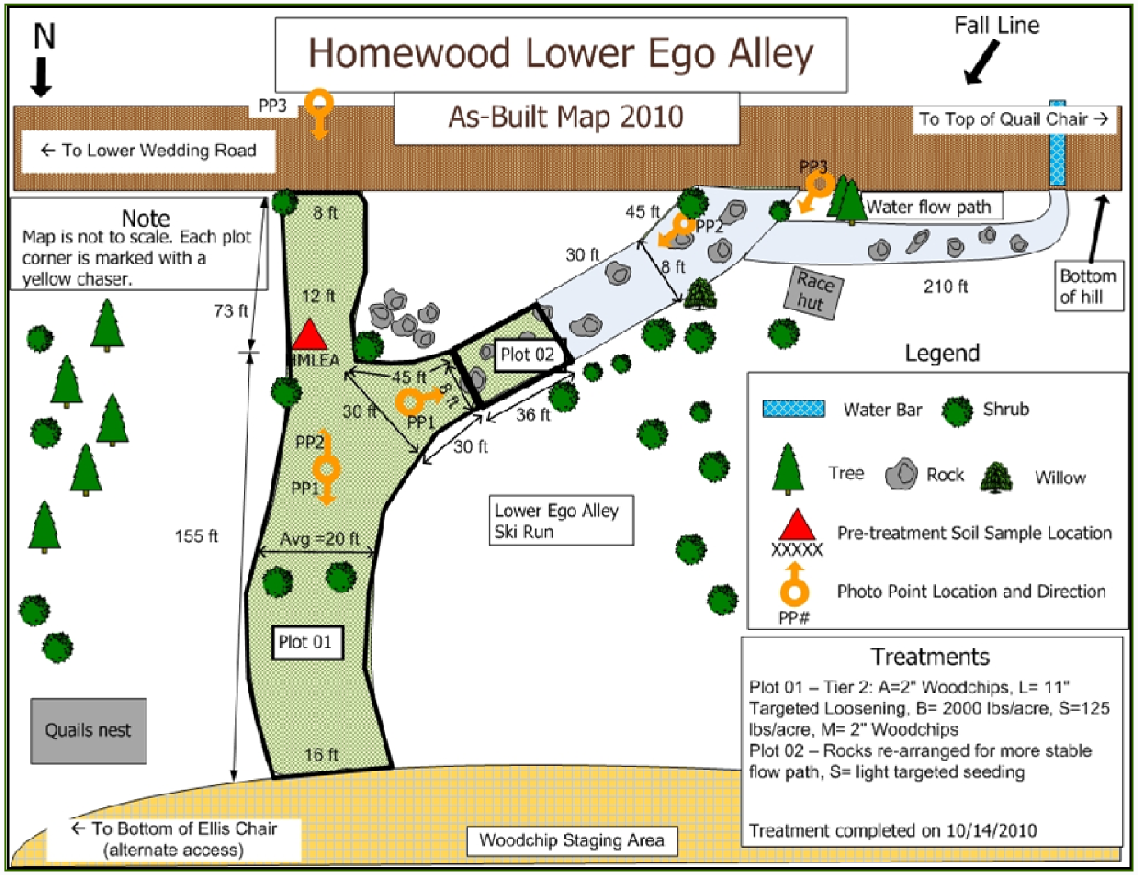


Figure 55. Example as-built map showing photo point locations and directions.

Tool 4.12 Visual Erosion Assessment

	Definition	Purpose	Output Data	How to Use it
	The process of identifying physical signs of erosion from direct or indirect field evidence	To identify active erosion and signs of erosion in order to determine the source(s) of erosion problem and connectivity to other areas (e.g. run-on and runoff areas). The overarching purpose is to use this assessment to develop effective treatment approaches	1. Map showing erosion "hot spots" and connecting features 2. Photo documentation of erosion issues and connecting features	1. Visually survey the project area and/or known erosion problem areas, ideally during or immediately after rain or snow melt 2. Track erosion problems (e.g. rills) upslope to identify their source(s) 3. Document erosion areas and connecting features on project plans, a topo map, or using GPS 4. Develop a stepwise treatment approach based on connectivity of erosion features
	Input	**Output**	**Equipment Needed**	
	$	★ ★	Camera and map to document	

Input

$ = low, $$$ = high

Combination of required training, equipment cost and personnel time

Output

★ = low, ★ ★ ★ = high

Combination of applicability/usefulness and robustness/defensibility of output data and information

Data Interpretation Example

Photo sequence from visual erosion assessment—from source, to conveyance (road), to stream.

The example photo sequence at left shows an area of road erosion directly above a live stream that was identified during spring snowmelt. Tracing the erosion upslope identified a large rill that led to an area where water was pooling next to a ski lift. The pooling water in a compacted area (used for seasonal vehicle parking) was identified as the primary source of runoff causing the road erosion problems downslope. Rather than simply installing a water bar on the road, the compacted areas next to the ski lift was tilled and 4 inches of wood chips were incorporated into the soil to create high infiltration rates and reduce the chances of pooling water running down the road again the following spring.

Assessment of the source of this particular erosion problem area was documented with photos as well as on a water flow map. This map was used to determine all the areas where roads were capturing runoff and to prioritize road maintenance efforts each spring and fall.

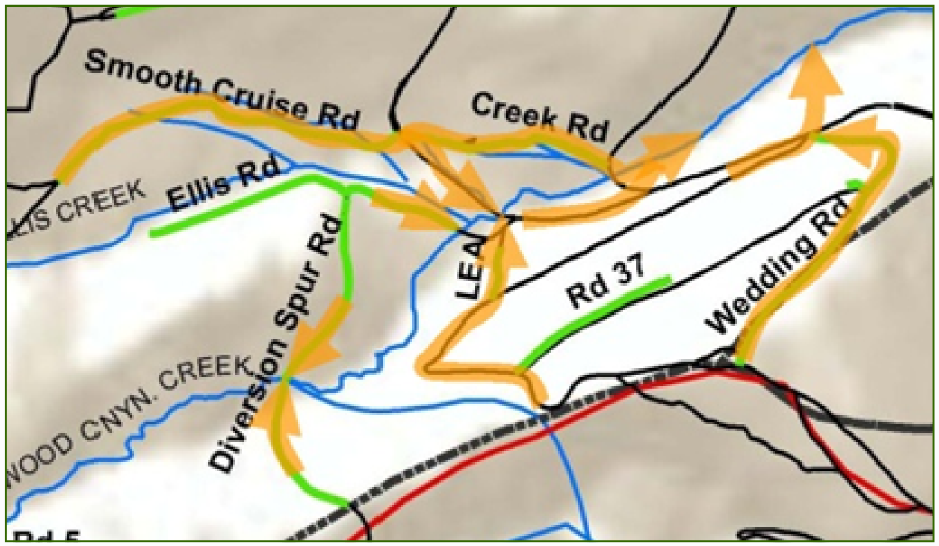


Figure 56. Map showing erosion problems and water flow paths, produced using visual erosion assessment in field.

Tool 4.13 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 towards achieving the 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 outcome-based management process. Outcome-based 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 outcome-based 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.

Effective management responses are explicitly linked to success criteria and monitoring, which ultimately determines whether project goals have been met and whether a management response is necessary. Outcome-based 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 turbidity less 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, these are the potential actions we will take to ensure that the goals are met."

Section 5: IMPROVING

Not getting the desired outcome from a project on the first or second attempt can be seen as a huge opportunity, rather than a failure. "Failure," if viewed in this way, opens the door to meaningful progress. If what we are currently doing is shown not to work, we are afforded the opportunity to improve. This shift in thinking requires a few changes in the current general practices of projects in watersheds. First, the outcomes must be checked (see Section 4.0 Achieving). Second, "failure"—or rather the lack of meeting the expected success criteria—needs to be accepted and shared openly. Third, partnerships must be formed and creative thinking employed in an attempt to IMPROVE on the practices that did not achieve the desired outcome.

This section addresses the third step, where partnerships must be formed and information shared. It presents methods to reflect critically on post-treatment monitoring results, share them in a network of people and agencies trying to reach the same outcome, and create forums to improve future projects. To fully enter the cycle of outcome-based management, actors in watershed projects need to realize that we are not there yet. Our practices are not perfect, and we need to improve if we are going to meet the goals we have set for ourselves in terms of water quality improvement and environmental protection.

Tools:

5.1 Exchanging Information

5.2 Improving Future Projects

Tool 5.1 Exchanging Information

Project partners and funders on a tour of restoration projects at Homewood.

Definition

Information exchange refers to the process of asking questions, sharing information and experiences, and being open to discovering new perspectives.

Purpose

In the context of watershed improvement efforts, the overarching purpose of exchanging information is to **improve project outcomes**. Project improvement requires active learning, which tends to be limited when information is confined to an individual or a small group of people who are all closely engaged with a particular project. Exchanging project results, ideas and experiences with other people throughout an industry or community engaged in similar work can be a gateway to discovering new perspectives and innovative techniques. This Guidebook is itself an effort to exchange information in order to improve the outcomes of watershed efforts. Information exchange is foundational for the **IMPROVING** step in Outcome-Based Management, but is also an important element of the **GAINING UNDERSTANDING** step.

Overview

Sharing information can take multiple forms: online media (website, blog, database, discussion forums, RSS feeds, Facebook pages), in person meetings, workshops, reports, publications, small conferences, weekly discussions, meetings, newsletters, etc. The important aspect is how to share information effectively so that it directly impacts/improves future work. This process can be broken down into the following steps:

1. Assess available information and what you can "offer" to others
2. Assess how your information is useful to others, in what realm, and for whom (who is your audience?)
3. Based on your audience and level of information, assess which form the sharing would do best through (and why), and create an action plan
4. Distribute your information with others via specified realm and assess how it is working (or not) and re-evaluate if needed to improve

Tool 5.1 Exchanging Information

Options for Exchanging Information

Information exchange can range from one-on-one to large groups, one-time to long-term, simple to complex. The table below provides a small cross-section of information exchange options with key uses and considerations for each.

Table 32. Information Exchange Alternatives Matrix

Category	Mode	Uses, Considerations
In-Person	Meetings	Smaller groups; relationship building; can define target audience; strong facilitation can be highly beneficial
	Conference/Workshop Presentations	Larger groups focused on specific topic; relationship building opportunities; often requires travel and substantial planning/prep
Documents	Newsletters	One-way communication; can target specific audience; one-way communication
	Reports	Tend to be written for narrow audience; large documents can discourage some potential readers; one-way communication
	Peer-reviewed publications	Builds credibility; reaches narrow, technical audience; rigorous review and feedback; one-way communication
Web/Online	Blog	Efficiently reach large number of people but little control over audience; not ideal for 2-way communication and building relationships;
	Discussion forums	Efficiently reach large number of people; can define audience/participants; designed for 2-way communication; limited relationship-building; requires designated moderator; keeps record of dialog

Tool 5.2 Improving Future Projects

Definition

Improving future projects refers to learning from current projects, applying lessons learned to future projects, and sharing information with others to improve similar projects. Outcome-based management encompasses learning from "mistakes," or more appropriately, bumps in the road, and using them as fuel towards project improvement. Nothing is gained if nothing is learned from the process. Currently, there exists a common misconception that projects are finalized once the box has been checked, the paper turned in, and the site signed off on. However, this is just the starting point in the improvement process. When reflecting on a project, ask yourself, what went well? What did not go smoothly? What can be done better (more efficiently, more economically, better researched, etc.)? How can I mitigate/improve/remedy this for the future? Who can I collaborate with and ask for advice? What kind of feedback have I received regarding this project and what is the significance?

Purpose

To gain a sense of awareness and reflection concerning the project successes and areas to improve in order to enhance relevant future tasks/projects.

Overview

Steps in improvement/feedback process:

1. Assess project on a whole
2. Identify gains and "failures"
3. Look for specific reasons why things worked vs. didn't work
4. Create action plan to mitigate and/or remedy future situation
5. Ask for feedback, advice, and collaboration opportunities for improvement
6. Commit to future change

Tool 5.2 Improving Future Projects

Cost Effectiveness

Improvement does not suggest failure of the current state. Instead, improvement is an opportunity to increase understanding and effectiveness. Improvements should be aimed at cost savings. Since effectiveness cannot be accurately assumed, it is imperative that it be measured or otherwise assessed.

Projects are seldom perfect and a great deal remains to be learned about why projects perform as they do. Perhaps one of the greatest ways to gain that understanding is within the projects themselves, as opposed to traditional research. The ability to assess a project's performance offers insight into how to increase that performance, especially when outcomes are not at first achieved. It is in not reaching goals that one can find a rich opportunity for learning. Thus, improving future projects depends in part on understanding shortcomings of current projects and using that understanding to adjust unsuccessful elements of the project. Those elements may include physical processes, materials, timing, coordination or any number of things.

How Regulation can influence Improvement

Many regulations have been interpreted as binary-either you have completed the requirement or you have not. Implementers often feel that there is little flexibility within regulations, and therefore try to do the bare minimum of what is required to get a project permitted or signed off. This perception of inflexibility can be a significant impediment to looking at a project critically in order to make improvements.

In order for improvement to take place in meaningful manner, this perception must be changed. Changes can include:

- Agency staff clarifying what flexibility exists in current regulations (there is often more flexibility than perceived, as long as the project meets regulatory goals).
- Regulatory agencies incentivizing implementers to take risks and try new approaches to achieve project goals. This requires both regulatory agencies and implementers to accept that previous projects may not have met all the intended goals.
- The willingness of implementers to work toward a clearly defined project outcome and to take responsibility for the outcome.

In the end, both regulators and implementers must take responsibility for goals being achieved:

1. **Creative flexibility** - Regulatory agencies define opportunities for flexibility and try to incentive risk-taking to meet project goals.
2. **Commitment to outcome** - Implementers take responsibility for a project's functional outcomes rather than just trying to meet regulatory requirements.

Decommissioned road at Homewood Mountain Resort, Lake Tahoe California.

"If there is no struggle, there is no progress."

Frederick Douglass

PART THREE

LITERATURE REVIEW

Part Three: Literature Review

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Section 1: Toward a New Watershed Management Paradigm

For the past 40 years, so-called "command-and-control" regulatory approaches have been employed to effectively address discrete and obvious or single point sources of water and air quality degradation These sources include industrial discharges to waterways, pollutant emissions from smokestacks, and disposal of hazardous wastes. Traditional, top-down regulatory programs have been successful at achieving the intended outcomes of point-source pollutant reductions (Office of Management and Budget 2005). These scenarios share a few common characteristics in that they are relatively simple, replicated systems with single management objectives backed by broad public support (e.g. remove specific pollutants from a single source) (Johnson 1999). Additionally, a single agency is typically in charge of regulatory oversight. Therefore, improvements in management of these systems arose largely from identifying and addressing technological and scientific issues (Brunner and Clark 1997).

The key environmental management challenges that we face today, ranging from non-point water quality pollution to suburban sprawl to climate change, are broadly distributed. Today's challenges are ecologically and politically complex and rarely have clear or single lines of causation. Our prescriptive regulatory model is not well-suited to address these types of complex problems. This is partly due to the lack of information we need to develop appropriate targets for the prescriptions, the ability to fully understand how systems will respond (or are responding) to particular treatments and the lack of robust or cost effective monitoring methodologies. Increasing recognition that a number of our most pressing environmental degradation problems are complex, dynamic and adaptive in nature demands that our regulatory programs themselves must be managed adaptively to be effective (Ruhl 1997).

TRADITIONAL ENVIRONMENTAL DECISION MAKING IN THE 21ST CENTURY

Before we explore adaptive approaches to environmental management, it is useful to first compare some of the most common approaches to management decisions. Johnson (1999) outlines four traditional agency decision-making approaches with the fifth being adaptive management (summarized below). Each approach builds on the previous, moving from most simple to most complex.

1. **Political/social approach** – main concerns are public and political response to a decision. Sometimes dictates a specific course of action to appease a powerful interest or to keep options open for the future. However, a decision to do nothing or to delay action until more data becomes available is often a political/social decision.
2. **Conventional wisdom approach** – use a historical method or rule-of-thumb that has been applied in similar situations in the past. Key assumption is that the response to management will be similar to that experienced previously. Many of an agency's recurring decisions, such as how many fish to stock, how many board feet to cut, or what level of a pollutant to allow, are often made using this approach.
3. **Best-current-data approach** – uses current data collected through new or existing sampling programs. Managers analyze the data using the latest techniques, assess their management options, and then choose the best option to implement. Examples of this approach include many habitat enhancement projects and management for various forms of optimal sustained yield.
4. **Monitor-and-modify approach** – policy decisions are typically made using the conventional wisdom or best-current-data methods, and then the policy is implemented along with a monitoring plan. Monitoring data is used to evaluate and periodically modify the policy relative to a specific goal, such as total allowable harvest, production of habitat units, or concentration of some pollutant. The purpose of periodic modifications is to "hone" the management policy and to <u>maintain the system in an optimal state</u>. Most management that involves annual resource assessments and policy updating is conducted using this approach, including management of many marine fish stocks.
5. **Adaptive management approach**- begins by bringing together interested parties (stakeholders) to define the management problem, the need for action, goals, and key information gaps. Decision support tools, such as computer models, are sometimes developed that express participants' collective understanding of how the system operates and to assess the significance of data gaps, areas of highest uncertainty, and to predict the effects of alternative management actions. A management plan is then developed and implemented along with a monitoring plan that will help assess progress toward management goals by evaluating the effects of specific actions. Monitoring data and information can be used to fill critical data gaps and reduce uncertainties. As implementation and monitoring proceed, results are analyzed, and management plans are revised as we improve our understanding of how the system works.

We address these commonly used approaches to management in this Guidebook. Ultimately, this Guidebook is based on the hypothesis that complex, adaptive systems require adaptive management processes that can embrace complexity and lack of complete knowledge without getting bogged down or even stopped by knowledge gaps.

A PLAN IS NOT A PROJECT

A common characteristic of traditional top-down decision-making approaches outlined above (particularly in approaches 1-3) is that the focus is heavily weighted on the "front end" of the project process – planning and predicting – with limited focus on the "back end" – project implementation and checking actual outcomes. In short, we focus primarily on the *PLAN* rather than the *PROJECT*. This "front end" focus is exemplified in the formulation and implementation of the National Environmental Policy Act (NEPA), where project proponents are required to analyze and predict the potential impacts of alternative management actions before any actions are taken. The financial costs and time associated with computer modeling, data analysis, public involvement and litigation on the "front end" can be daunting, while relatively little attention is paid to measuring, understanding and improving actual on-the-ground results on the "back end" of projects. Further, NEPA, California Environmental Quality Act (CEQA) and other regulatory tools have

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little recourse to address projects that do not meet goals, short of extended litigation, which typically does not directly address the problem itself. Agencies are rarely rewarded for flexibility, openness, and their willingness to experiment, monitor and adapt (Grumbine 1994). Thus, agencies seldom require changes to a project over time if the preliminary assessment of the likely environmental impacts proves inaccurate (Doremus 1999). In our current management paradigm, the focus tends to be on implementing the plan rather than committing to achieving specific outcomes.

Environmental Management Systems (EMS)

The concept of Environmental Management Systems (EMS) has grown out of international discussions related to the ISO 14001-certified management framework (established by the International Organization for Standardization), embraced and popularized by the U.S. Environmental Protection Agency (EPA) in recent years. The primary guidance document for developing and implementing an EMS in the U.S. is "Environmental management systems: An implementation guide for small and medium-sized organizations" (Stapelton et al. 1996). EMSs are built on the "Plan, Do, Check, Act" model, which aims to systematically identify, control, and monitor the performance of environmental systems (Stapelton et al. 1996). EMSs are most commonly applied in industrial settings, such as wastewater treatment plants or power generation facilities, and for emergency response preparation.

A key assumption built into the EMS framework is that the environmental system being managed can be controlled, which is often the case in linear, engineered, anthropogenic systems, but is limited in its applicability to complex, interactive and distributed ecosystem processes and watershed management. EMSs are used to respond to the need for regulatory compliance, with the EMS cycle being set in motion by an environmental policy or legal requirement (Stapelton et al. 1996). Lastly, there is no emphasis on explicitly stating assumptions or hypotheses early in the planning process. The implicit assumption is that managers have enough knowledge of the system to set appropriate targets, which may limit learning opportunities. Some proponents of the EMS process have put forward suggestions on how EMS principles could be applied effectively to watershed management (Schramm 2009). Yet few real-world successful demonstrations from these suggestions can be found. In short, EMSs provide a practical framework for optimizing the performance of controllable systems, but their efficacy has yet to be demonstrated in the more complex socio-political realm of watershed management.

Integrated Water Resources Management (IRWM)

The concept of Integrated Water Resources Management (IRWM) arose out of the first United Nations Educational, Scientific and Cultural Organization's (UNESCO) International Conference on Water in 1997. IRWM utilizes an "integrationist" agenda – integrating and coordinating management of water and land as a means of balancing resource protection while meeting social and ecological needs and promoting economic development (Odendaal 2002). IRWM is focused on creating increased cooperation and collaboration between governmental institutions for more effective water and land management across large spatial scales. A common theme in IRWM literature is that it is not an end state but a continuous process of balancing and making trade-offs between different goals and views in an informed way. However, many have criticized IRWM for being an elusive and fuzzy concept with no agreed-upon definition (Ven der Zaag 2005). This ambiguity itself may be a barrier to implementation. Additionally, the cross-sector, multi-stakeholder approach advocated by IRWM creates significant political and economic challenges. This results in management efforts that are so complex, they are extremely challenging to implement and even more difficult to assess performance. While the IRWM approach has merit, the focus on institutional and political change has resulted in slow adoption, even slower implementation, and few tangible outcomes to demonstrate its claimed benefits (Varis 2006).

Adaptive Management

Adaptive management (AM) has been described in a number of ways. Originally described by Holling in his semnal Adaptive Environmental Assessment and Management (1978) as "an integrated, multidisciplinary and systematic approach to improving management and accommodating

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change by learning from the outcomes of management policies and practices." It has been variously described, defined and implemented since Hollings' original work. Hollings' version of AM involves the design and implementation of management programs that offer the possibility to experiment with and compare selected policies and practices. This comparison takes place through evaluation of alternative hypotheses about the system (Holling 1978, Walters 1986, Lee 1999). Lee (1993) highlights the usefulness of this approach: "if human understanding of nature is imperfect, then human interactions with nature should be experimental." At its core, AM is "learning by doing" (Walters and Holling 1990), and is grounded in the understanding that we do not have complete knowledge relative to ecosystem and natural systems management. In this context, learning is essential for effective management, and much of the information needed can be gained during the implementation of projects if the project is structured in a specific way.

Although the "management-as-experiment" concept is at the core of how management knowledge should be produced through the AM framework, several other integration-centered definitions have been commonly used to describe AM, including:

- AM integrates environmental with economic and social understanding during the design phase and after implementation (Holling 1978);
- AM is a concerted effort to integrate existing interdisciplinary experience and scientific information into dynamic models that attempt to make predictions about the impacts of alternative policies (Walters 1997);
- AM combines democratic principles, scientific analysis, education, and institutional learning to increase our understanding of ecosystem processes and the consequences of management interventions, and to improve the quality of data upon which decisions must be made (Ecological Society of America 1996).

Examples of successful AM programs exist at a range of spatial scales and complexity (Gunderson 1999, Grismer et al. 2010); however, like IRWM and EMS, there are large gaps between concept, claim and outcomes in most applications of so-called AM approaches. Despite AM programs arguably chalking up more failures than successes, some believe that regulation and management of natural resources by AM is *inevitable* (Grumbine 1994). The remainder of this section focuses on exploring the evolution and future of AM, and supporting the premise that AM offers the most practical roadmap for effective natural resource management in the 21st century.

The Evolution & Future of Adaptive Management

The Role of Science and Research in Adaptive Management

Early definitions and natural resource applications of adaptive management were developed by ecologists (Holling 1978, Walters 1986). These definitions focused heavily on developing computer models to predict the effects of alternative management actions and identify key areas of uncertainty from which hypotheses could be developed and tested. The focus on hypothesis testing and data collection resulted in a general perception that engaging in adaptive management is expensive and, at times, cost-prohibitive (Walters, Goruk, and Radford 1993). This approach to adaptive management rests on a judgment that a scientific way of asking questions produces reliable answers at lowest cost and most rapidly; however, this may not always be the case (Lee 1999). Adaptive management practitioner and scholar Kai Lee elaborates:

> *"Adaptive management is not laboratory science where the burden of proof is tilted toward highly reliable findings by rules such as p<0.05, the notion that one's inferences should be reliable 95 percent of the time. In public policy and the world of action, the usual test is 'more likely than not' -- that is, p<0.5. The findings that emerge from such roughshod hypothesis testing will not be as reliable as academic science. But that is the point: adaptive management is likely to be worthwhile when laboratory style precision seems infeasible but trial-and-error seems too risky. And that's much of the time in conservation."*

Management of What, for What?

One of the primary challenges of trying to manage ecological systems is that they are dynamic and ever-changing. They integrate countless interconnected variables, including human activities. One goal of adaptive management that distinguishes it from the other traditional decision-making approaches, is that it aims not to manage or control resources in some optimal state (equilibrium-based approach; Caddy 1996), but aims to develop an optimal management capacity (resilience-based approach; Johnson 1999). Equilibrium-based approaches aiming to maintain natural systems in some optimal state with minimal variation tend to reduce the ability of the system to respond to stresses (e.g. fire suppression increasing wildfire risk in forests). In the resilience-based approach, the intention of management is to restore or maintain ecological resilience (in the sense proposed by Holling 1973, Holling and Meffe 1996) such that the system is able to react to inevitable stresses and changes, and to develop flexibility in institutions and stakeholders, which allows managers to react when conditions change (Gunderson 1999). The result is rather than managing for a single, optimal state, we manage within a range of acceptable outcomes while avoiding catastrophes and irreversible negative effects. As C.S. Holling stated, "environmental quality is not achieved by eliminating change."

Key Challenges in Implementing Adaptive Management

Practitioners have had a difficult time translating promise into practice, despite the promise of adaptive management as an effective approach to managing natural resources in the face of uncertainty. Below is a summary of key challenges for implementing adaptive management compiled from several publications and studies (Walters 1997; Lee 1993; Johnson 1999; Grumbine 1994):

- **Focus on modeling over direct measurement-** difficulties in developing acceptable predictive models; focus on perfecting models rather than field testing them
- **Heavy research emphasis-** narrowly focused research disconnected from management needs; inadequate attention to non-scientific information (e.g. local knowledge)
- **Political risks and fear of failure-** political risk of increased transparency and uncertainty of future benefits; expense and risk of large-scale experiments; agency fear that AM might undermine their credibility; inter-jurisdictional turf wars
- **Cost and funding cycles-** high cost of information gathering and

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monitoring; difficulty securing funding for long-term monitoring; short-term accounting focus (costs of AM may be higher up front but less expensive in the long-run if it leads to successful outcomes)

- **Administrative law and public scrutiny-** legal barriers in administrative law and court challenges; lack of trust by environmentalists that agencies can adapt policies responsibly
- **Conflicts over management objectives and ecological values-** competing management objectives among agencies; fundamental conflicts among stakeholders over ecological values

Compliance and Collaboration

Regulatory compliance is built on the assumption that achieving compliance also achieves the intended goals. For instance, it is assumed that if water quality related best management practices (BMPs) are implemented, water quality will be protected and/or enhanced. There are a number of issues with this assumption that make achieving the stated goals problematic. First is the measurability of compliance assessment. Mazur (2010) reports a relatively low level of actual compliance quantification. Further, he describes a number of problems with the ability to consistency quantify compliance based on standardized measurements given the complexity of natural systems. Mazur reports on efforts to measure or quantify actual field outcomes given the "difficulty of measuring a cause and effect relationship between the relationship between the activities and the changes in the ambient environmental quality." Mazur (2010) goes on to discuss the main issues in assessing either compliance or environmental quality monitoring. He suggests that the three key elements of a sound monitoring program are measurability, analytical soundness, and policy relevance.

Given the difficulties of assessing compliance, let alone actual environmental improvement of activities, the slow shift to performance-oriented regulatory requirements, and the lack of clear environmental responses to regulatory processes, we suggest that some additional elements need to be added to the regulatory process in order for goals to be truly achieved. We suggest that these new elements will be based on ownership of outcomes.

Ownership of Outcomes: Towards an operational Definition of Adaptive Management

A new brand of AM has emerged over the past decade, one that emphasizes committing to outcomes over predicting outcomes (Hogan and Drake 2009). Where many AM efforts get "trapped in an apparently endless process of model development and refinement" (Walters 1997), this outcome-based approach to AM puts the responsibility for achieving agreed-upon outcomes on the implementer (in collaboration with regulatory agencies) while offering them a reasonable degree of regulatory flexibility in the implementation approach. At its best, the outcome-based approach can inspire creativity and incentivize innovation in the implementation team to develop the most efficient and effective treatment methods to achieve outcomes. This approach may also offer the regulator a higher degree of certainty since conditions of project approval rest on ***outcomes*** rather than adherence to standard but often untested BMPs.

One of the realities of environmental management plans and policies is that they are often developed within the (largely academic) research literature, with limited meaningful input from the community responsible for implementing the plans and policies (Madema et al. 2008). One of the key limitations to effective implementation of adaptive management is inadequate attention to non-scientific information (Johnson 1999). According to Daniel Kemmis (2002), one of the greatest challenges and opportunities to environmental managers and policymakers in this century is "to reposition the role of science in natural resource decision-making such that adversarial use of science is minimized, local knowledge is emphasized, and science and scientists are routinely called upon to fill consensually identified information gaps". This is a different expectation than what we currently operate under: that scientists will provide the answer as to how management should take place. In this collaborative environment, scientists play a support role, recognizing that implementation is based on a number of other decision inputs aside from science, including political will and economic pressures and realities (Kepkay, 2003; Kepkay, 2002; Ludwig et al, 1993).

The operational model of adaptive management described in this Guidebook creates a new context in which the local knowledge and management needs of field personnel, land managers and other "non-scientific" stakeholders drive scientific inquiry versus the conceptual idea that science is driving on-the-ground management. Rather than looking to researchers for 'clean' answers to complex management questions, operational adaptive management recasts policies as management hypothesis aimed at achieving goals, granting implementers greater flexibility in reaching agreed-upon targets (within boundaries of acceptable risk) in exchange for taking responsibility for actual outcomes. In this way, implementers are empowered to test and demonstrate innovative on-the-ground solutions that provide a basis for both learning and collaborative policymaking.

Key Elements of Outcome-Based Watershed Management

AIMING

- The need for action is identified
- Goals and objectives are clearly defined
- Measurable success criteria are developed
- Responsibility for outcomes is clearly defined and decision-making is transparent

GAINING UNDERSTANDING

- Information gaps are identified and viewed as opportunities for learning
- Expert opinions, model predictions, scientific findings and "common sense" are viewed as hypotheses and guidance but not guarantees of outcomes
- Field-based management realities and questions underpin inquiries into information gaps
- Local knowledge and non-scientific information is valued and integrated
- Recognition of common knowledge gaps supports open communication between field personnel, scientists, policymakers and other stakeholders as peers (not top-down or bottom-up)
- Direct assessment is used to gain understanding of site-specific conditions
- Watershed flow patterns and connectivity are considered in planning and prioritizing management efforts

DOING

- Each project is recognized as unique rather than as something that can be easily fit into a ready-made template
- Field-fit adjustments are made during implementation with the end in mind and as appropriate to achieve project goals
- Treatments are well-documented to support future assessment and improvement
- Risk is minimized and chances of success are increased through small to medium-scale testing, then scaled up

Figure 56. Outcome-Based Management Process.

ACHIEVING

- Actual outcomes of treatment and management efforts are assessed and compared to goals and success criteria
- Unexpected outcomes are recognized as learning opportunities
- Direct monitoring of treatment effectiveness is conducted whenever possible
- Information from assessment can be used to help increase the usefulness and accuracy of models

IMPROVING

- Project participants are committed to learning and improvement
- On-the-ground adjustments are made when project outcomes do not align with goals
- Results and lessons learned are documented, shared and used to improve future projects
- Goals may be adjusted if actual outcomes clearly suggest a more appropriate goal is seen in the outcome

Section 2: Sediment TMDL Assessment & Effectiveness

According to the U.S. EPA's 303(d) lists, there are approximately 3,440 waters impaired by sediment in the U.S. (USEPA 2009). Many of these waters already have a Total Maximum Daily Load (TMDL) developed and many more are currently being developed. A TMDL is a calculation of the maximum amount of a pollutant that a water body can receive and still safely meet water quality standards. Of the thousands of TMDLs developed and being developed throughout the US, models are used in most of them (Borah et al. 2006). Of the eight examples of approved sediment TMDLs on the EPA's website (http://water.epa.gov/lawsregs/lawsguidance/cwa/tmdl/sediment.cfm): 6 relied on modeling to develop their baseline sediment loading estimates and allocations; 2 utilized direct monitoring to establish baseline conditions; 5 planned to use stream and lake monitoring methods to measure progress toward TMDL targets; 3 did not even include implementation or monitoring plans, deferring instead to a future Regional Water Board actions; and none planned to monitor treatment effectiveness at sediment source areas.

The heavy emphasis on modeling and nearly complete absence of directly measured results from sediment TMDL programs is concerning. Plus, the number of impaired water bodies being added to the EPA's 303(d) list is growing every year. The EPA has begun to solicit suggestions from implementers on how to improve TMDL program effectiveness. Some of the key suggestions from the March 2007 TMDL/Monitoring National Workshop Session on Program Effectiveness (USEPA 2009) included: more careful monitoring of treatment implementation; monitoring of source reductions, not just streams/lakes; more long-term BMP effectiveness monitoring; more *targeted* monitoring (not just more monitoring). Several comments suggested that the types and methods of monitoring being used on many TMDLs do not directly link to whether or not the TMDL actions were effective.

A core purpose of this Guidebook is to provide user-friendly approaches to water quality improvement that produce tangible, defensible outcomes and support more cost-effective treatment approaches. The types of monitoring tools offered in this Guidebook are intended to help users gain a more complete understanding of erosion processes and the effectiveness of their efforts to prevent erosion, which has been cited as a key research need for sediment TMDLs (Hantush 2005). We hope that this Guidebook helps to inspire and support a more outcome-based approach to TMDL implementation and erosion problems in general.

Section 3: Characterizing the Problem – Watershed Assessment & Analysis

There are many watershed assessment handbooks and related papers and articles available. Three primary resources that have been widely accepted and used are presented and reviewed below. These include the:

1. US EPA Handbook for Developing Watershed Plans to Restore and Protect Our Waters (EPA 2008)
2. California Watershed Assessment Manual (Schilling, et al, 2005), and
3. Watershed Assessment of River Stability & Sediment Supply (WARSSS) process, developed for and produced by the US EPA.

Watershed Assessment Manuals & Methodologies: A Brief Review

US EPA Handbook for Developing Watershed Plans to Restore and Protect Our Waters

The U.S. EPA Handbook for Developing Watershed Plans to Restore and Protect Our Waters (EPA 2008) is an extremely comprehensive assessment tool that attempts to address water quality and other beneficial use issues that relate to the Clean Water Act (Copeland, 2010). This assessment is extremely thorough in terms of planning. Little discussion is given to implementation (3-4 pages), and a similar amount discusses how to respond when goals are not met. Our Guidebook attempts to provide substance in this area. We recognize that implementation is the commonly overlooked or undervalued element of project and goal delivery. Thus we provide information and tools to support proper implementation and implementation monitoring.

The EPA Handbook likewise relies heavily on modeling, which can be a powerful planning tool. Little emphasis is placed on direct measurements, especially of sources of sediment pollutants. Even where monitoring is discussed (EPA, 2008, pg 8-4), long term water quality monitoring is suggested, but with a disclaimer to the linkage between project impacts and water quality data only where long term data sets exist. This Guidebook emphasizes the value of monitoring projects at the treatment sites in order to truly determine project outcomes and treatment effectiveness. We further highlight that relying on water quality monitoring to assess project benefits can be problematic. For instance, NCSAI (1999) stated that when considering the range of issues included in the project and water quality linkage: "Taken together, these factors suggest that we should not expect to detect less than a two-fold change in sediment transport rates or sediment yields." Others including MacDonald (2000) and Elliott et al, (2010), have suggested that linking project benefits directly to water quality is difficult at best since water quality integrates so many variables that water quality measurements will be unlikely to pick up the small amount of change that results from projects. Grismer (2012b) has proposed a targeted sampling methodology focusing on the rising limb of the daily hydrograph during snowmelt periods that shows promise for detecting changes in watershed sediment loading in relatively short time periods of 3-5 years.

The EPA's Watershed Handbook is extremely comprehensive from a planning perspective when attempting to understand and address water quality issues, especially TMDL implementation. However, it does not go into detail about specific tools and as previously stated, does not discuss monitoring to any great extent.

The Watershed Management Guidebook is designed to address both the monitoring and difficulty in discerning water quality improvements directly as a result of project implementation. We suggest that monitoring done at the project scale can be designed such that the manager can determine whether sediment has been reduced at the source. The assumption of benefit is found in the idea that if sediment does not leave the site, it obviously cannot reach water courses and thus will no longer contribute to water quality degradation. This Guidebook is intended to help fill niches that are not directly filled in the EPA's Watershed Handbook.

California Watershed Assessment Manual

The California Watershed Assessment Manual (CWAM) provided a great deal of general and some specific guidance on how to undertake a watershed assessment in California. The manual "…focuses on watersheds of northern and central California. It also focuses primarily on the processes of planning and conducting assessments and secondarily on the specific tools associated with investigating particular watershed processes. Future volumes will include protocols for assessing specific watershed conditions (e.g., land-use analysis) and functions (e.g. groundwater supply)." (Shilling, et al., 2005, pg 20)

The CWAM is an expansive and important resource for watershed assessments. This Guidebook is not intended to replace the CWAM but is rather intended to integrate with it and provide some of the elements that the CWAM intended to provide, including specific tools for investigation, implementation and monitoring. The CWAM includes adaptive management as a key element of watershed assessment and management. However, it does not provide a great deal of direction or insight into adaptive management. We assume that AM will be included in the next volume.

The Watershed Management Guidebook is built around AM or 'Outcome-based management'. Thus, this Guidebook is essentially an adaptive management or outcome-based management tool which includes and embraces many of the elements of the CWAM and in some cases narrows or focuses those elements.

Watershed Assessment of River Stability and Sediment Supply (WARSSS)

The Watershed Assessment of River Stability & Sediment Supply assessment process, or WARSSS, aligns closely with the approach and intent of this Guidebook in many ways. WARSSS was designed collaboratively between the USEPA, "WARSSS seeks to use hillslope, hydrologic and channel erosional/depositional process relations to identify specific sediment sources and their locations that may impact beneficial water uses, rather than to attempt to predict total annual sediment export from the watershed. When used to implement clean sediment TMDLs, WARSSS offers more emphasis on the potential, proportional contribution of sediment sources by various processes influenced by land uses than on model outputs that predict "absolute" total annual sediment yield." WARSSS, like the other two assessment methodologies, is expansive, and very inclusive. It does not directly address implementation elements or adaptive management directly but recognizes their importance in the entire process of watershed assessment and management. Likewise, WARSSS recognized the importance of the adaptive management process.

WARSSS, like the other two primary assessment methodologies described above, is resource intensive. According to the WARSSS website, the process "…requires considerable effort".

Again, this Guidebook is prepared such that many of the same goals can be met but with a more realistic level of effort. Since WARSSS is not expected to be fully accurate in many situations according to WARSSS, the considerable effort invested may at times not produce a relative amount of useable information. The Watershed Management Guidebook focuses effort on implementation and monitoring as a direct method of improving watershed conditions.

Cumulative Watershed Effects (CWE) Analysis

Assessing the potential impacts to watersheds from a range of anthropogenic disturbances can be difficult and daunting. However, the 1969 National Environmental Policy Act (NEPA) requires that these effects be analyzed. Specifically, NEPA requires assessment of the "results of all past, present, and reasonably foreseeable future actions" (*40* C.F.R. 1508.7). Further, FEMAT (1993) reported that "Cumulative effects can result from individually minor but collectively significant actions taking place over a period of time". This general concept has, through court cases, been developed into specific cumulative effects (CE) regulations (Thatcher, 1990). There is implicit in this mandate one of the foundational elements of CE or CWE (cumulative watershed effects) assessments: they are nearly always compliance-driven and thus may not be primarily aimed at protection of the resource itself but with attaining compliance under the law. This critical but subtle distinction flavors all analysis and understanding of the nature of CEs.

Since CEs are not likely to be discontinued as a legal requirement, a number of questions arise regarding CEs:

1. Are CEs valid to assess *actual* impacts in watersheds?
2. Are CEs even valid as an assessment approach?
3. Can CEs be enhanced through monitoring?

CEs are model-based and used primarily to predict cumulative impacts to the resource. Lee MacDonald (2000) describes CEs in detail and outlines strengths and limitations of developing, using and improving CEs. MacDonald clearly lays out a number of nearly insurmountable limitations and constraints in producing effective CEs but suggests that CEs can be improved and strengthened though a clear process. MacDonald suggests that while CEs are legally required and that most CEs stop short of actually monitoring, that monitoring can test the validity of a CE and help determine whether the resource is actually at risk. Thus, while monitoring is a potentially powerful element of a complete CE, it is seldom conducted. This reality highlights the compliance-over-resource-protection intention of most CEs.

MacDonald also ties CEs to TMDLs in that a TMDL (Total Maximum Daily Load, an element of the Clean Water Act) is essentially a CE study. In a similar manner, TMDLs tend to be model-based (Borah et al. 2006) and thus far have been associated with very spotty monitoring requirements. The issue of monitoring is discussed elsewhere. Suffice it to say that the concept of CEs is powerful, essentially attempting to understand at which point too much disturbance occurs. In practice, CEs do not provide much information that can be used for management. We argue throughout this Guidebook that outcome-based management is much more effective than regulations in protecting and improving watershed resources. In fact, regulations are designed to guide management. As the current application of CEs and TMDLs point out, however, the critical element that is required to link regulations to the resource – monitoring – is often overlooked or intentionally excluded from projects as 'too expensive'. But, as MacDonald and others (Marion and Clingenpeel, 2008; Hawkins et al, 1994; FEMAT, 1993) point out, monitoring is the first step in actually understanding the resource. Further, models are based on what we currently understand (or at least think we understand). Monitoring can be used to uncover that which we don't understand.

A primary challenge to the validity of CEs as management tools is that CEs have seldom been tested or validated in the field. In an extensive survey of 45 mountainous watersheds in California, Hawkins et al. (1994) studied the relationship between the predicted outcomes of CWEs for those watersheds and actual watershed responses to disturbances. What they found was that variability was so great in actual outcomes (impact on stream biota) that CWE predictions were not useful.

We suggest that adaptive management (referred to in this Guidebook as outcome-based management) may be a useful addition to, or even replacement for, CWEs if done properly and with adequate safeguards. MacDonald (2000) suggests that in some cases, adaptive management may be a useful alternative or addition to CEs, offering an element of completeness that doesn't often exist. Thus, we suggest that if CEs are to shift from essentially a mandated regulatory tool to a tool that actually helps protect the resource, adaptive, outcome-based management can provide a useful addition to current practices.

Connectivity & Water Flow– Linking Sediment Sources to Surface Waters

Watershed researchers have made great progress toward understanding erosion rates from small plots and, to a lesser degree, watershed-scale sediment loading rates. The pathways and processes by which sediment is transported from source areas to surface waters are chaotic and non-linear, making it challenging to assess in the field, and even more difficult to represent accurately in mathematical models. The likelihood of runoff and hence sediment reaching the stream is referred to as the degree of "connectivity". Roads are a key feature in forested watersheds that alter hillslope drainage patterns and tend to increase connectivity by facilitating gully development below road drainage structures such as culverts, water bars, and rolling dips (Wemple et al. 1996; Croke and Mockler 2001). Connectivity is often expressed as the percentage of the total road length that is connected to the stream channel network (Wemple et al. 1996; Croke and Mockler 2001). Between regions, connectivity is positively correlated with annual precipitation, which is cross-correlated with stream density (Coe 2004).

Many methods being developed and used to study connectivity rely on some combination of mathematical models and Geographic Information Systems (GIS) analysis (Farabi and James 2005, McGuire and McDonnell 2010). Farabi and James (2005) suggest that the key variables that influence connectivity between roads and streams are hillslope steepness, contributing road length and area, surface topography/roughness and distance to stream. McGuire and McDonnell (2010) reported challenges in scaling between hillslope runoff and catchment runoff and that antecedent soil moisture conditions are an important and confounding factor in modeling surface runoff patterns.

Some direct field assessments of gully initiation and road-stream connectivity have also been conducted (Coe and MacDonald 2001, Croke and Mockler 2001, Veldhuisen and Russell 1999, Wemple et al. 1996). Generally, these field studies surveyed whether or not concentrated road drainage was physically connected to the stream channel. These studies suggested that connectivity is related to annual precipitation, soil depth, geology, road design, hillslope gradient, and topography (Wemple et al. 1996, Croke and Mockler 2001, Veldhuisen and Russell 1999). They also suggested that connectivity of road and channel networks occurs most often at stream crossings and through road drainage-induced extensions of the channel network (i.e. gullies).

This Guidebook offers several tools in Section 2 of the Toolkit (Gaining Understanding section) to identify key erosion source areas and connectivity to streams. These tools emphasize the value of integrating direct field assessment and GIS analysis (such as flow accumulation modeling using high-resolution LiDAR imagery) in order to gain as complete of an understanding of watershed flow patterns as possible, which is key to the success of erosion-focused watershed improvement efforts.

Erosion Modeling & Monitoring

Erosion is a complex process involving many interdependent variables. Direct measurement of erosion rates during natural rainfall or snowmelt events can be problematic. Many mathematical models have been developed and used to predict erosion in a variety of landscape types and management scenarios at scales ranging from a small road segment to large watersheds. However, modeling is always limited by our incomplete understanding of the individual and interdependent processes associated with erosion. Direct measurement approaches have also been used to quantify erosion rates, though the scale of measurement is generally small areas and the results have been difficult to scale up to larger areas such as catchments and watersheds. Below is a short discussion of predictive (modeling) and measurement-based (monitoring) approaches to assessing erosion.

Predictive Approaches

Modeling offers a quantitative predictive approach that has been applied for many years in an attempt to understand the nature and magnitude of erosion issues. This approach is attractive because the output is clear and quantitative, which can create an illusion of certainty or even accuracy. In fact, watershed and erosion model predictions can differ substantially from measured outcomes (Grismer 2012c; Tiwari 2000). Watershed models have been shown to be inaccurate at predicting the actual sediment impacts of projects (Elliot, 2010; MacDonald, 1999). In order for a prediction to be accurate, the processes being modeled must be completely understood. All variables of any importance and feedbacks must be accounted for if the model is to have any usefulness (Pilkey and Pilkey-Jarvis 2007). Since we obviously do not understand all ecosystem variables or their interactions and feedbacks, interpretation of model predictions as actual outcomes can be misleading at best and costly at worst. Since watersheds are so complex and difficult to understand, models have often been used as surrogates for actual field assessment.

Modeling can be an extremely useful tool when used as intended. Models are not generally designed to predict, per se, except in unique situations where the model parameters are defined by a robust and field-tested body of data (Pilkey and Pilkey, 2007). However, both mathematical and conceptual models can be powerful tools for forming and communicating hypotheses about watershed and erosion processes. When the predictions of watershed and erosion models are treated as hypotheses and tested using direct field assessment, that data can be used to help improve the accuracy of models (Foltz et al. 2009, Grismer 2012c) and facilitate learning and improvement in watershed management.

Measurement Approaches

Many researchers have measured erosion rates from natural rainfall and snowmelt events. However, most have highlighted the challenges of this approach, mostly due to the spatial and temporal variability in rain events (Spigel and Robichaud 2007). For this reason, portable rainfall simulators have been developed and used to directly measure erosion rates and the efficacy of different erosion control and soil restoration treatments (Grismer and Hogan 2004, Young and Burwell 1972). These methods are especially useful because they enable direct measurement of both erosion rates and soil hydrologic function. Recent studies in the Lake Tahoe region by Grismer et al. (2009) demonstrated how rainfall simulation can be coupled with other monitoring methods – such as cone penetrometers, soil sampling and statistically-defensible cover monitoring – to directly measure indices of erosion resistance and to evaluate the longer-term resilience of restoration treatments. Such monitoring approaches not only provide direct feedback on the efficacy of erosion control treatment effectiveness, but provide valuable data with which to improve erosion model predictions.

Linking Monitoring and Modeling

A key challenge in watershed management is linking small, plot-scale (1-3 square meters) erosion measurements and sediment discharge at the catchment or watershed scale. Recent research by Grismer (2012a) focused on developing runoff-dependent scaling factors necessary to predict daily stream sediment loading based on plot-scale erosion measurements from rainfall simulation. Other recent work in the Tahoe Basin has focused on shifting from compliance-oriented methods for monitoring stream water quality to methods aimed at detecting sediment loading. By targeting stream grab sampling on the rising limb of the daily hydrograph during spring snowmelt periods, Grismer (2012b) demonstrated the potential to calculate defensible sediment loads (on a sediment yield per unit streamflow basis) and evaluate the watershed-scale sediment loading effects of on-the-ground management actions in a relatively short time period (3-5 years) in snowmelt-driven watersheds. Using this "rising limb" load detection monitoring approach, a nearly 1.5-fold decrease in watershed sediment loading was measured in Lake Tahoe's Homewood Creek watershed after targeted restoration and hydrologic disconnection of dirt roads throughout the watershed. Model-derived estimates of Homewood Creek watershed's annual sediment loading for the Lake Tahoe TMDL were shown to be more than 300 times higher than those measured using the "rising limb" load detection monitoring approach (Grismer 2012c). While continued monitoring is needed to verify these observations, initial results suggest that this targeted monitoring approach may be useful towards developing more defensible TMDL crediting tools and helping to better understand the impacts of watershed management actions.

Section 4: Key Variables Influencing Erosion & Runoff

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 our capacity to predict project outcomes.

Photo shows rocks suspended on soil "pedestals" due to raindrop splash erosion.

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 worth noting.

Water

Liquid water erosion is the most commonly cited, and possibly best understood, type of erosion. A strong linkage exists 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

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

Freeze-thaw erosion showing detached soil particles.

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

Currently, 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

Types of Erosion

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.

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.

Often, when erosion is assessed by engineers, engineering geologists or geotechnical engineers, they look primarily at mass stability in soils. Often, mass stability is considered as the main erosional property of soils and thus, surface, rill and gully erosion is not considered (WSDOT, 2010).

Mass failure on the American River in 1997.

Colluviation

Colluviation is a lesser-known type of erosion that is significant on bare areas. Colluviation is a type of 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.

Sediment Source Control

The process commonly called erosion actually consists of both erosion and sedimentation. 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 down slope 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.

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 to 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 rivers and streams than any other pollutant."

Estimates of erosion rates vary. According to the EPA, rates range from a low of fifteen tons/mile2/year for natural or undisturbed areas, to a high of 150,000 tons/mile2/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 or more 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 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 likely to be enhanced by focusing on physical processes in the soil and interactions between

Key Variables Affecting Erosion

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, suggests that soil structure is of primary importance to sediment source control. When soil structure is severely disrupted, its structure must be rebuilt if erosion is to be controlled. The following sections discuss some of the attributes and elements of soil structure.

This compacted road cut slope exhibits widespread erosion and a slope failure, largely due to lack of infiltration capacity.

Infiltration and Water Storage

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 sub-surface 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 underway 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).

Infiltration is heavily influenced by soil density. Each "native" soil has a density associated with it. Generally, the denser a given soil is, the lower its 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/cm3, kg/m3, or mg/m3. 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 results in increased erosion (Kay and Angers 2002; Radcliffe and Rasmussen 2002).

A compacted soil is high-density by nature. 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/m3, whereas graded high density soils were 1.8 mg/m3. 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 suggests that shallow rooting depth is often associated with lack of vegetative cover.

Two considerations connecting rooting depth and erosion are:

- First, 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.
- Second, 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

Key Variables Affecting Erosion

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;
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.

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

Surface Cover/Mulch

Soil surface cover plays a critical role in not only 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."

Classic photo of raindrop splash effect.

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)
- 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 is 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 understated. 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 laying 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).

Key Variables Affecting Erosion

Soil Microbial Communities/Mycorrhizae

Microbial activity is the chief driving force behind many soil functions (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. There are a number of microbial "types" that 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; Batanny 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 5: Addressing the Problems—Treatments for Sediment Source Control

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.

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 often not the case. The following section discusses tools used in site-specific erosion control and restoration treatments.

Erosion– Key Concepts

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" includes ski runs, unpaved roads, 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 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:

- **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.

- **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 is 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 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

There has been a great deal of information 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, 1998b and Benoit/Hasty 1994:

- **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 multivariate environment.
- **Site specificity:** studies and tests that are 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.
- **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. 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.
- **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).

Restoration Treatments

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, fertilizer, 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).

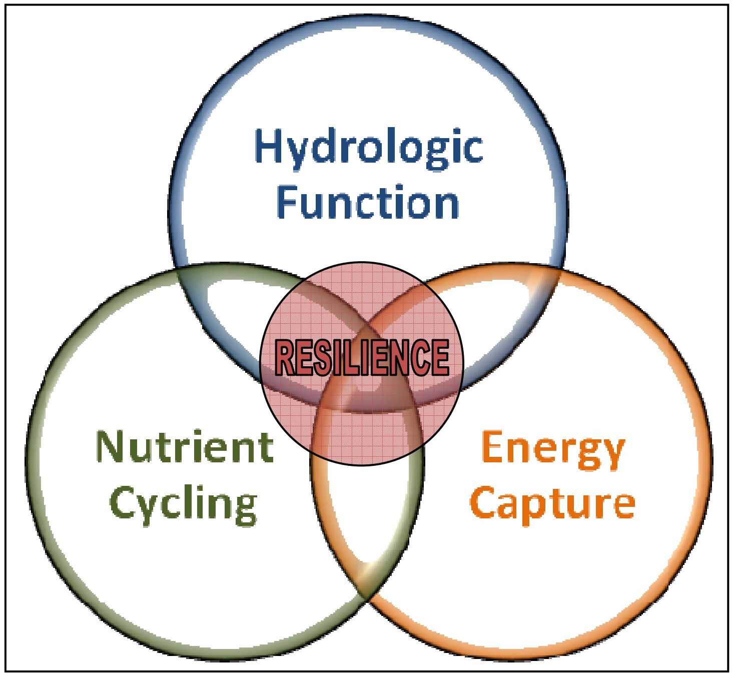

Figure 57. Functional parameters for assessing and rebuilding ecosystem resilience (adapted from Cummings 2003). In a robust and resilient ecosystem, the area of over-lap between the three functional parameters (the "resilience zone') is actually much larger than depicted here.

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 has 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 soil-based restoration 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.

Watershed Resilience and Climate Change

Increasing the ecological resilience of watersheds is a critical strategy for adapting to climate change. Throughout the west and in California in particular, the amount and timing of water leaving upper watersheds plays a crucial role in the economic sustainability of the region. Californians can expect rising temperatures over the next century to increase snowline elevations, deliver an increasing proportion of precipitation as rain rather than snow, increase rainfall intensity, shift peak stream flows to earlier in spring, and decrease summer stream flows (base flow) from snowmelt-driven watersheds in the Sierra Nevada (Coats 2010, Maurer 2007, Null et al. 2010). This will have many implications for water supply and how reservoirs are managed, as well as for spawning fish and other stream-dependent wildlife. Observed changes in air temperature, precipitation form, and snowmelt timing indicate that the Sierra Nevada region is warming, and that the Lake Tahoe Basin is warming faster than the surrounding region (Coats 2010). Recent studies in the Tahoe Basin indicate that climate change trends are likely to result in increased loading of biologically-available nitrogen (and other nutrients), which is likely to increase algal growth and accelerate the decline of Lake clarity (Sahoo et al. 2012).

A resilient watershed is a reservoir, holding onto water and releasing it slowly and steadily throughout spring and summer. By restoring ecological function (using the above framework, based on Cummings, 2003) to disturbed and degraded sites throughout our watersheds, we can store more water in the soil to compensate for the decreasing water reservoir stored in the snowpack, reduce erosion (carbon loss), attenuate (spread out) stream flows, and improve the quality and reliability of water supplies conveyed to our towns and farms by streams. The treatment approaches offered in this Guidebook are aimed at rebuilding watershed resilience where it has been lost, and assessing the results of these efforts so we can be sure that we are getting a return on our investment.

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

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against frozen water erosion (by insulating soil against freeze-thaw and by providing additionally surface roughness for snow melt). 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 are 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 tend to increase sediment source control in areas with water and wind pressures, are:

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

Soil Nutrient Treatment Considerations

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) and produce a response (plant growth) that is then removed from the system. 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 that 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). Re-establishment 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 Considerations

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 incorporation of organic material in a depauperate (low nutrient) soil may provide additional benefits beyond nutrient additions, such as increased water holding capacity, 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 both 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 an increase in the soils ability to support high infiltration rates and resist erosion (Grismer et al. 2009; Drake et al. 2012). 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 Considerations

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 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 (Roberts R. D. et al. 1980; Bradshaw, Marrs et. al. 1982; Bloomfield, Handley et. al. 1982; Marrs & Bradshaw 1982; Woodmansee, Reeder et al. 1978). Further, Claassen & Hogan (2002) found that adequate organic matter and mineralization of the N in organic matter was directly linked to plant growth in the Lake Tahoe

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underpinning of most reclamation or restoration on drastically disturbed land. Reeder & 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 (Tisdale et al. 1993; Soil Improvement Committee 1998).

Mycorrhizae Treatment Considerations

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 worlds’ plants (Israelsen 1980) and thus are of critical concern.

The microbial community within a soil are 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, 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 pots.

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 tall grass prairie in three years. At the same time, organic matter accrual increased and litter breakdown rate decreased, inferring long-term plant community sustainability. In a greenhouse study, Stahl et al. (1998) discuss the increased 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.

Plant Treatment Considerations

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; U.S. 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 and Others 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 see ("Infiltration, Soil Density" section above). Further, plants have been used successfully in combination with soil rehabilitation treatments in the Lake Tahoe and Truckee areas to successfully stabilize loose soils of up to 1:1 slopes (Hogan 2005).

One additional consideration for plant use is that claims made by suppliers may not live up to their billing, given that site conditions vary widely.

Mulch Treatment Considerations

A large body 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 ecological "services". Some of these services are listed in Table 33.

Applying 2-3 inches of wood chips or pine needles was shown to reduce sediment yields on inactive roads by 72-96% and 60-90% on a ski run during rainfall simulation (Drake et al. (2012). Foltz (2012) measured sediment reductions of 42-76% on forest roads with much lighter applications of wood chips/shreds (40% surface cover) on forest roads in the Rocky Mountains. Additionally, Foltz observed that none of the wood mulches tested inhibited vegetation growth.

Restoration Treatments

Drake et al. (2012) reported that a berm of wood chips constructed near the bottom of the Lake Tahoe ski run (~1 foot thick by 10 feet wide across the width of the entire ski run) reduced sediment yields in surface runoff by 45%. Mulch berms may be a cost-effective erosion control technique for large disturbed slopes (such as ski runs) where access issues and high costs can make large-scale restoration treatments impractical, especially where wood chips can be acquired for free from nearby forest fuels reduction projects.

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 percent 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 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; Grismer et al. 2009). 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 transportation costs and reducing the risk of importing weeds.

Native plants, such as this Penstemon newberyii, can thrive and grow vigorously in low density soils with adequate carbon and water-holding capacity.

Tilling Treatment Considerations

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 Pacific Northwest forests by up to 15%. Tillage of compacted soil can be effective in reversing compaction. Luce (1997) 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 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 greater than four inches per hour on a Tahoe area ski run where wood chips had been tilled into a highly compacted soil. In a multi-year study in the Tahoe area, Grismer et al. (2009) reported that soils loosened to at least 12 inches, rather than surface treatments with no soil loosening, exhibited the highest infiltration rates, lowest sediment yields and highest cover by native perennial bunchgrasses after three growing seasons. In a comparison of two soil loosening techniques – tilling with an excavator bucket and targeted loosening with bucket-mounted infiltration tines – Drake et al. (2012) found that the "targeted loosening" method resulted in similar cone penetrometer depths (surrogate for soil density) and higher native plant cover compared to bucket tilling in a west shore Lake Tahoe watershed. Targeted loosening was also faster to implement than bucket tilling in the rocky soils at this site, suggesting that targeted loosening can be very cost-effective.

Table 33. Ecological Services Provided by Mulch

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	Mulch 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	Mulch 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.

Restoration Treatments

Torbert and Burger (2000), reporting on research by Larson and Vimmerstedt (1983), state that soil 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, thus limiting the potential for vegetation establishment and long-term stabilization.

Road Treatment Considerations

Roads, especially unpaved dirt roads, represent one of the most insidious sources and conveyors of erosion in forested watersheds (Zheng, 2000; Ziegler, 1997; Ahn, 2003, Arna'ex, 2004; Costantini, 1999; Forsyth et al, 2006; Sheridan and Noske 2007). Roads change the "plumbing" of watersheds by intercepting and concentrating runoff, altering the amount and timing of water delivery to streams (Beechie et al. 2005, Madej 2001). Saturated hydraulic conductivities (Ksat) of forest roads can be one or more orders of magnitude lower than undisturbed forest (Ziegler et al. 1997) and road sediment yields can be 1-3 orders of magnitude higher compared to undisturbed forested areas (Drake et al. 2012). Overall, the impacts of roads on water quality, watershed hydrology and habitat impairment are very well documented in research literature.

The good news is that effective road management practices can reduce the sediment and hydrologic effects of roads. While the relatively common road maintenance practice of surface grading has been shown to increase sediment yield by 33 times compared to ungraded conditions, applying gravel surfacing to active roads (graded and ungraded) was shown to reduce sediment yield by up to two orders of magnitude (Drake et al. 2012). Applying mulch (2-3 inches of wood chips or pine needles) was shown to reduce sediment yields on inactive roads by 72-96% during rainfall simulation (Drake et al. 2012). Foltz (2012) measured sediment reductions of 42-76% on forest roads with much lighter applications of wood chips/shreds (40% surface cover) on forest roads in the Rocky Mountains.

Road decommissioning is becoming a priority in many sediment-impaired forested watersheds, and landowners are looking for cost-effective road decommissioning practices. In a multi-year Tahoe Basin study, Grismer et al. (2009) reported that restoration methods that incorporated soil loosening to a minimum depth of 12 inches and incorporation of coarse organic material (wood chips, tub-grindings, composted wood chips or coarse-overs) at a rate of ~4,000 kg/ha into the soil had the greatest increase in onsite infiltration and the largest reduction in sediment yield over time. This same study found that three years after treatment, plots amended with wood chips, tub grindings, or coarse-overs supported similar native perennial plant cover to the plots amended with compost, suggesting that less expensive soil amendments can be just as effective as compost at re-establishing native plant communities. In a related multi-year study of road decommissioning treatments in the Homewood Creek watershed (Lake Tahoe), Drake et al. (2012) reported sediment yield reductions of 80-100% and infiltration rates of up to 4.7 inches per hour (using simulated rainfall) one to three years after treatments including soil loosening and incorporation of aged wood chips. In contrast, Luce (1997) reported that ripping forest roads without incorporation of organic matter did increase hydraulic conductivities but not to levels comparable to nearby forested areas.

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

Economic Considerations in Treatments

An extremely important consideration in designing and implementing a restoration, erosion control or revegetation project is cost. 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 ecological 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 last five seasons, then the actual cost would be exactly the same per year effectiveness. More cost-effectiveness assessments will be critical to determining 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 begs the question, "How many times do you apply something that doesn't work before realizing that resources are not being spent effectively?"

One area of watershed management that warrants further study is the *cost over time* or *cost per unit of pollutant reduction* for erosion control and restoration treatments. In the Homewood Creek watershed in Lake Tahoe, the costs of decommissioning eroding road segments were carefully tracked and watershed-scale reductions in sediment loading were directly measured (see Tool 2.6. Targeted Water Quality Monitoring), enabling the project team to calculate the *cost per kilogram of sediment reduction*. In 2010, the estimated cost per kilogram of sediment reduced through targeted road restoration and hydrologic disconnection was $5.85. Since the treatments used for decommissioning have been shown to maintain very high infiltration rates with increasing plant cover over time, the actual cost per kilogram of watershed sediment reduction is expected to decrease over time as cumulative sediment reductions add up from year to year, even with no further investment in restoration. While these cost-effectiveness estimates are considered preliminary, they represent an important step toward assessing the return on investment for different watershed restoration approaches.

SECTION 6: UNDERSTANDING OUTCOMES– MONITORING

One of the primary purposes of this Guidebook is to provide a roadmap for the ongoing improvement of watershed projects. As you considers its use, two questions might arise: "Do we need better projects?" and "Why?" Don't we already know the outcomes? Don't the models show us what the results of our efforts will be? Don't the layers of regulations ensure positive project outcomes?

In this Guidebook, we suggest that models and regulations, as useful as they are, provide *hypotheses* of outcomes from watershed projects of all scales. They cannot, however, predict exact or in some cases even general outcomes. The essential issue and driving force behind development of this Guidebook is the fact that ecological processes are infinitely variable, complex, not well understood and cannot be predicted by models or 'best practices' suggestions (Walters, 1986; Holling, 1978; Lee, 1993; McDonald, 2000). We present an assessment-based process that directly identifies watershed project outcomes. Numerous researchers and social scientists have identified many shortcomings of the current risk averse approach to project delivery. We suggest that by embracing risk in a structured and responsible process, great advances in watershed management are to be made. The primary addition to the outcome-based management process presented in this guidebook is the focus on outcome rather than just gathering of knowledge.

While the accumulation of knowledge through adaptive management is assumed to produce better projects, Walters (1986), Holling (1978) and others tend to define adaptive management in a relatively narrow hypothesis-testing process that doesn't incorporate many of the human elements that commonly play in decision making (Kepkay, 2003). We add the focus on OUTCOME which qualifies adaptive management relative to what actually takes place in the field, whether we fully understand it or not.

Striving to Better Understand Outcomes

Striving to Better Understand Outcomes

Scientific studies about watersheds and watershed processes are extremely numerous. Still, much is unknown and may never be fully understood (Walters, 2001; Walters and Holling, 1990, Ludwig et al, 1993). The scientific process suggests that those things that we 'understand' today may be understood differently in the future. Most major scientific findings of the past century have been shown to be erroneous or not fully correct as subsequent research uncovers new information (Brooks, 2012). Thus, it is unlikely that we will be 'saved by science' or that reductionist scientific studies can be applied universally. In order to link expectations to the outcomes themselves, we must shift approach in order to better embrace uncertainty, risk and the unknowns embedded in projects. This can be done by assessment and monitoring embedded in an overall program or process of leaning and gathering of information.

The Role of People: Are we Missing the Main Issue?

Thus far, we have discussed ecosystem projects, improvements, monitoring and feedback as if they were objective realities separate from those of us who engage in watershed activities. One of the most essential elements of any project is people. Aside from the obvious issue of non-objectivity, humans are driven by complex and often conflicting motivations. According to Ludwig and Walters (1993), resource use and the promise of wealth, either directly from resource sale, or indirectly from income associated with resource extraction and regulation, causes humans to respond to some range of the promise of benefits beyond purely logical, scientific or altruistic ones. Thus, the possibility of developing, let alone implementing 'objective' regulations may be essentially non-attainable. This subjectivity and non-obvious personal motivations applies to modeling as well. Both sides of the monitoring question (should we or shouldn't we monitor) are heavily impacted by human motivations, often enveloped and made opaque by more 'logical' concerns such as time or cost. According to Kepkay (1993), human motivations played an overriding role in the outcome and (lack of) effectiveness of forest management efforts in Washington State, where adaptive management was considered to be a cutting edge approach to forest management. Kepkay, in analyzing the effectiveness of the Washington program, found that the disappointing outcomes produced could not be accounted for by adaptive management procedures alone. In fact, he concluded that human motivations played the critical role in the lack of overall effectiveness of the program. Despite that finding, Kepkay also found that a large body of 'non-scientific' management lessons had been learned from the Washington State program that could ultimately benefit forest management, but that the program itself did not accommodate the direct experiential type of learning that he believed was critical to the success of management programs.

According to the Sierra Nevada Science Review (1998) "Adaptive management and monitoring include more than traditional data collection and analysis of environmental variables (Everett et al. 1993, Kusel et al. 1996). Dynamic ecological and social systems require institutional policies that are more capable of monitoring changes in human-nature interactions, and responding to these changes more effective than the Forest Service has in the past (Cortner et al. 1995, Gunderson et al. 1995). Adaptive, flexible institutions, fluid boundaries among agencies, open and collaborative planning and management, public engagement, close collaboration with science communities, risk analysis, and risk-taking will better enable national forests to conduct effect monitoring and meet sustainable science-based management goals (Cortner and Shannon 1993, Gericke and Sullivan 1994, Kusel et al. 1996, Lee 1993, Mohai 1995, SPDR 1997)."

Embracing Uncertainty and Risk

Given the complexity and our incomplete understanding of the ways in which ecosystems work, projected (modeled, assumed) outcomes will embed potentially high levels of uncertainty. Uncertainty and risk are inextricably linked. This uncertainty is not dealt with effectively in most of the current regulatory processes in place (Walters and Holling, 1990; USDA Sierra Nevada Science Review, 1998)

Kepkay (1993), as well as others (Lindenmayer and Likens, 2009; Walters and Holling 1990; Walters, 1986; Lee, 1993; USDA 1998) suggest that the human aversion to uncertainty may drive an unwillingness to embrace that uncertainty. The results, as have been seen in the financial crisis/meltdown of

Striving to Better Understand Outcomes

2007, can be catastrophic. It can be argued that by not embracing uncertainty and the perceived risk embedded in that uncertainty, we actually increase real risk. That is, if we are not willing and able to monitor/assess actual processes as they occur, and to be able to recognize departure from expected outcomes, we will not be able to make the course corrections necessary to achieve an effective outcome. By relying on models and/or other predictions only, we will be unlikely to actually achieve intended outcomes, just as a ship at sea who relies only on models of course and objective, will not make the course corrections necessary when variables such as wind, waves, engine speed or physical malfunctions are encountered, and thus will not reach the intended destination.

Nature of Assessment

Assessment can take many forms. Within the adaptive, outcome-based management framework, monitoring is used to determine change over time (Elzinga et al 1998). However, there are a number of other types of monitoring that are key to understanding the system that is being worked in and the outcome of projects. Monitoring and assessment, terms which we use interchangeably here, are essential to understanding if a project is meeting the goals set and whether changes need to be made in order to reach goals. Where adaptive management or outcome-based management is to be used, monitoring must be done. In fact, according to the Sierra Nevada Science Review (USDA, 1998), "Without effective monitoring, whatever else we do is not adaptive management."

There are a number of types of monitoring and thus the term monitoring can be somewhat confusing and misused or at least misunderstood. Here we describe the main types of monitoring. It should be mentioned that at times, especially when monitoring is used to meet some regulatory requirement and/or legal requirement, data is collected without a clear sense of use and thus can be of very limited use. It should also me mentioned that monitoring is not always expensive if done creatively. But monitoring should be done in such a way that information developed is defensible and useful.

Purpose of Assessment

The purposes of assessment and monitoring can be varied and can include identification of baseline conditions, understanding of ecological, hydrologic and soil function, determination of whether a project is implemented properly, how well a project is functioning, whether a project is meeting its stated goals though attaining success criteria and whether a project needs adjustments and alterations following implementation. Each assessment type must be well defined and done in such a manner that it can produce the information needed.

Type of Assessment

There are a myriad of assessment methodologies from soil, vegetation, hydrologic, chemical, biological and physical. One may wish to measure water quality, quantity, water chemistry, soil density, organic matter, vegetation cover and type, erosion rates and so on. We will not develop a full treatment of monitoring methods here as there are a number of other publications and papers that address that issue.

For clarity, we describe the general types of monitoring as Baseline, Implementation, Performance, Trend and Compliance. Each type of monitoring is designed to address one or more of these areas. Further, while the terms monitoring and research are often used as exclusive terms, Salzar, in Elzinga, et al (1998) shows how research monitoring is generally a matter of scale rather than type. Thus, monitoring used for project performance assessment, may, if designed and implemented properly, be used as research data to test specific hypotheses.

Measuring Outcomes

Monitoring will be useful to the extent it is defensible. When an individual visually and casually observes something, they may accept their interpretation of that assessment as having some level of validity. This condition is generally referred to as an 'opinion', based on some type of input but generally not 'provable' in any scientific fashion. If that individual considered that observation as a hypothesis and set up a rigorous set of tests that was designed to measure whether that observation carried with it a high level of measured repeatability, the probability that the observation was 'true' may be high. Of course, there is always the possibility that 1 in 100 of the observations might be different. Thus, we begin to apply the scientific process to help us understand whether the outcome we expect has a probability of actually taking place.

Measuring outcomes to the greatest extent possible, given funding and time constraints, offers a higher level of reliability in observations, interpretations and expectations of outcomes. While outcomes change with every project, the ability to measure creates and empowered project that has a higher probability of reaching the desired outcome since we base our plans on our assumptions that the plans will actually achieve the desired results. Many times, we do not achieve the desired results and in those outcomes lay the possibility of learning, adjusting and ultimately achieving the desired result. Monitoring and assessment is the key to that outcome.

Feedback Loop-Project Improvement

Monitoring is most powerful when it is used not just to assess regulatory compliance but measures actual outcomes. When monitoring shows that an outcome is not being achieved, adjustment can be made such that the trajectory toward the desired outcome can be reset. The result is project improvement.

Final Note: The Secret Life of Watersheds

Watersheds are complex and will never be completely understood. While watersheds can not be simply explained , we offer the following as a context to increase or grow our relationships with the watersheds.

Watersheds

Watersheds are all around us. We all live within a watershed. Aside from the atmosphere, watersheds may be the most ubiquitous element in our physical realm. And yet, so little is known about watersheds. Watersheds hold more secrets than they reveal. That may partially be the result of the nearly infinite number of pieces and processes that make up a watershed. It may also be the fact that we tend to define watersheds as much (or more) by what they LOOK LIKE rather than what they DO. That is, we tend to define things by what we SEE whereas so much of what actually drives a watershed and what occurs within it are processes, most of which are not visible at any given point in time.

This Guidebook strives to recognize and address that situation in a way that can assist us in managing, repairing and improving watersheds. This is not an easy task but one that may be the very foundation of our **survival as a species**. Our initial response to issues tends to be that if we can't see it, it may not exist and thus may not take action until irreparable damage has been done. The approach employed in this Guidebook is that **the unseen may be as or more important** in many ways than that which is seen. We present methods to address the unknowns, especially those in the soil.

Watersheds as Reservoirs

One of the relatively invisible functions of a watershed is its function as a water reservoir. Watersheds are often thought of primarily as the water courses and 'drainages' within them. They may just as easily and perhaps more accurately be thought of as a **massive potential water storage facility.** While soil seems like something made up of minerals and organic matter, soils can contain nearly as much air and/or water as minerals. Thus, when a soil is healthy, water can be stored on a massive scale. Conversely, when soil is compacted or otherwise degraded, water storage potential can be reduced by 10 times or more. Restoring water storage function to watersheds is one of the most compelling reasons to do restoration and management work in the watershed.

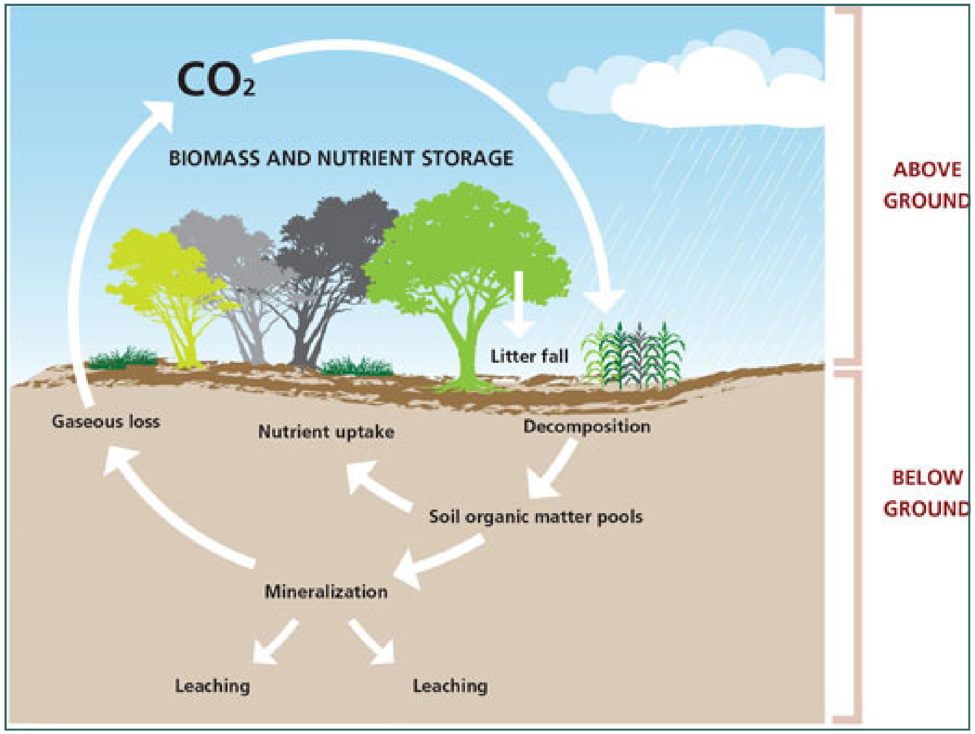

Figure 58. Terrestrial carbon storage via the carbon cycle. http://www.fao.org/es/esa/pesal/AgRole2.html

Carbon Storage

Carbon is a key ecosystem driver. The majority of terrestrial carbon is stored not in vegetation but in the soil. Long term and short term (slow and fast turnover) carbon is stored in the soil. When soil is disturbed, a great deal, perhaps even a majority of the carbon content can be released and/or displaced, either into the atmosphere (oxidized) or off site (eroded). Carbon is not just passively stored in the soil. **Carbon is the workhorse or energy driver in the soil**. Where adequate amounts and types of carbon are present, the soil system functions at a high level, providing a foundation for plants, soil aggregation and other critical soil services. Thus, during specific types of soil restoration, increasing carbon storage can be an invisible, but critical benefit of restoration.

Water + Carbon

When considered together, water and carbon are inseparable in that **carbon drives biological function in soil** and that **biology drives aggregation** which creates and maintains void space and infiltration channels that store water.

These edaphic factors **drive plant growth**, which collects and stores additional carbon in the soil. Restoration will increase both carbon and water in the soil, thus directly addressing two key climate change cohorts or issues.

Thus, the invisible combination of carbon + water is that the soil can be thought of as a measure of resilience. That is, where carbon and water are absent, a watershed or site will tend to be less able to respond to disturbance or drastic change. *As climate change becomes more apparent, resilience will become more and more important.*

Beyond Water Quality

Water quality is an indicator of watershed health. A main driver of degraded water quality stems from erosion. Erosion is loss: loss of soil, loss of nutrients, loss of the very capital that drives watershed function. Healthy or high function watersheds erode less than the same watershed when disturbed.

While a great deal of focus is placed on water quality, this Guidebook emphasizes the health or function of the contributing areas, or the watershed itself. By addressing issues at their source, and considering the interconnection between processes, erosion is minimized, water quality is improved, and overall watershed health or function is protected or increased.

Unlocking the Secrets

Robust, resilient and high functioning watersheds provide the myriad of services that maintain human and animal health. **Disturbed watersheds are compromised** on some level and provide less of those services. This Guidebook is designed to help individuals and entities better manage watersheds to their maximum function. Water delivery and carbon storage are two of the critical services provided. By understanding and acting upon watershed disturbance issues and owning the outcomes of those efforts, watershed managers can restore damaged watersheds to health and can minimize impacts to watersheds where development takes place.

Here's to a resilient future!

Connecting the Dots

Our future is uncertain. Some will debate climate change but even that debate is losing traction given increasing data and observations. One thing is certain, however: population is increasing and pressure on our finite resources is increasing, some say exponentially. Especially water and soil are coming under immense pressures. Yet we understand so little of how those elements function, what drives them. The process described in this Guidebook is designed to assess what IS rather than what SHOULD BE. That approach may be a critical tool in moving into a more understandable future, a way to directly study or understand what actually takes place in natural systems. We have a long way to go but if we are to address so many of the issues we face, we will need to move beyond models and interact directly with the world that surrounds us. This almost overwhelming task will most likely require a series of very small steps. We will learn to walk before we can run.

This Guidebook is the result of many years of effort toward achieving better environmental improvement projects and many, many conversations about what was missing, what should be done, how to do it. We have tried to offer an approach and some tools to help move in that direction. We have field tested each of the elements offered in this Guidebook. Still, each project is different and one size definitely does not fit all. This Guidebook and its contents are offered as a start, a place to begin or continue a journey through watershed projects that will hopefully last a lifetime. There is no single answer, just as there is no single watershed. And yet all projects and all watersheds contain at least some similarities and some foundational principles. We sincerely hope you find this Guidebook useful and that is leads to a deeper appreciation for your work and your place in watersheds and on this planet we live on.

This Guidebook embodies change… simple to say, difficult to achieve.

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