

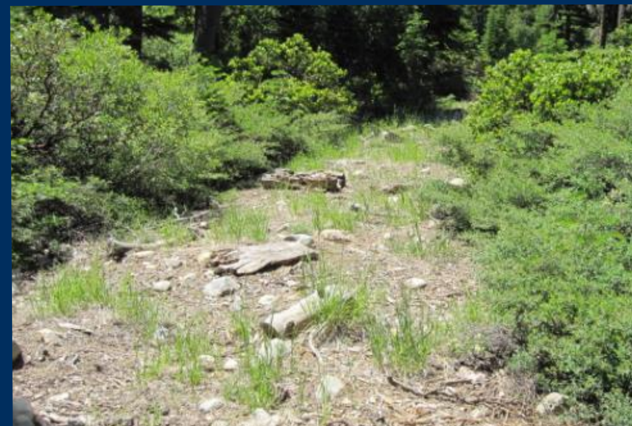

Forest Management Guidebook

An Outcome-Based Approach to Water Quality Protection





A publication of Integrated Environmental Restoration Services, Inc.
June 2015

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This research was supported using funds provided by the Bureau of Land Management through the sale of public lands as authorized by the Southern Nevada Public Land Management Act (SNPLMA), and was funded in part through a grant from the USDA Forest Service Pacific Southwest Research Station. The views in this report are those of the authors and do not necessarily reflect those of the USDA Forest Service Pacific Southwest Research Station or the Bureau of Land Management.

Acknowledgements

This Guidebook is the outcome of interest and energy from a wide range of individuals and organizations. The idea of developing a document that focused on outcomes and a practical scientific process has been an outgrowth of two other efforts: The Sediment Source Control Handbook and the Watershed Management Guidebook. Both of these products came out of many years of discussion and work with Martin Goldberg, John Loomis, Harold Singer, Scott Ferguson and many others. The real heavy lifting and clear vision of how this document looks and feels came from Kevin Drake (IERS), a true partner, teacher and all-around inspiration.

We believe this document is also the result of an unusual alignment of individuals within organizations and agencies. It is likely that if just one of these individuals was not present and supportive of this work, it may not have happened, since whenever change is proposed, a great deal of resistance is encountered. It is through these folks that we were encouraged to carry on. We feel fortunate to have their support and friendship. They include (in no particular order): Martin Goldberg (Lake Valley District), Stewart McMorrow (formerly with North Tahoe Fire), Dave Jaramillo (Whole Earth Forestry), Mike Vollmer (TRPA), Doug Cushman (Lahontan Regional Water Quality Control Board), and Kim Boyd (Tahoe Resource Conservation District). And last but certainly not least, Dr. Mark Grismer (UC Davis), who is an ongoing inspiration and mentor to the rest of us 'mere mortals'.

A special thanks goes to Brian Hirt, Juan Carlos Urizar and Milan Yeates of the California Tahoe Conservancy for their support, special brand of enthusiasm, flexibility and commitment to this project. Without their willingness to make their fuels treatment sites available for study, we might still be in the planning phase of this project.

There have been a number of folks who have offered encouragement, insight and support at various times during this project. During conversations with these folks, we recognized that there is a larger understanding of a need for focusing on actual outcomes. Elwood Miller, Rich Adams and Forest Schafer particularly come to mind. To others who we haven't mentioned, we truly hope that this document and the ideas it contains does justice to your interest and support.

Thank you to Chad Praul and Trish Sussman (Environmental Incentives) for their assistance with early project scoping, targeted document review and input on policy integration.

We would also like to thank the folks at the US Forest Service—Lake Tahoe Basin Management Unit for supporting this project, the Southern Nevada Public Land Management Act for funding this project, and the US Forest Service—Pacific Southwest Research Station staff (Jonathon Long and Tiff van Huysen) for grant administration and ongoing encouragement.

A special thanks also goes out to Dr. Ken Busse and Dr. Matt Hubbard from the US Forest Service—Pacific Southwest Research Station for their input and clear-eyed approach to forestry issues and research.

This project has confirmed my belief that there are many very dedicated and capable individuals within public agencies and research organizations who truly put good work and positive outcomes first. Thank you all.

We hope that this document can serve a small part in protecting and improving our watersheds throughout the West and can continue to lead to new understanding of how those watersheds work and how we can find that sweet spot between needed forestry vegetation management and water quality protection.

Michael Hogan

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Integrated Environmental Restoration Services, Inc

Forest Management Guidebook:

An Outcome-Based Approach to Water Quality Protection

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June 2015

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Manifesto

This Guidebook is a departure from the standard 'how to' approach to environmental protection practices. There is no shortage of prescriptive guidance for a wide range of environmental protection and improvement activities, including forestry projects. However, we recognized a significant gap in the literature regarding carrying projects through to a desired outcome, rather than assuming that the action taken would produce the outcome intended. With that in mind, we set out to produce a document that provides guidance that can, if used intentionally, actually help achieve forest vegetation management goals, specifically as those goals relate to water quality protection.

What we have come to believe, through years of field observations and measurements, is that regulatory rules and predictive models alone do not always produce the intended outcomes in the field and on the ground. We have come to the conclusion that a different way of approaching projects is required. That is, we have come to realize that we need to CHECK or ASSESS project outcomes in order to have any real sense of whether those projects are actually achieving the intended goals. But beyond checking we believe that taking follow-up actions when goals are not met can be the crux of the outcome-based management process and also the foundation of learning and improving.

Just as a gas gauge and speedometer are essential to our safe and responsible operation of a motor vehicle, direct assessment of project outcomes is essential to ensure responsible and effective management of watersheds.

For many years, we have assumed that 'common sense' and 'best management practices' are adequate to achieve water quality protection goals. However, there is an increasing body of information that clearly suggests that many—if not most—of our environmental protection and improvement projects don't meet all of their goals. The problem has been that since we rarely check, we continue to assume positive outcomes. The lack of checking our outcomes has limited our ability to improve, to innovate, to develop more cost effective management approaches.

Invitation

This Guidebook is an invitation to participate in creating a different sort of future than is currently outlined: a future where outcomes, and learning from those outcomes, is embraced, and where innovation and improvement is incentivized. Accepting this invitation requires humility, commitment and the willingness to swim upstream against the strong currents of 'common sense'. However, if this invitation is accepted by a significant number of practitioners, planners and regulatory staff, we believe that we can reverse the trends toward soil degradation in many forest treatment projects and can produce substantial improvements in watershed function and condition.

Some amount of soil damage and loss is generally considered to be inevitable in forest vegetation management. That may not be the case in all circumstances. We believe the future holds the clear possibility that vegetation management and other forestry activities can play a key role in improving water quality and watershed-wide resilience. And we believe that these outcomes can be achieved in a very cost-effective manner. We hope that this Guidebook provides a healthy mix of guidance and encouragement for those of you who accept this invitation.

User's Guide

Why

While a great deal of literature exists on the use of forest practices to reduce the potential for catastrophic fire, few field-verified practices and tools exist for the protection of water quality during and after forest vegetation management. Most water quality protection measures are based on models, model assumptions and expert opinion.

What

This Guidebook offers processes and tools to not only implement water quality practices within vegetation management projects, but more importantly, to assess whether those practices are actually working. Further, and perhaps most important of all, where they don't achieve the intended goals, this Guidebook proposes methods to adjust practices and improve conditions so that goals are achieved. Associated with the last step, we propose that when goals are not reached, that situation poses a prime opportunity for follow-up and learning.

Specifically, this Guidebook provides an outcome-based management process to help forest practitioners define project goals, identify success criteria, and achieve project goals by making adjustments throughout the duration of a project. This process was developed, applied and adapted on the ground, in real time, with forest practitioners. Rather than simply modeling potential outcomes, we outline methods to measure those outcomes and translate those into 'tools' which can, if applied properly, be used to achieve forestry goals (such as fuel reduction), while protecting water quality.

Who

This Guidebook is intended to be used by forest practitioners, land managers, field staff, regulatory/permitting agency personnel, land trusts, and other citizen stakeholders.

Where

The information and tools in this Guidebook are intended for use within all forests 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 forests near Lake Tahoe.

How

This Guidebook can be used in a modular format (ex. Individual tools) or as entire system (outcome-based management). While it is not intended to read cover-to cover, and is not intended as a 'how to' manual, we strongly encourage users to become familiar with outcome-based management in conjunction with exploring the technical tools that are presented throughout the Guidebook.

Navigation Guide

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 outcome-based management process in **Part One** will be useful. Specific management, treatment and assessment tools are found in **Part Two**. Relevant research is summarized in the Annotated Bibliography, **Part Three**, which provides a technical 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: Outcome-Based Management Steps

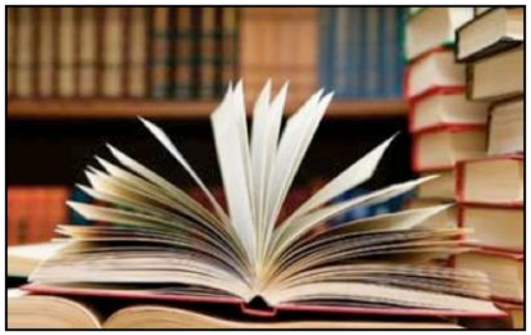
Part One lays out a stepwise, outcome-based management process through easy-to-use steps for achieving breakthrough outcomes in watershed management.
As you review these steps, we suggest that you pick a real-world project you are working on or about to begin and apply the steps to that project.

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: Annotated Bibliography

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



Quick Reference Guide

For all you non-linear folks out there who don't read documents beginning to end, here is a list of particular topics and numbers that may be of interest to you.

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Integration with the Watershed Management Guidebook

The Forest Management Guidebook shares a common foundation with the **Watershed Management Guidebook**, published in 2013 (Drake and Hogan 2013). The Watershed Management Guidebook (WMG) was designed to be a comprehensive overview of Outcome-Based Management principles as well as tools for overall watershed management and restoration projects. The Forest Management Guidebook (FMG) focuses primarily on forest vegetation management practices as they effect water quality. For continuity, the FMG includes some information and details from the WMG, but in an abbreviated fashion. With this in mind, the WMG can be considered the parent document of the FMG. When used together, these documents offer a fairly complete approach for water quality protection in actively-managed watersheds.

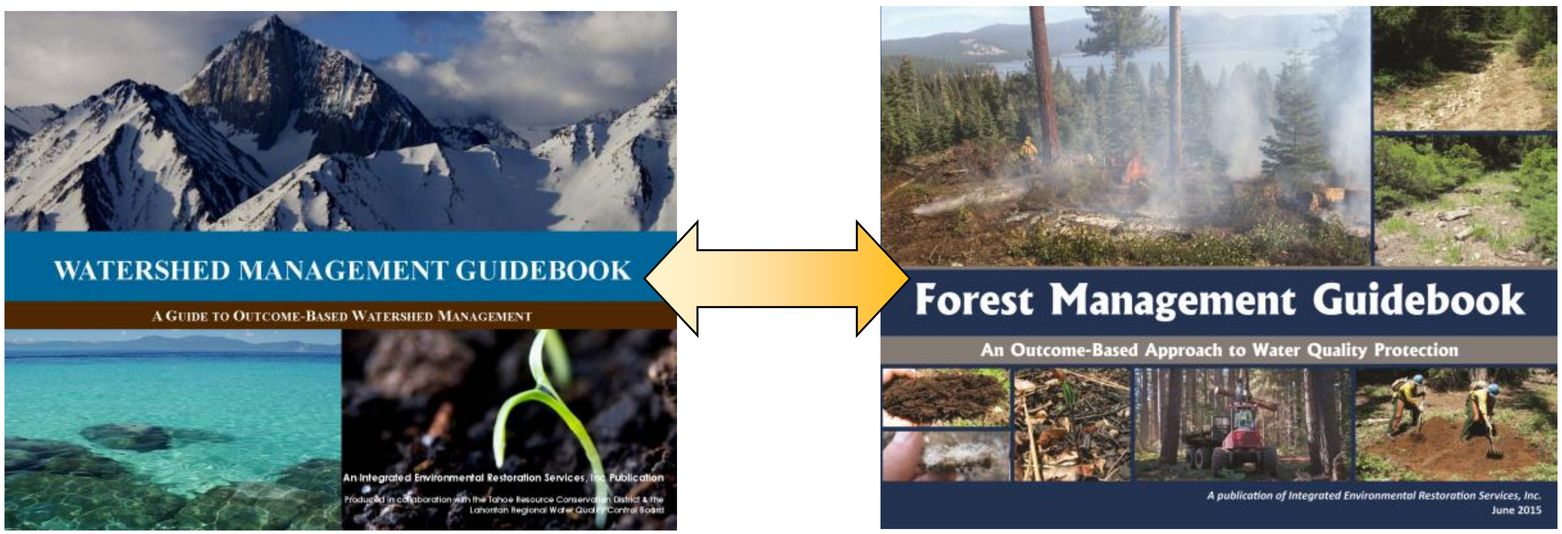

Figure 1. Linkage between Watershed Management Guidebook and Forest Management Guidebook.

VIDEO LINKS

If a picture is worth one thousand words, then videos are surely worth an entire book. We feel that videos can be incredibly powerful visual tools for communicating tools and techniques. For this reason, we produced 7 short videos linked to different tools in this document.

You will see this film reel icon in a few pages of this document where a video corresponds to the content on that page. Click on the hot link and you can watch a short video covering different elements of this printed Guidebook.

For convenience, we have also listed each video with web links below:

Video Title
CLICK HERE

Pile Burning: Part 1 (Overview)
https://youtu.be/PJqxDtuwmtw

Pile Burning: Part 2 (Mitigation)
https://youtu.be/thd-3cuj6ic

Mechanical Treatment
https://youtu.be/YR6UZzt5AXE

Assessment Tool: Cone Penetrometer
https://youtu.be/QR4hl5BK5A8

Assessment Tool: Runoff Simulator
https://youtu.be/dDumsT2gS3k

Assessment Tool: Constant Head Permeameter
https://youtu.be/5CuIK7Ukgm8

Assessment Tool: Soil Moisture
https://youtu.be/GVr0swAyIFg

"It ain't what we don't know that gets you in trouble. It's what you know for sure that just ain't so."

--Mark Twain

Part One
Outcome-Based Management

Overview of Outcome-Based Management

Outcome-Based Management

Outcome-based management is a stepwise process that enables effective forest management by embracing the fact that we do not fully understand the range of complex variables within a forest or 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 differs from current regulatory framework by focusing on outcomes instead of plans, and is also complimentary. Outcome-based management is simple to understand, but requires engagement and commitment on behalf of the project managers. It also requires accountability while supporting innovation.

How to Use Outcome-Based Management

This is 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 forest management and 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.

Steps to Achieve Outcomes

These outcome-based management steps are the guiding principles that shape a watershed management framework. The five main steps include: 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. Each step is briefly described here:

Figure 2. Outcome-Based Management Process (from Drake and Hogan 2012).

AIMING: articulating goals and objectives, defining success criteria, and identifying known and unknown information.

GAINING UNDERSTANDING: gathering on-the-ground information the site/project and watershed and assessing strategies for a site-specific implementation plan. Assessment results from past projects are used as the basis for developing treatment strategies for new projects that are most likely to achieve project objectives and success criteria. Often this step includes small-scale treatment plots to test different treatment approaches.

DOING: the part of the process where the plan is understood, implemented, and documented to support monitoring and continual improvement.

ACHIEVING: directly assessing project performance/effectiveness relative to goals and success criteria.

IMPROVING: embracing unexpected project outcomes, sharing

"Restoration of a disturbed ecosystem is an acid test of our understanding of that ecosystem."

--A.D. Bradshaw

"Discovery consists of looking at the same thing as everyone else and thinking something different."

-- Albert Szent-Györgyi

Part Two
Toolkit

Part Two: Toolkit

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Introduction to the Toolkit

This Guidebook is a combination of philosophy or overall approach, process (Outcome-Based Management) and specific tools. The Toolkit (Part Two) focuses on the specific tools. The tools that follow are 'how-to' elements that are used with some level of knowledge in order to get a specific job done. And as with most tools, an understanding of how the tool works is critical. At the same time, it is as important to understand what the larger job is and that understanding allows the implementer to choose the right tool. The saying 'When all you have is a hammer, everything looks like a nail' tends to be true. The point is that understanding the *context* of the job to be done, the many different parts of that job, and the intended outcome, can be absolutely critical to getting the job done correctly, particularly when something unusual or unexpected comes up. An apprentice uses a particular tool as instructed without asking too many questions. A journeyman may ask questions but may also not understand the nuances of a particular project. A master craftsperson knows how to use the tools, the different tools that may be used, they understand the job itself and why it is being done and check their work to make sure it is as intended. And a master craftsperson checks and adjusts as he or she goes along.

This Guidebook is intended to help us all grow from apprentice to journeyman to master as we do the work itself. We hope that the tools that follow are useful to you in your daily work.

STEP 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).

TOOLKIT

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***."

1.1: Setting Goals and Objectives

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, 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

Setting goals is 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 disturbed soil areas 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.

TOOLKIT

1.1: Setting Goals and Objectives

Setting Goals

Setting goals is a critical first step toward quantitatively defining and determining success (see 1.2 Defining Success). Specific watershed protection goals for a fuels reduction project may include:

- Reduce the presence of roads within the project area boundary
- Reduce runoff and sediment yield from road system
- Minimize amount of land area disturbed by mechanical treatment
- Avoid operating machinery during high soil moisture conditions
- Reduce erosion from historic legacy areas
- Maximize onsite reuse of wood chips and masticated debris
- Maintain or increase total soil cover within project boundary

The list above contains some goal statements that may begin to meet the criteria of an objective. For instance, "Maximize onsite reuse of wood chips and masticated debris," may be an objective that is also linked to the goal of "Reduce runoff and sediment yield from road system."

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 maintaining or increasing total soil cover in the project area.

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 square feet of dirt road surface (8% of all roads within the property boundaries) within three years, and

2) to demonstrate a complete restoration of surface hydrology on the restored road areas by establishing infiltration rates that are equal to or greater than the surrounding native (reference) conditions.

These two objectives become the foundation of success criteria, which may also be useful as permit conditions. See Table 1 for examples of goals, objectives, and success criteria.

1.1: Setting Goals and Objectives

Success Criteria

Success criteria are included in this Tool in order to demonstrate how they relate to goals and objectives. Refer to 1.2 Defining Success, 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 tend to not be very useful.

Table 1. Examples of goals, objectives and success criteria.

Goal	Objective	Success Criteria
To minimize erosion from the road cut on Upper Elbow Road.	Stabilize the Upper Elbow road cut using full soil restoration treatment such that erosion is reduced by at least 50% within 1 year.	Sediment yield from the Upper Elbow road cut is reduced by 50% compared to background rates as measured with simulated runoff in the field.
To increase summer habitat value for Loomis' Ground Squirrel.	Establish a robust community of Mann's Groundcherry and Knudsen's Squirrelbrush.	• 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 burn pile scars.	Increase plant and surface cover on burn pile scars throughout the project area.	• Native plant cover of at least 15% on mitigated burn scars by July 15th following pile burning. • Total cover (including mulch) of at least 85% by June 1 following pile burning.

TOOLKIT

1.2: Defining Success

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, a runoff simulator can be used to directly measure sediment yield and demonstrate the site's propensity for eroding over a range of non-saturated conditions (see 4.6 Runoff Simulator). 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 4.4 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.

1.2: Defining Success

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 2.

Table 2. 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

1.2: Defining Success

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 3). 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 3) 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

TOOLKIT

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.

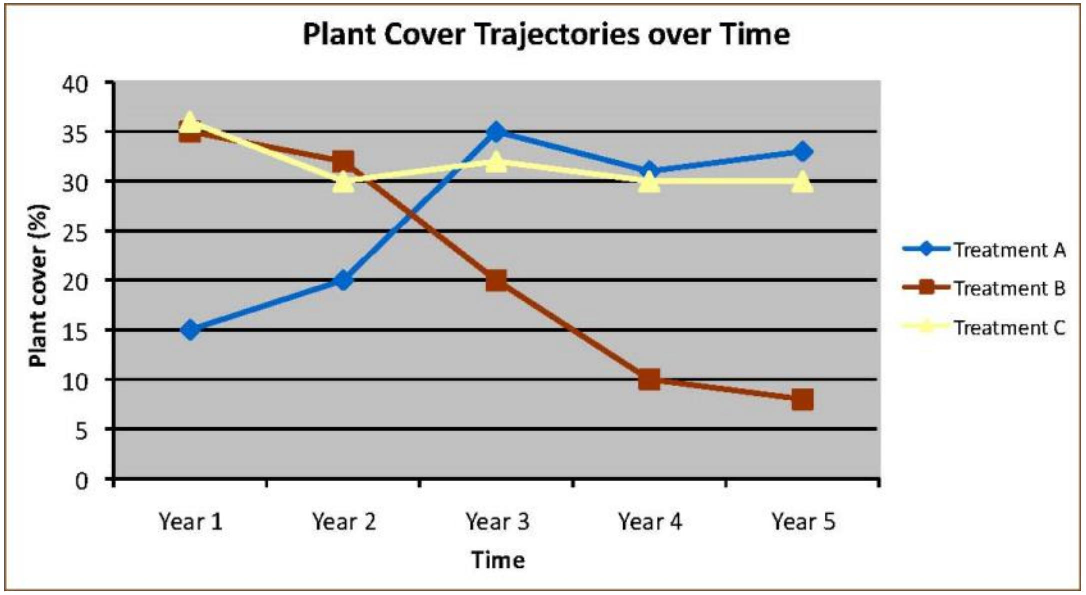


Figure 3. Plant cover trajectories over five years.

1.2: Defining Success

Table 3. Example success criteria matrix.

Monitoring Parameter	Year 1	Year 2	Year 3	Year 2	Year 3
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.				

TOOLKIT

A Word About Statistics in Measuring Success

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

STEP 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. 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.

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 transparent and effective process to target limited resources on actions that will yield a measurable return on investment in watershed protection and improvement.

Purpose

The purpose of EfRA is to provide a simple, direct assessment process to expand understanding of watershed conditions, hydrologic linkages, and restoration opportunities. This process is systematic, accessible, easy to use, and serves as a strategic methodology to protect and repair watersheds as part of forest management efforts.

Goals

- To document drainage patterns in the watershed as a context for large -scale understanding of connectivity and potential water quality liabilities
- To define watershed conditions relative to sediment sources, sinks and water quality
- To identify sediment source areas and areas for avoidance, protection and/or restoration during forest management efforts
- To prioritize, group and sequence restoration treatment opportunities into forest management projects
- 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 potential for erosion problem areas
- Improved ability to prioritize and target protection and restoration actions
- Improved ability to assess project outcomes and benefits
- Improved ability to respond when project outcomes fall short of goals

Outputs

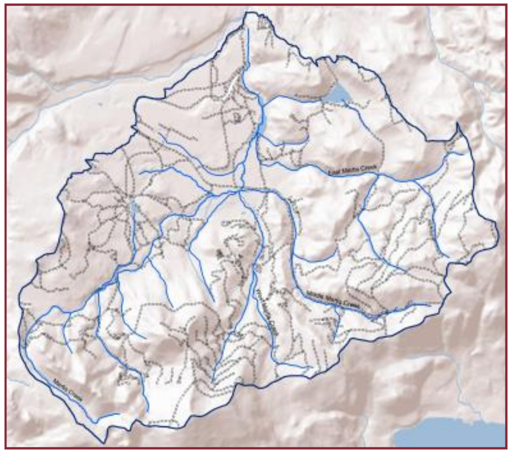
- Mapped erosion problem areas and hydrologic linkages
- Project prioritization framework based on site condition and sediment delivery risk for each site
- Project implementation plan that integrates key protection areas and restoration opportunities
- Outcome-based management process to asses actual project outcomes relative to goals

2.1: Erosion-Focused Rapid Assessment—Step by Step

1 Define the goals of the project

In addition to silvicultural goals and prescriptions, other goals that should be considered for multiple-benefit forest management projects, such as:

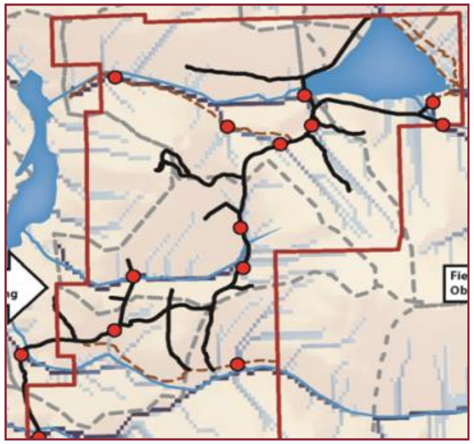
- To reduce sediment loading to a stream.
- To create a new road system that does not increase erosion.
- To reduce runoff from legacy landings and roads.

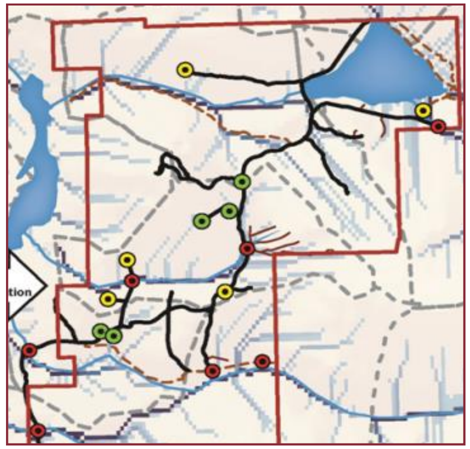


2 Create base map(s) with key watershed attributes

- 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 USGS 7.5 min topo map, 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, geology/soils, and riparian buffer areas.

2.1: Erosion-Focused Rapid Assessment—Step by Step





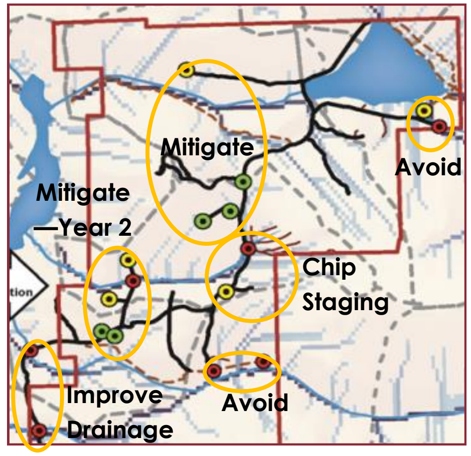
3 Identify known and potential erosion problem areas

- Review the map and identify known and potential erosion problem areas.
- Identify potential erosion areas and potential "hot spot" locations, such as steep road sections or road-stream crossings.
- 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 actual erosion problem areas and interconnections

- Using the map created in Steps 2 and 3, conduct targeted field assessment to verify and further investigate erosion problem areas and key features.
- Where problems are identified, trace those problems upslope to their source(s).
- Document these additional drainage features using GPS. Document connectivity between problem areas and to drainages and streams (see 2.4 Water Flow/Connectivity Assessment).
- Document all problem areas with photos, field observations, notes, potential treatment and/or protection approaches, and GPS locations.

2.1: Erosion-Focused Rapid Assessment—Step by Step



TOOLKIT

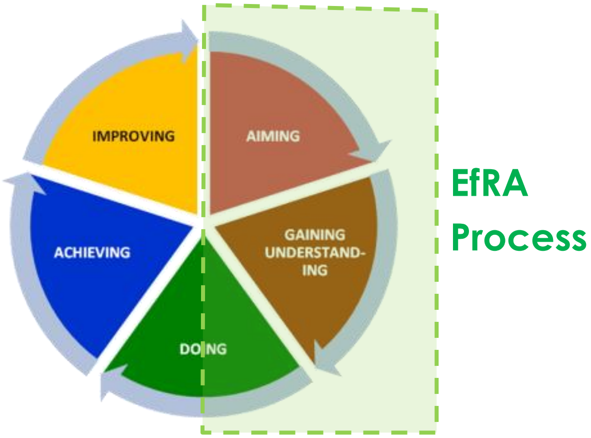
5 Conduct site condition and connectivity assessments

- At each site, assess 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/duff cover and thickness, vegetation, soil nutrients and organic matter, and evidence of erosion or ongoing disturbance.
- Develop specific treatment approaches to address impaired functions.

6 Develop an integrated project implementation plan

- Identify drainageways and erosion hot spots for avoidance/protection and prioritize post-project mitigation treatments.
- Develop restoration treatment approaches that efficiently integrate with forestry operations, such as:
  - ⇒Selecting forestry equipment with subsoiling rippers integrated on boom-mounted masticators.
  - ⇒Planning to either stage or directly apply wood chips or masticated debris to roads, landings or equipment travelways.
  - ⇒Integrating these treatment approaches into forestry contracts.
- 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.

2.1: Erosion-Focused Rapid Assessment—Step by Step



7 **Close the loop and manage to outcomes**

Congratulations — it's time to implement projects!

- 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 protection and improvement goals are achieved along with other forest thinning goals.
- 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.

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 forest management projects that produce a net benefit to soil and water quality. Gathering baseline information about your watershed will also help 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. Going to 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

2.2: Characterizing your Watershed

1 Create a watershed base map

This is your reference map (See Figure 4). 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 2.3 Hot Spot Identification). Only the key site characteristics need to be included: **stream and road networks**, **watershed boundaries**, **property or project boundaries**, **buildings and topography**.

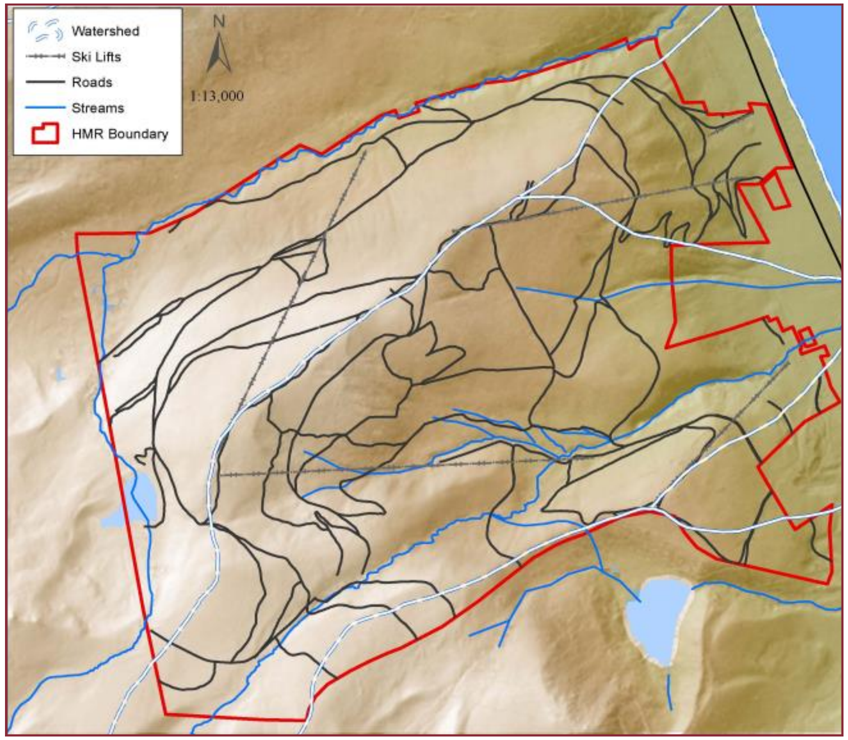


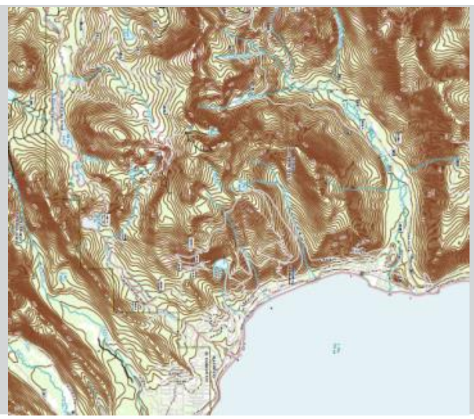
Figure 4. An example of a watershed base map made for road system improvement planning on the West Shore of Lake Tahoe.

Finding GIS Data

- Begin by collecting **geographic data** from land owners and stakeholders. Some landowners may have their own geodatabase (collection of geographic data) cataloging 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.

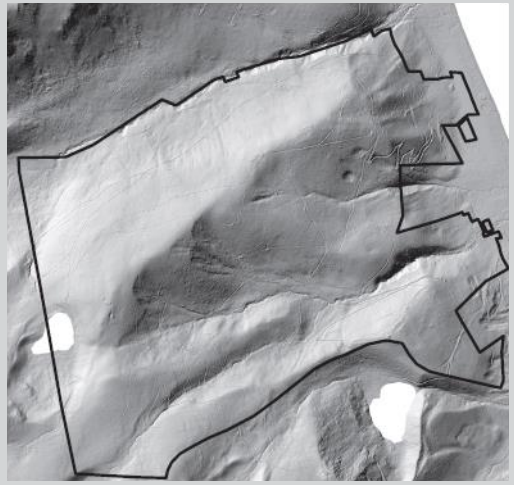


2.2: Characterizing your Watershed

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

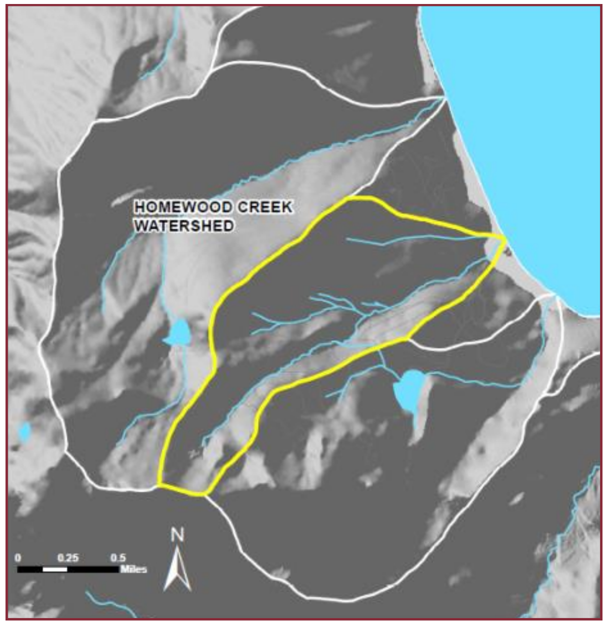


Figure 5. Example map showing basic hydrological features such as streams, lakes and watershed boundaries.

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 efforts. 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.

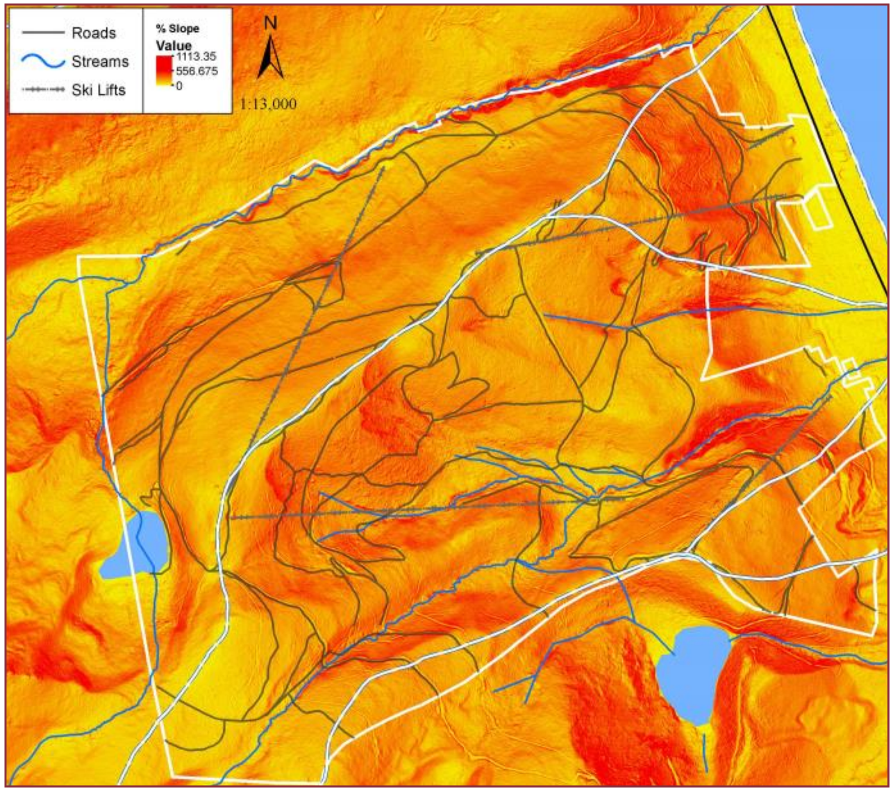


Figure 6. Map illustrating percent slope. Steepest slopes are highlighted in red.

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 erosion sources and streams. Knowing the slope of a site relative to the surrounding features can identify areas of higher erosion potential (and limited equipment access) and help target subsequent field assessment. This is especially useful in larger watersheds where complete field surveys are not possible.

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 tend to be 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 exhibited evidence of 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.

2.2: Characterizing your Watershed

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.

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 and forestry 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.

Figure 7. Map showing approximate locations of historic logging and ranching activities in the Martis Watershed. Map prepared by Balance Hydrologics, Inc. and Susan Lindstrom.

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. In the context of forest management efforts, the purpose of identifying erosion hot spots before implementation is to develop plans to prevent exacerbating existing erosion issues and ideally, to develop plans to mitigate some existing high priority hot spots during forestry treatment implementation.

Approach

Using this tool, you will first identify <u>potential</u> hot spots using GIS maps and information produced in 2.2 Characterizing your Watershed, and <u>known</u> hot spots based on input from people familiar with the watershed. You will then head to the field to determine <u>actual</u> hot spots and discover <u>new</u> 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.

2.3: Hot Spot Identification

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.*

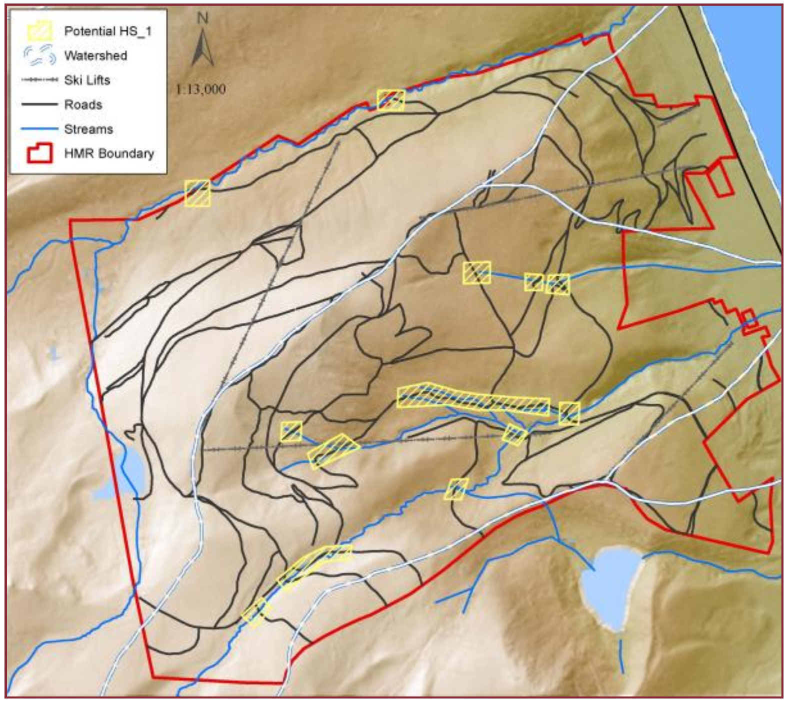
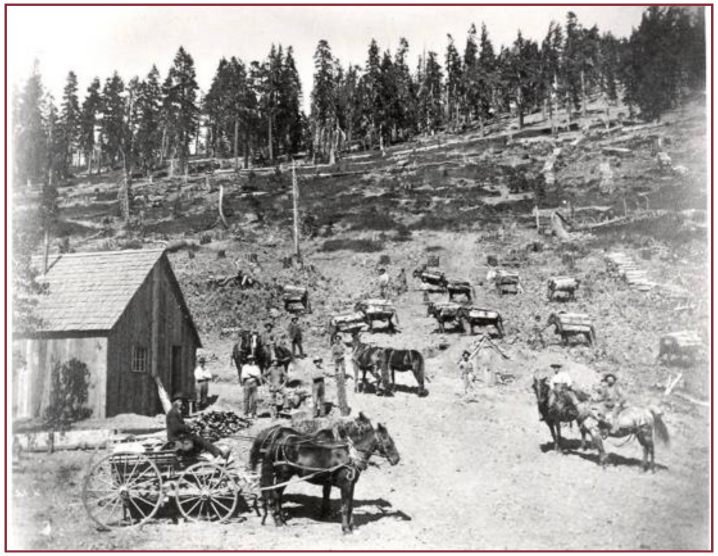


Figure 8. Example map showing potential hot spots identified prior to field investigations.



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

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 2.5 Flow Accumulation Analysis.

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.

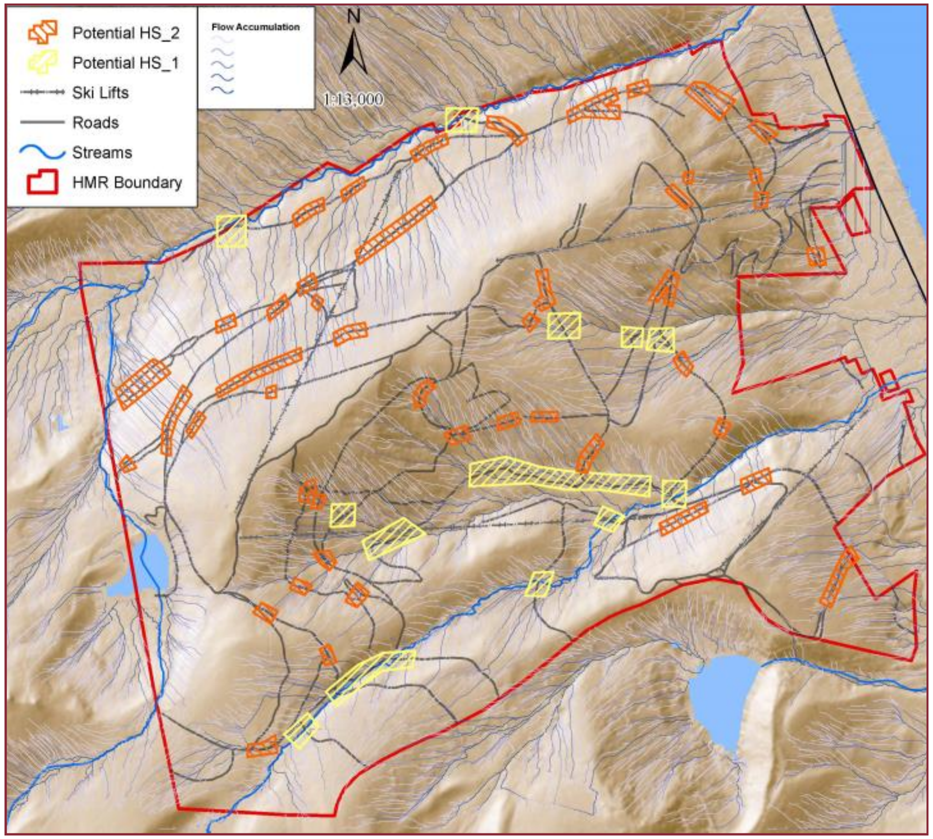


Figure 9. Example map showing known and potential hot spots. Creating a map like this can help to target subsequent field investigations.

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.

TOOLKIT

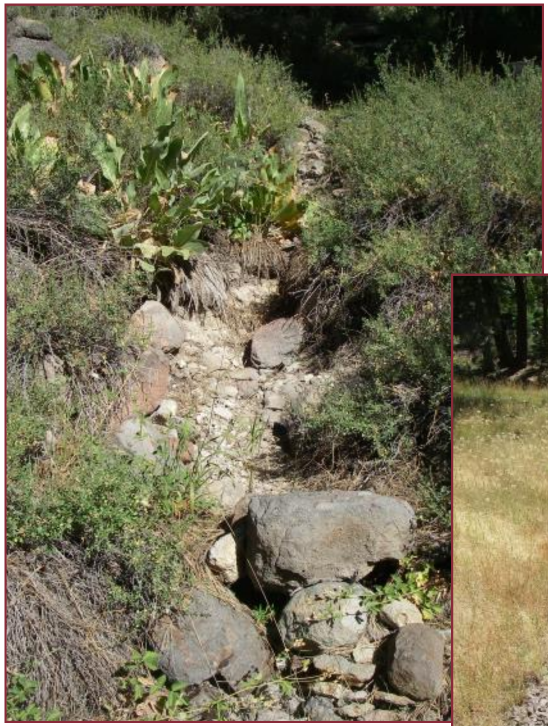
2.3: Hot Spot Identification

3 Conduct Field Assessment to Identify Actual 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 assessment tools in Step 4: Achieving).

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 its source and end point using 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.

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 the access plans for forest management projects. 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?*** The assessment steps in this tool can be taken to the next level by combining them with a GIS-based flow accumulation analysis (see 2.5. Flow Accumulation Analysis).

A recently graded logging road intersects with an ephemeral drainage near Truckee, CA. Sediment from this roadway is directly connected to this drainage, which has high connectivity to a Lake 500 feet downstream. This is one of many examples of the interconnected nature of erosion issues in high-use watersheds.

TOOLKIT

2.4: Water Flow/Connectivity Assessment

Overview

When prioritizing restoration projects or areas for forestry equipment to avoid, it is important to consider 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 represent actual, complex runoff and erosion patterns. However, the ability to understand this connectivity on the ground is, in many ways, the crux of sediment reduction and watershed management efforts. Additionally, water flow and connectivity assessment is an important step in planning forest management and development projects 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 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.

2.4: Water Flow/Connectivity Assessment

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/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.

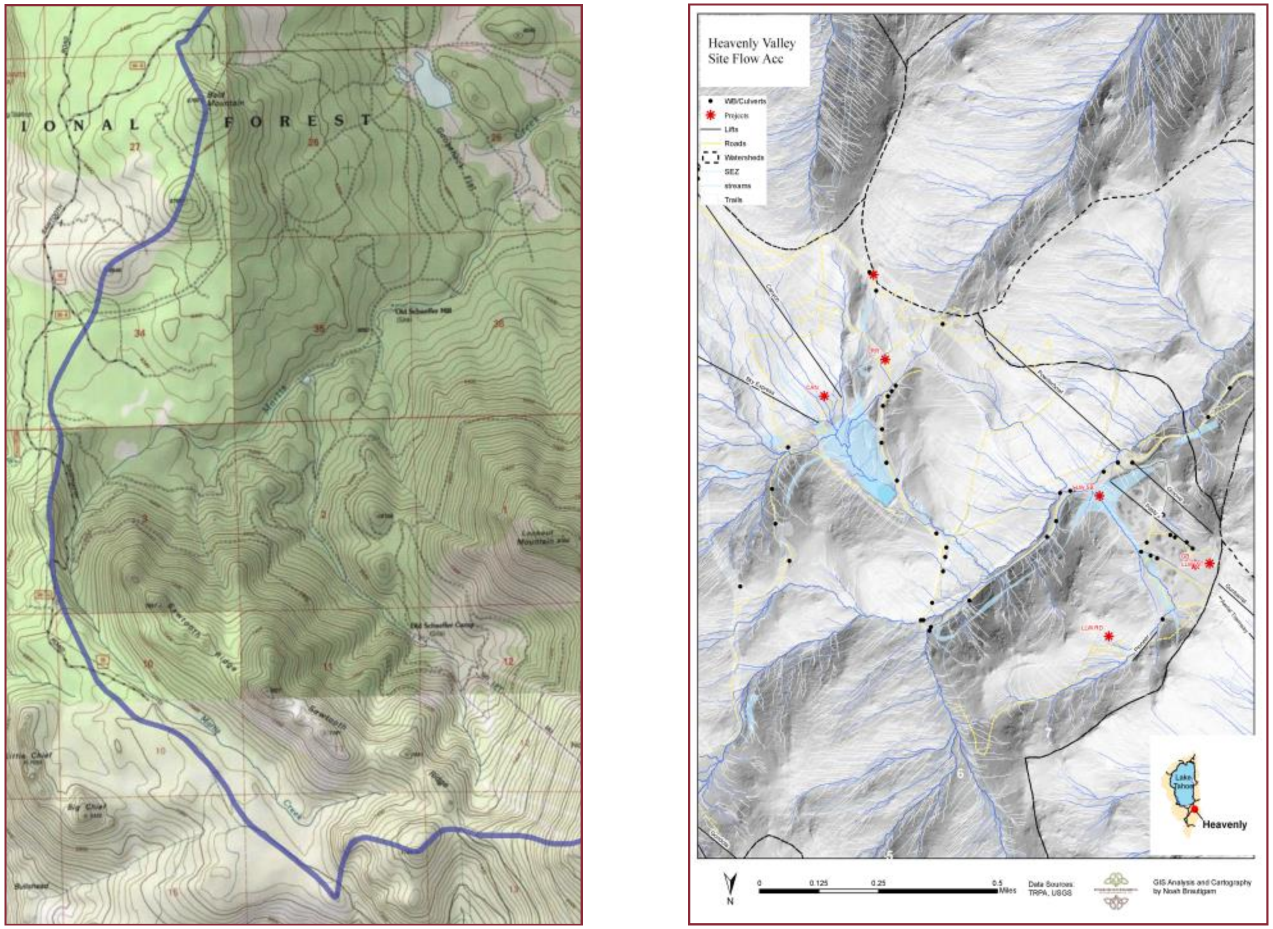


Figure 10. Example water flow base maps. At left is a USGS 7.5 minute quad map with the watershed boundary added. At right is a GIS-derived map showing flow accumulation paths, shaded relief, roads, water bars and ski lifts.

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.

Water flow and connectivity assessment can be taken to the next level by combining them with a GIS-based flow accumulation analysis (see 2.5. Flow Accumulation Analysis).

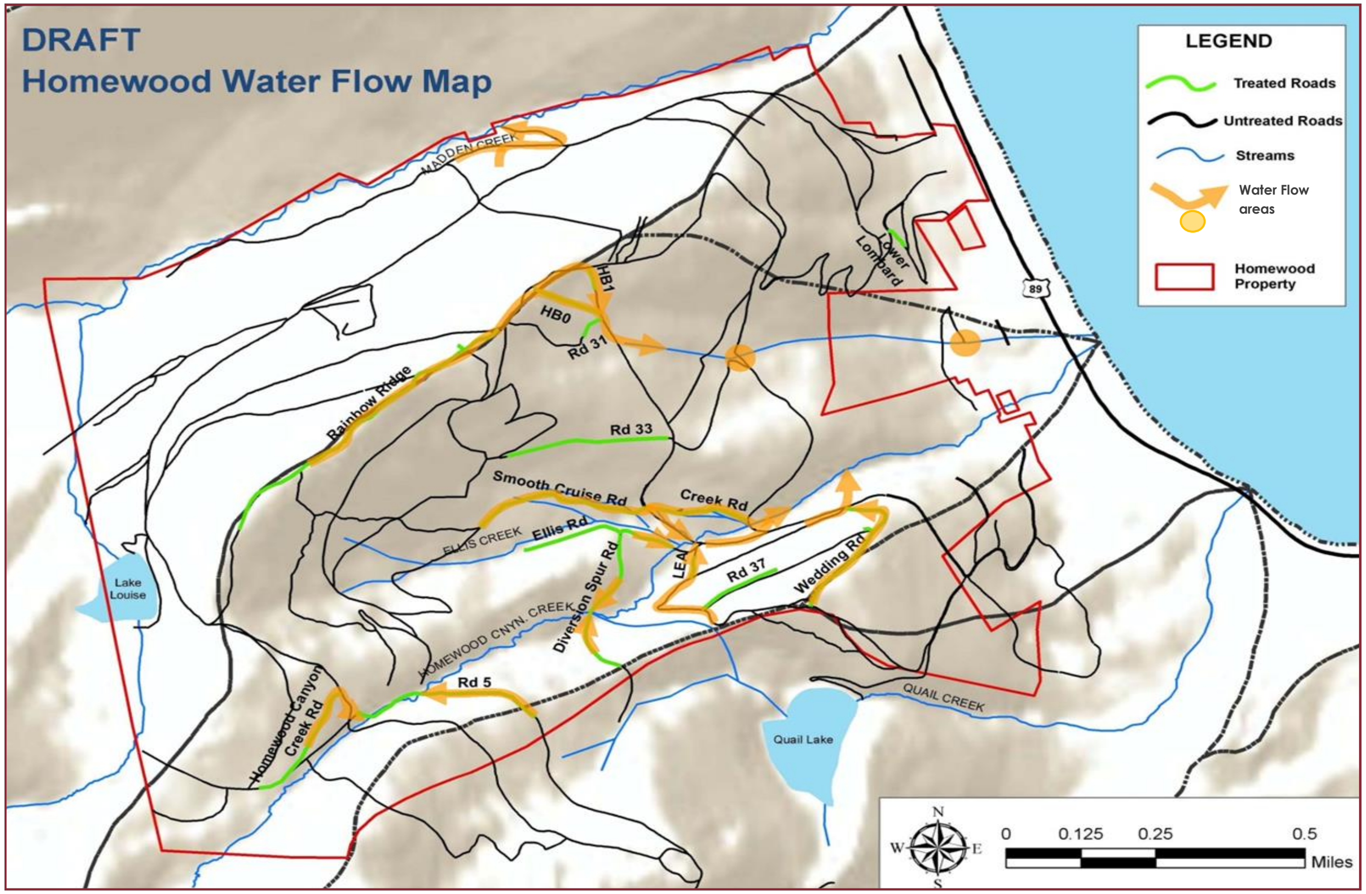


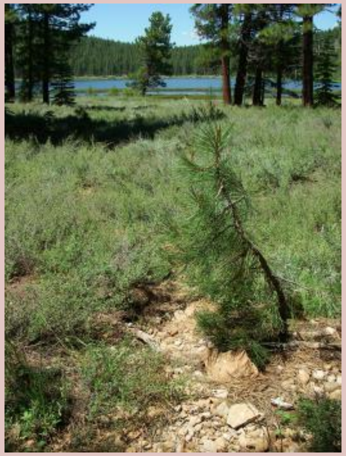
Figure 11. Example water flow and connectivity assessment map showing key upland water flow areas and connectivity to streams.

2.4: Water Flow/Connectivity Assessment

3 Assess Connectivity in Field

Once water flow areas are located and mapped, particularly those that connect to and from hot spots (identified in 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 4. 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

2.5: Flow Accumulation Analysis

Definition

Flow Accumulation Analysis is the process of using GIS tools to identify and map ephemeral drainageways and potential surface flow paths (in addition to stream channels), then field-checking the results on the ground.

Purpose

The intent of conducting a Flow Accumulation Analysis is to understand surface runoff patterns within a given drainage area before implementing a project. A flow accumulation is used to visualize, discuss and plan for surface runoff, drainage, erosion pathways and connectivity between disturbed areas and streams.

Approach

Flow Accumulation Analysis uses hydrologic information from a digital elevation model (such as elevation, aspect and slope angle) to model the movement of water over the soil surface. The finer the resolution of the digital elevation model (DEM), the more precise the flow accumulation map is likely to be. Like any computer-generated model, flow accumulation areas should always be field-checked and compared to on-the-ground observations (during or immediately following runoff events whenever possible).

Potential Uses and Applications

- Identifying potential erosion source areas and restoration options
- Planning for vehicle and equipment access and travelways
- Identifying avoidance/protection areas
- Assessing hydrologic connectivity between disturbance areas and water ways
- Prioritizing mitigation/restoration actions
- Creating drainage base maps for Stormwater Pollution Prevention Plans
- Designing effective water quality monitoring programs

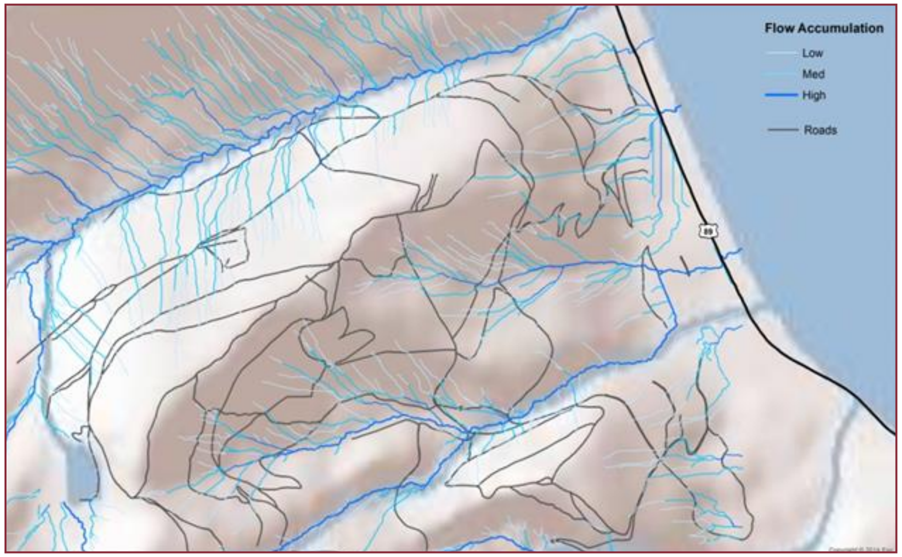


Figure 12. Flow accumulation map over shaded relief for a Lake Tahoe watershed.

Effort Required

For most projects, a flow accumulation base map can be prepared in 3-4 hours by someone who is reasonably familiar with GIS. Once a flow accumulation shapefile is created in GIS, it can be easily modified for future projects and different applications.

Steps in Conducting a Flow Accumulation Analysis

1. Download GIS data
2. Create a Flow Accumulation shapefile
3. Symbolize your Flow Accumulation map
4. Field-verify mapped flow accumulation areas

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2.5: Flow Accumulation Analysis

Step 1: Download GIS Data

Download normal resolution (3-10m) Digital Elevation Models at: http://viewer.nationalmap.gov

Download high-resolution (<1ft) Digital Elevation Models and other LiDAR data products for the Lake Tahoe Basin at: http://www.opentopography.org/index.php/news/detail/lake_tahoe_basin_lidar_data_released

Other GIS data for the Lake Tahoe Basin can be downloaded on the Tahoe Regional Planning Agency website at: http://gis.trpa.org/datadownloader/

If your project is located outside the Lake Tahoe Basin, contact your local City, County or State planning agency to locate publically-available GIS data.

Step 2: Create a Flow Accumulation Shapefile

The workflow diagram (at right) provides a step-by-step process for creating a flow accumulation map using ESRI ArcGIS. All GIS flow accumulation tools can be found in the Spatial Analyst extension under Hydrology. The process begins with the DEM as the primary dataset, which is the input for the first tool. The output file from running each tool typically becomes the input file for the next tool, but the last two tools require two inputs, as shown in the diagram.

For information on tool use and function in the ArcGIS Hydrology Toolbox, see: http://help.arcgis.com/en/arcgisdesktop/10.0/help/index.html#//009z0000004w000000.htm

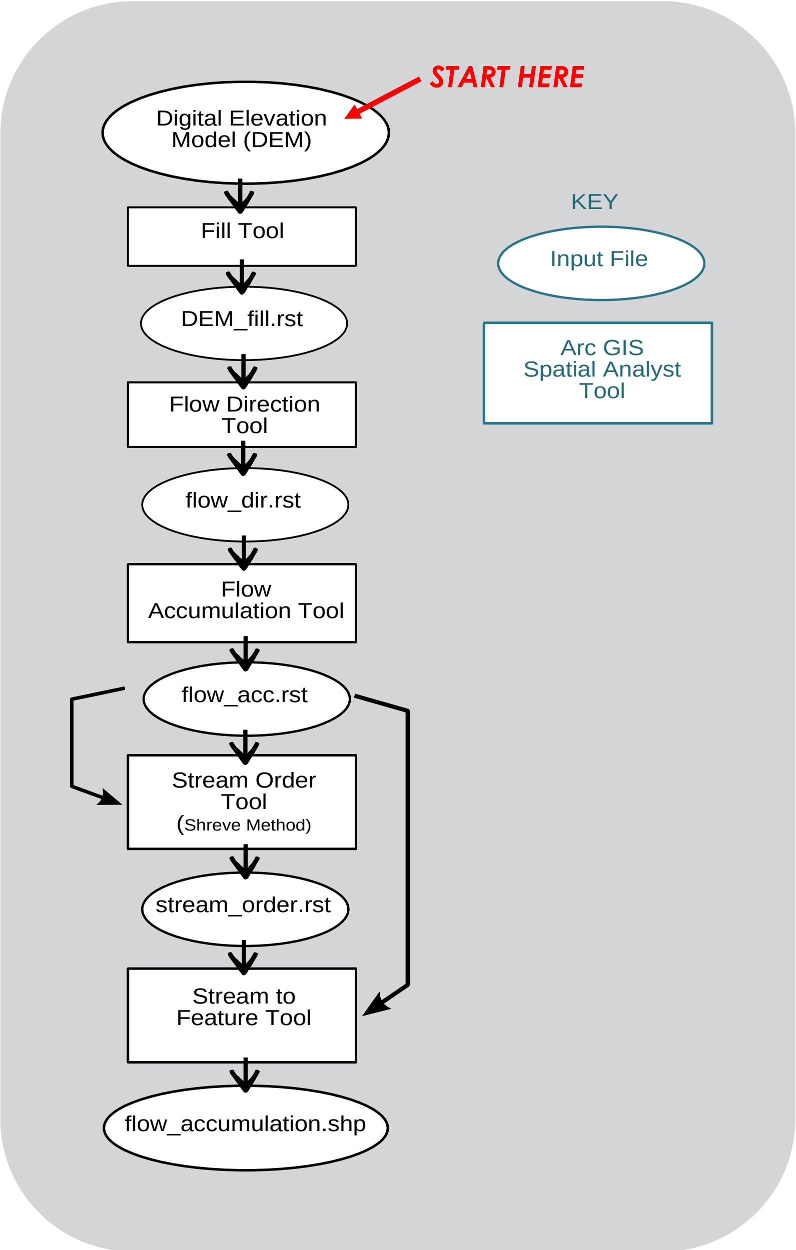

Figure 13. ArcGIS workflow diagram for creating a Flow Accumulation map.

2.5: Flow Accumulation Analysis

Step 3: Symbolize Your Flow Accumulation Map

Once you have generated a flow accumulation shapefile, you will need to adjust the symbology to display the layer at an appropriate resolution.

1. Under Layer Properties, select the “Symbology” tab.
2. In the Quantities menu (at left), select “Graduated colors”.
3. In the Value drop-down menu, select “GRID_CODE”.
4. Then, select the number of classifications you wish to display (typically 3 -5).
5. Lastly, adjust the colors and value ranges for each classification to best represent flow accumulation paths for your project.

Tips and Suggestions

- **Adjusting value ranges:** Click the “classify” button and select an automatic classification method (such as Natural Breaks or Quantile) as a starting point to display and review your flow accumulation paths. Then you can manually adjust the value ranges to fit your needs. You will likely want to set a lower limit for the values to be displayed, in order to avoid the “spider web” effect, especially with high-resolution DEMs.
- **Color and width of line symbols:** while there is a great deal of personal preference here, we have found that increasing line width and darkening the color as values increase is the most intuitive approach. Blue colors are also a natural choice, as flow accumulation lines symbolize potential water flow paths.
- **Color contrast:** it is useful to select line colors that contrast with the background layer. Aerial photos can be challenging as background layers, but setting transparency of the image to 30-50% can sometimes be helpful. Displaying flow accumulation lines over a shaded relief background tends to draw the most attention to the flow accumulation areas

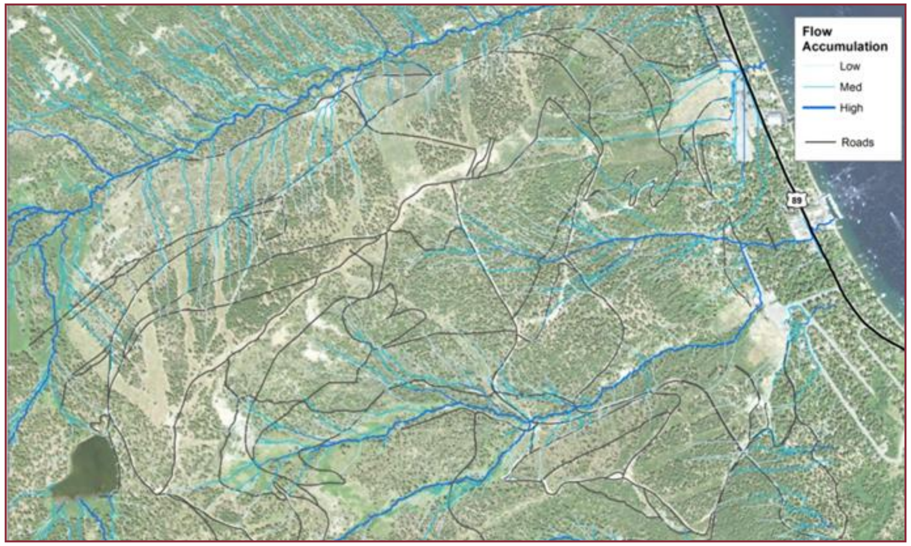

Figure 14. Flow accumulation paths over aerial photo.

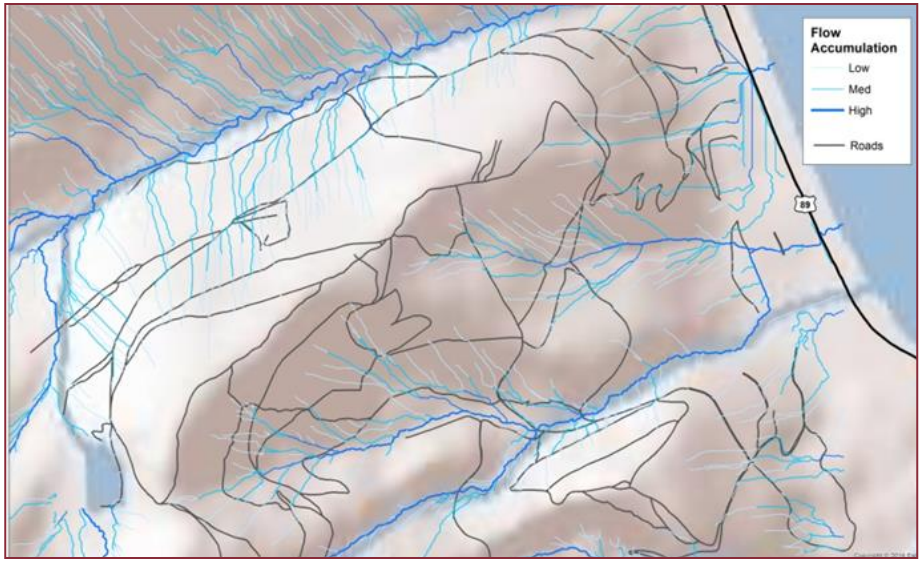

Figure 15. Flow accumulation paths over shaded relief background.

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2.5: Flow Accumulation Analysis

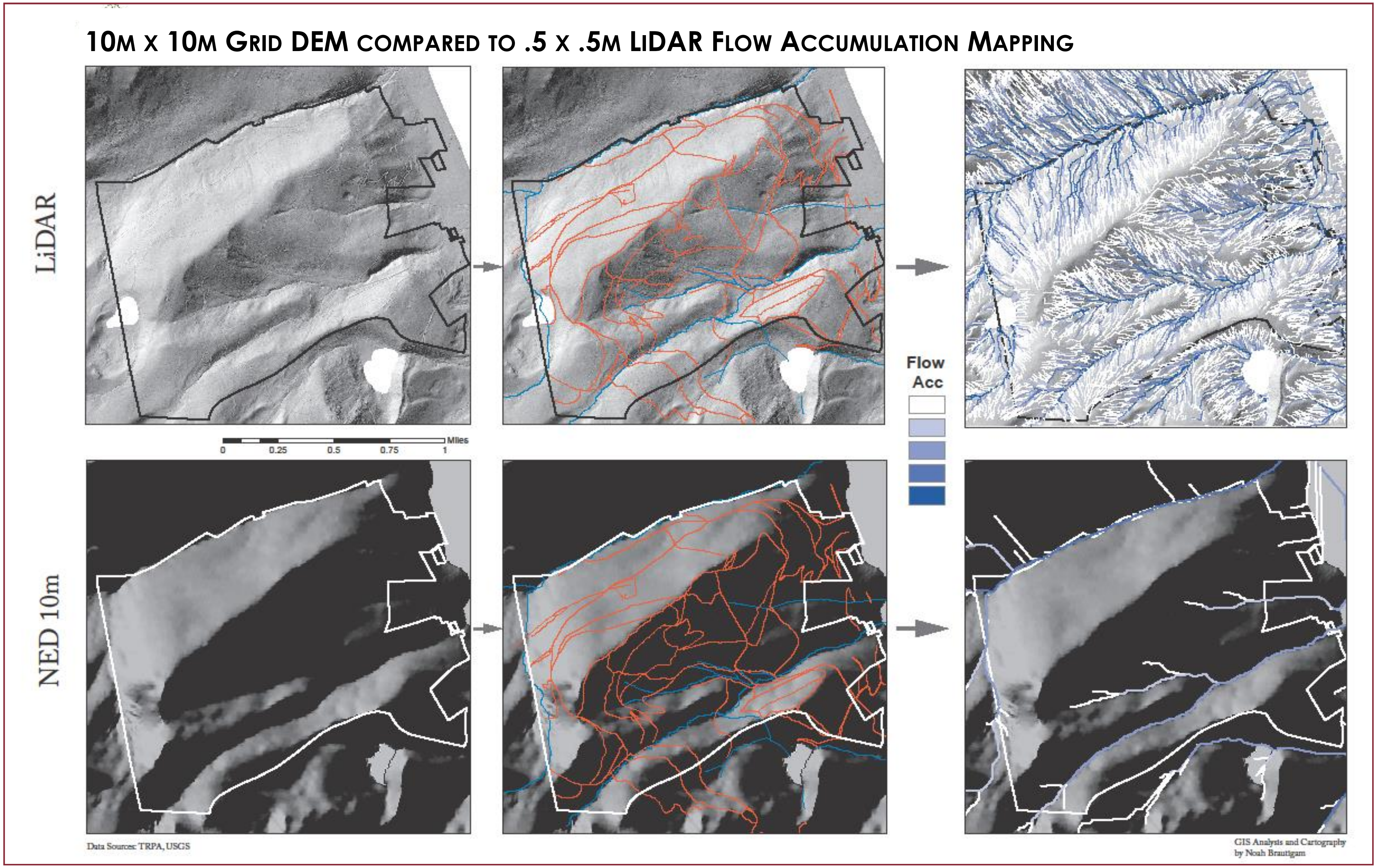


Figure 16. Where available, LiDAR data is very useful for characterizing the land surface and processes of your watershed.

2.5: Flow Accumulation Analysis

Step 4: Verify Mapped Flow Accumulation Areas

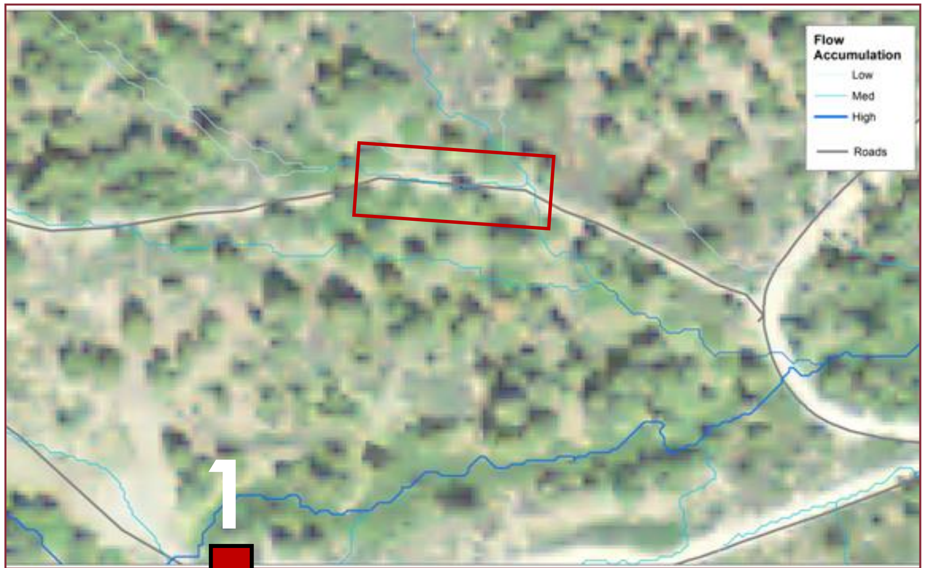
With large watershed areas to manage, it can be difficult or impossible to assess the entire area on foot. Flow accumulation analysis is a useful tool that land managers can use to identify potential erosion areas and prioritize time in the field doing on-the-ground assessment. However, even with high-resolution topographic data, flow accumulation analysis is still a computer model of reality. Use targeted field visits to determine the location and severity of actual erosion and surface flow areas and to make modifications to maps to best represent actual drainage conditions.

Road Capture Example

In this example (Figure 17, at right), a particular road segment was identified using flow accumulation mapping that appeared to be capturing and concentrating surface drainage and routing the concentrated flow to a live stream. A field visit verified that indeed, an old and rarely used forest road had captured and concentrated several small ephemeral drainages, causing severe erosion and sediment delivery direct to a live stream.

The land owner determined that the road segment was no longer needed for their operations, so the road was functionally decommissioned using soil-based restoration treatments. The decommissioned road has now been completely stable for more than 5 years and is now a "sink" rather than a "source" for runoff. Furthermore, flow accumulation mapping provided documentation that the road restoration project had a direct linkage to reducing sediment loading to the nearby stream and, ultimately, Lake Tahoe.

Figure 17. The three photos at right illustrate the process of conducting a flow accumulation analysis, from office to field to addressing the problem.



Identification of road segment capturing runoff.

Confirmation of road flow capture and erosion in field.

Decommissioned road, post-treatment.

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 4.1 – Developing a Monitoring Plan). For the purposes of this document, 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.

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.

2.6: Targeted Water Quality Monitoring

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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.

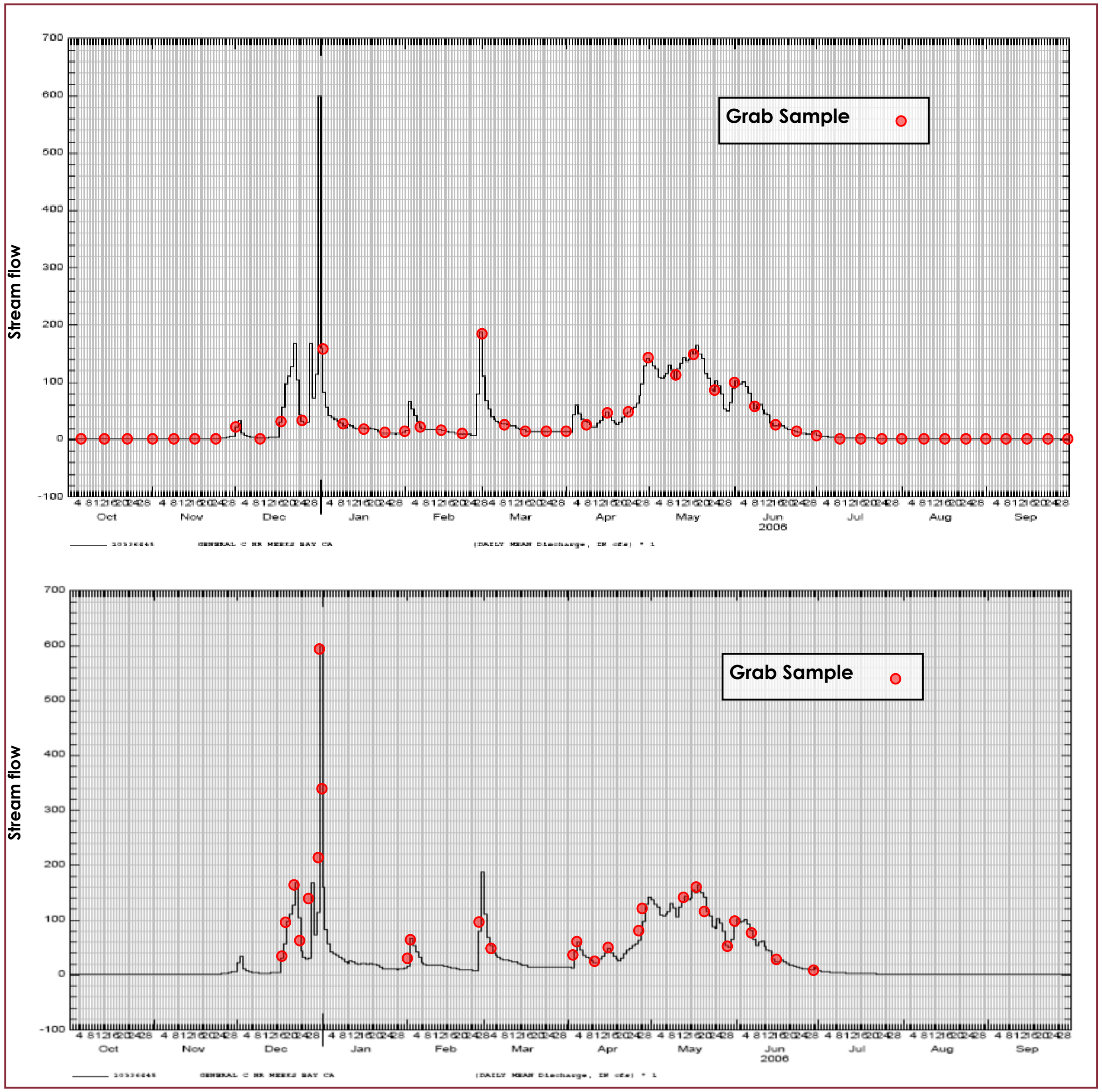

Figure 18. Example hydrographs illustrating routine (weekly) and targeted sampling approaches.

2.6: Targeted Water Quality Monitoring

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 19 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.

2.6: Targeted Water Quality Monitoring

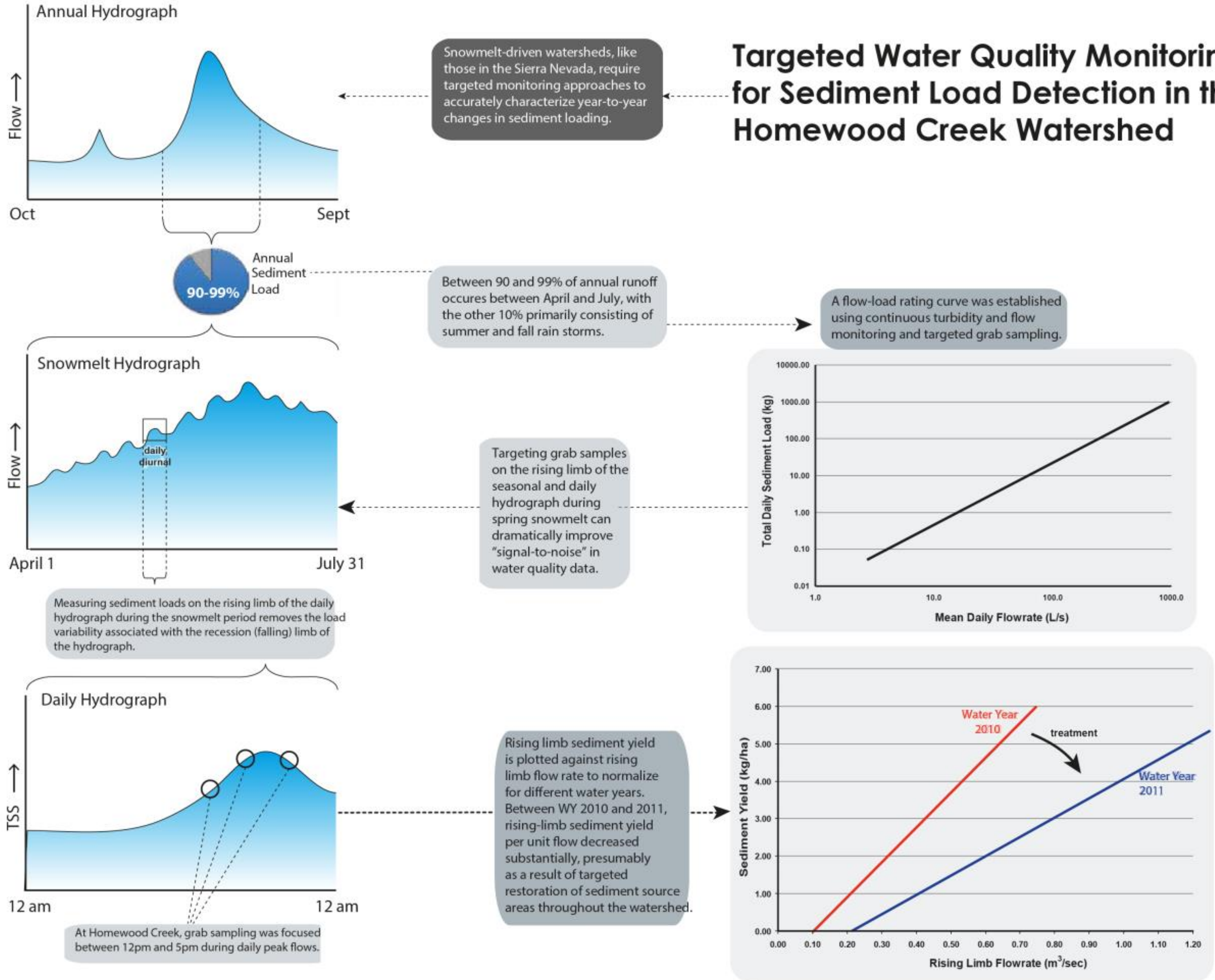

Figure 19. Targeted Water Quality Monitoring for Sediment Load Detection.

2.6: Targeted Water Quality Monitoring

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. Volume 28. Issue 2.
- Grismer, M.E. 2013. Stream Sediment and Nutrient Loads in the Tahoe Basin – Estimated versus Monitored Loads for TMDL "Crediting". Environmental Monitoring & Assessment. Volume 185, Issue 3.
- Grismer, M.E. 2014. Soil Disturbance/Restoration effects on Stream Sediment Loading in the Tahoe Basin – Detection Monitoring. Environmental Monitoring & Assessment. Volume 186, Issue 7.
- 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/

STEP 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.

3.1: Pile Burning

Definition

Pile burning is a disposal method for limbs, tops, small trees and dead downed material typically associated with forest hand-thinning treatments.

Purpose

The primary purpose of pile burning is to effectively eliminate excess vegetation in a forest without having to physically remove it.

Overview

Pile burning as a follow-up to forest hand-thinning treatments is both an effective and economical tool for disposal of excess vegetation or biomass. Hand crews typically cut, top and limb trees or cut large shrubs with a chainsaw and physically pile the material. Piles are typically constructed for optimum combustion with easily ignited fine fuels on bottom and larger fuels on top. Piles are allowed to cure and then ignited with a drip torch during the winter months. Pile sizes can range widely based on treatment specifications, topography, vegetation type and capabilities of the hand crew.

Context

Ecological Considerations

- Pile size and fuel composition impacts on soil organic matter, and its impact on water infiltration and runoff
- Influence of slope angle on erosion
- Plant recovery and trajectory post-burn
- Soil sealing/hydrophobicity in response to burning
- Proximity and connectivity of burn site to water bodies

Burn Pile Overview Video
CLICK HERE

Burning a forest fuels pile.

Management Considerations

- Access to the site
- Project site slope
- Treatment prescription—stand density, fuel type/composition

Regulatory Considerations

- Risk of pollutants reaching surface waters?
- Allow burning in stream zones and other sensitive areas?
- Require mitigation of soil and vegetation impacts?

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3.1: Pile Burning

Potential Impacts of Pile Burning

In the Lake Tahoe Basin, forest and fire managers have turned to hand-thinning and pile burning as a primary means of reducing fire hazard vegetation. Stream buffers or stream environment zones (SEZs) as they are identified in the Lake Tahoe Basin are slated for hand-thinning and pile burning treatments. With hundreds of acres of sensitive land needing treatment, regulatory agencies were concerned that burning of piles may cause permanent soil and vegetative disturbance. Impacts of pile burning vary widely but can all be alleviated using relatively simple mitigation measures, which are described later in this section.

Impact	Observed at/by
Erosion of ash and sediment	Integrated Environmental Restoration Services, Inc. (IERS): Old Mill, Alpine
Increased surface runoff velocity	IERS: Ward, Alpine
Nutrient leaching	Busse (numerous)
Very slow vegetation recovery	IERS: Old Mill, Alpine,
Changes in vegetation cover and composition	IERS: Dollar Hill, Old Mill, Granlibakken, Alpine
Loss of fungal and microbial biomass	Busse (numerous)
Hydrophobicity/soil sealing	Doerr et al. (2010)

Dense crust of ash discovered 3 years post-burn.

Turbid water running off surface of unmitigated burn scar during runoff simulation.

3.1: Pile Burning

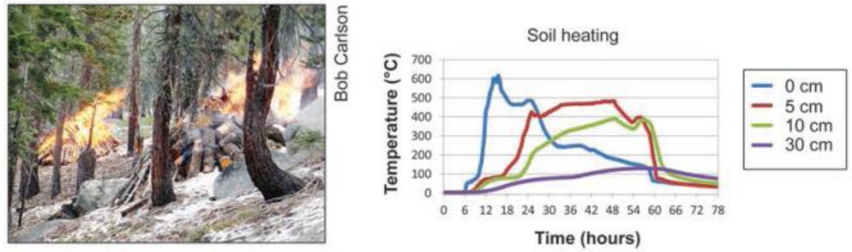
Soil Heating: A Key Factor

Key Findings from Tahoe Basin case study by Busse et al. (2013):

- Fuel composition/size class is primary driver of soil heating. As fuel diameter increased, maximum temperature and duration increased.
- Pile size had little effect on maximum soil temperature or heat duration.
- Soil heating declined rapidly with depth. Greatest impacts were observed in 0-5cm depth.
- Piles with large wood consistently reached soil temperatures known to destroy the seed bank (>200 degrees C for 20 hours or more at 10cm depth).
- Burning resulted in loss of fungal and microbial biomass.
- Soil carbon concentration generally increased immediately following burning (due to ash and charcoal) then decreased to near pre-burn levels after 1-2 years.
- Soil heat penetration is substantially lower in moist soils compared to dry soils.

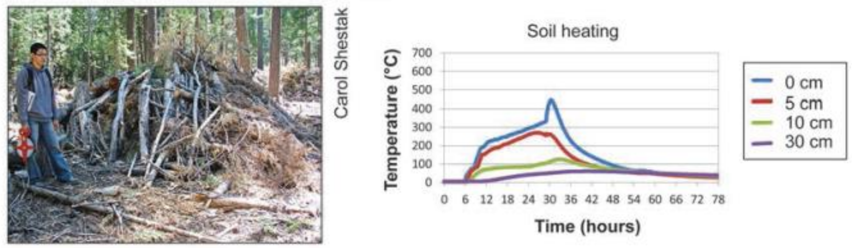
Fuel type 1:

- Dominated by large bolewood, including numerous pieces >40-cm diameter
- Severe soil heating to a depth of 10 to 30 cm



Fuel type 2:

- Mix of all fuel sizes (most common fuel type among inventory plots)
- Moderate soil heating to a depth of 5 cm



Fuel type 3:

- Mostly small-diameter wood and slash
- Low soil heating

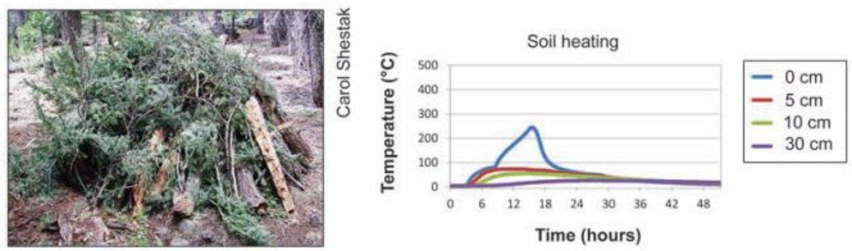


Figure 20: Soil heat pulse during pile burning in the Lake Tahoe Basin varies considerably depending on fuel size class (adapted from Busse et al. 2013).

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3.1: Pile Burning

Potential Impact: Increased Runoff and Erosion

Key Findings from IERS assessment at multiple Tahoe Basin sites:

- Surface runoff velocity roughly doubled following pile burning (without mitigation).
- Unmitigated burn scars generally had higher turbidity and faster surface runoff velocities than piles where duff was replaced post-burn.
- Replacement of duff after burning resulted in lower maximum runoff velocities than unmitigated piles, which were similar to unburned native reference areas.
- The till-only mitigation treatment (without duff replacement) can lead to increased turbidity in surface runoff.
- Hand crews relocating fuels (such as out of a stream zone) can leave compacted foot paths with increased runoff potential.

For more information on mitigation treatments and effectiveness, see Page 64.

Turbid water running off unmitigated burn pile during runoff simulation.

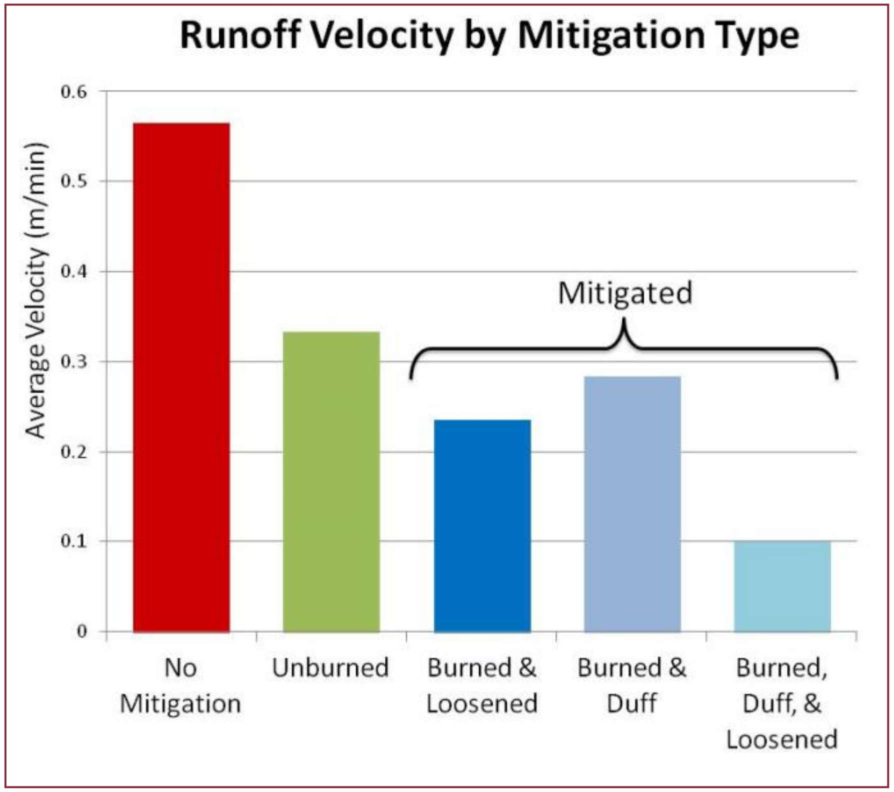

Figure 21: Graph comparing surface runoff velocities for different post-burn conditions (mitigated and unmitigated) at Ward Canyon, Tahoe Basin.

3.1: Pile Burning

Potential Impact: Changes in Vegetation and Surface Cover

Key Findings from IERS monitoring at multiple Tahoe Basin sites:

- Vegetation re-establishment very slow in unmitigated piles; mostly conifer seedlings.
- Charcoal (and in some cases, ash) were still visible on soil surface up to 6 years post-burn on unmitigated piles.
- Highest post-burn vegetation cover and lowest amount of bare soil observed in piles where duff was salvaged and replaced.
- Applying perennial grass seed mix (in addition to duff salvage and replacement) yielded the highest vegetation cover of all mitigation treatments tested.
- Application of native grass seed mix reduced short-term establishment of conifer seedlings after burning.

For more information on mitigation treatments and effectiveness, see Page 69.

White fir seedlings sprouting from an unmitigated burn scar.

A few annuals struggle to get established in a thick layer of ash.

Dense cover of native grasses on burn scar with seed and duff added—1 year after mitigation.

Part Two: Toolkit

3.1: Pile Burning

Burn Scar Mitigation Options

Below are a range of mitigation alternatives that can be implemented to mitigate burn impacts and rebuild soil health and erosion resistance after burning.

Burn Pile Mitigation Video
CLICK HERE

Table 5. Burn Scar Mitigation Options

Mitigation Type	Description	Purpose	Timing	Level of Effort (per burn scar)
Duff removal and replacement	Duff and topsoil is removed before pile construction and raked back over the scar after burn completion	To stabilize burn scars and accelerate soil development and vegetation re-establishment	Before and after burning	Removal: 1-2 min Replacement: 1-2 min
Duff collection and addition	Duff and topsoil is collected from the surrounding area and added to burn pile scar following burning	To stabilize burn scars and accelerate soil development and vegetation re-establishment	After burning	3-10 min
Hand-loosening	Burn scar is loosened to a depth of 4-6 inches (typically after reapplying duff) using a Pulaski following burning	To break up any hydrophobicity and incorporate ash/charcoal into soil	After burning	1-3 min
Seeding	Seed is applied to burn scar after duff replacement (typically native grass seed)	To accelerate native vegetation re-establishment and prevent encroachment by noxious or ruderal species	After burning	< 1 min
Pile locations and density	Piles are located away from potential flow paths and constructed in ways that limit the percentage of ground surface that is covered	To reduce risk of water quality impacts by avoiding potential flow paths and providing larger buffers between burn scars	Before burning	varies

3.1: Pile Burning

Mitigation Choices and Results: Alpine Meadows Stream Zone Case Study


Fall 2011


Fall 2014


Fall 2014

NO MITIGATION: Pile was constructed and burned as normal, within 50ft of a stream. **RESULTS:** Duff layer 100% consumed by burning. Dense ash layer persists three years later. Vegetation re-establishment extremely sparse; mostly annuals. Potential for water quality impacts high, especially due to close proximity to live stream.

MITIGATION: Duff and topsoil raked off before burning (note berm near pile), then raked back over burn area after smoldering ceased + hand tilling and seeding. **TOTAL EFFORT:** <5min per pile with 1 person. **RESULTS:** Immediate stabilization/cover. Robust native grass cover in 1 yr. Potential for water quality impacts very low.


Fall 2011


Fall 2014


Fall 2014

3.1: Pile Burning

Burn Scar Mitigation: Low Effort, High Benefit

In only 2-5 minutes per burn scar, one person armed with a Pulaski or rake can nearly eliminate the potential for a burn pile scar to degrade water quality and greatly accelerate recovery of soil and vegetation.

BEFORE BURNING: rake the top 2-4 inches of duff and topsoil from areas where piles are planned to be burned. Leave this material in a berm near the pile but far enough away that it will not be consumed by fire creep.

AFTER BURNING: once burn scar is completely done smoldering, rake the salvaged duff and topsoil back over the burn pile scar.

OR

AFTER BURNING: rake (or otherwise collect) duff and topsoil from surrounding areas (without leaving patches of bare soil) onto the burn pile scar.

FOR ADDITIONAL BENEFITS:

- **Hand-loosen** the burn scar with a pick mattock or Pulaski to help mix the salvaged duff with the existing soil. This also helps incorporate the ash into the soil, making it less likely to be mobilized by rain or snowmelt.

Note: hand-tilling should only be done in combination with duff replacement, as tilling alone can sometimes create more erosion-prone conditions.

- **Seed** the burn scar after applying salvaged duff in order to accelerate vegetation recovery and reduce potential for noxious or invasive plant establishment.

Note: for best results, combine seeding with duff replacement. Seeding directly on ash has been shown to produce very limited plant cover.

Hand crew removing duff before burn pile construction.

Hand-loosening burn scar with a pick mattock.

TOOLKIT

3.1: Pile Burning

Burn Scar Mitigation Treatments and Effectiveness

Runoff and Erosion Prevention

Surface runoff velocity, measured using a portable runoff simulator, is a relatively new metric for assessing erosion potential. At Ward Canyon and Alpine Meadows, unmitigated burn scars had the highest runoff velocities, on average 38% higher than unburned reference plots.

Different levels of mitigation treatment yielded different reductions in runoff velocities compared to unmitigated burn scars (Ward Canyon):

- 16% reduction with duff removal and replacement only
- 35% reduction with loosening only
- 100% reduction (no runoff) with duff removal and replacement plus loosening

Removing and replacing duff on burn scars has proven to be the most effective and important treatment for reducing sediment transport. At Ward Canyon, removal and replacement of duff with hand-loosening of burn scars led to at least a 95% reduction in turbidity in runoff (measured with runoff simulator), from more than 1000 NTU (burned, unmitigated) to generally less than 50 NTU (duff removed/replaced + hand loosening).

Field trials at several sites suggest that hand-loosening burn scars alone (without adding surface cover) can slow runoff velocity but still tends to produce very high turbidity in runoff consistent with unmitigated burn scars (>1000 NTU).

Vegetation Re-Establishment

Alpine Meadows: Two years after burning, unmitigated burn scars had 25-40% cover, predominantly by natural needle cast, and less than 2% vegetation cover.

At two burn scars where duff was removed and replaced and half the pile was hand seeded with native grasses, the seeded half of the piles exhibited between 10% and 25% vegetation cover two years after burning (mostly by seeded native grasses). The unseeded portions of the piles exhibited 0-5% vegetation cover, with a much higher proportion of herbaceous ruderal species and white fir saplings. Seeding combined with duff replacement treatments produced clear increases in vegetation cover and reduced the re-establishment of conifers, which has the potential to help increase the amount of time before another understory fuels treatment is required.

Related Findings from Korb et al. (2004):

- Adding both seed and salvaged topsoil more than doubled total native plant cover and decreased ruderal and exotic plant cover [consistent with IERS observations].
- Direct seeding on ash resulted in lower native species richness and less than half the native plant cover compared to burn scars treated with both salvaged topsoil and seed [consistent with IERS observations].
- They recommend that slash be piled and burned on existing forest roads whenever possible to minimize ecological impacts, including discouraging the establishment of exotic species.

Dense cover of native grasses on burn scar with seed and duff added—1 year after mitigation.

TOOLKIT

3.1: Pile Burning

Success Criteria

Project goals for burn piles focus on an economic and ecological way to manage forest slash. The goal of pile burns is to eliminate forest slash in an ecological and economic fashion. In doing so, it's important that the function and resilience of the soil is preserved and that erosion potential is minimized. In order to measure the achievement of goals, these goals must be translated into specific criteria. Success is defined by quantitative or at least clearly identifiable criteria. Below are a list of example success criteria that can be indicators for whether or not your burn pile project achieved project goals. These criteria are achievable and practical.

Table 6. Burn Pile Success Criteria Example Matrix

Success Criteria Indicator	Year 1	Year 2	Year 3	Response to Unmet Success Criteria
Visible Erosion	No visible signs of erosion including rotational failures, rilling, gullying, or other sediment transport and deposition	No visible signs of erosion including rotational failures, rilling, gullying, or other sediment transport and deposition	No visible signs of erosion including rotational failures, rilling, gullying, or other sediment transport and deposition	Appropriate combination of mulching, soil loosening and/or amendment additions
Penetrometer Depth (inches)	No more than 4 inches less than pre-burn depth	No more than 4 inches less than pre-burn depth	No more than 4 inches less than pre-burn depth	Soil loosening with amendments
Surface Cover (%)	80% or greater	80% or greater	80% or greater	Mulch or duff addition, seeding
Surface Cover Thickness (in)	Greater than 1 inch	Greater than 1 inch	Greater than 1 inch	Mulch or duff addition
Total Plant Cover (%)	Greater than 5%	Greater than 10%	Greater than 10%	Seeding, and soil amendments if low organic matter
Species Composition	No non-native or invasive species present	No non-native or invasive species present	No non-native or invasive species present	Remove and/or treat non-native or invasive species

3.1: Pile Burning

Recommended Actions

- Avoid building piles in drainageways or other areas that are hydrologically connected to stream channels (see 2.5: Flow Accumulation Analysis). When building piles in known flow areas, plan for post-burn mitigation treatment.
- Salvage duff from burn pile footprints whenever possible.
- Cover burn scars with at least 3 inches of duff after burning.
- Hand loosen and seed burn scars with native grasses (in combination with duff addition) for greatest erosion protection and to expedite vegetation recovery.
- Piles comprised of large-diameter fuels should be considered higher priorities for post-burn mitigation treatment.
- Revisit burn piles at least once the season after burning to assess stability and recovery trajectory.
- Photo document burn scars immediately following burning and in subsequent years to track recovery trajectory and learn from different management strategies.

Fir regeneration one year after pile burning at Dollar Hill – Tahoe City, CA .

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3.2: Broadcast Burning

Definition

Broadcast burning consists of applying fire along a burning front in a forest floor. The fire is intended to remove litter, shrubs and small vegetation.

Purpose

The purpose of broadcast burning is to remove biomass from the forest and reduce potential for catastrophic wildfire. Broadcast burning is often used to mimic a natural, low intensity ground fire in order to re-create a mosaic of various types of vegetation and habitat.

Overview

This Guidebook does not present any first-hand assessment of broadcast burning in the Lake Tahoe Basin for these reasons:

1. Broadcast burning is an infrequently used tool for forest management in the Lake Tahoe Basin.
2. Broadcast burning, when done, follows closely defined protocols that dictate safety as a primary focus and therefore does not allow for much management direction beyond what is already done.
3. Broadcast burning is the most 'natural' of treatment types and thus is not expected to (and studies support) result in a significant impact on water quality.

Context

The specific context of broadcast burning includes field conditions (density and constituents of biomass and weather/climate patterns. A consistent element reported in nearly all research that was investigated is that results are not linear but rather are related to weather patterns and resultant surface and stream flows. Therefore, no consistent results were found in the literature.

Broadcast (or understory) burn in progress.

Potential Impacts

Broadcast burns are generally expected to produce a low intensity and short duration impact to soil and thus are not expected to produce long lasting water quality impacts. Research done in the Lake Tahoe Basin at General Creek supported a number of other findings: broadcast burns generally represent a low probability of water quality impacts, *if* the fire intensity and duration are low. Further, impacts are linked directly to the amount and type of runoff. That is, if a broadcast burn takes place and a very large precipitation event occurs shortly after the burn, there is an increased likelihood of nutrient-laden runoff reaching nearby streams. However, if normal precipitation follows broadcast burning, nutrient levels may actually be lower than pre-burn conditions due to vegetation uptake, since vegetation response post-burn is usually robust, particularly with fast growing grasses and forbs,.

Impacts can occur when broadcast burns ignite larger live or standing dead trees, shrubs and deadfall on the forest floor. In those cases, impacts can occur and will depend upon whether the surrounding area still has an intact duff layer and how close to a live stream or waterway those impacts occur.

3.2: Broadcast Burning

Mitigation Options

If, upon assessment, it is determined that significant soil damage has occurred, similar treatments as used in the burn pile mitigation section (see page 66) can be used. If needles and/or duff are not readily available and if damage occurs near a stream or watercourse, pine or fir needles can be imported and applied and/or the burned area can be loosened with hand tools to increase infiltration.

Success Criteria

- Soil not sterilized
- Burn influence no deeper than 1/2 inch
- Shallow roots still intact

References

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3.3: Mechanical Treatment

Definition

Mechanical treatment is a method for fuel reduction or forest vegetation management whereby vegetation is removed and/or reconfigured using a range of mechanized, motorized equipment.

Purpose

The primary purpose of mechanical treatment is to remove or reconfigure forest biomass in order to reduce the probability of catastrophic wildfire and/or improve forest health.

Overview

Mechanical treatments can help create a fire-resistant forest structure or enhance forest ecosystems by removing excess vegetation. Vegetation or fuel can be removed by hand using a variety of tools such as rakes, shovels, shears and chainsaws. Often, mechanical treatment refers to the use of large equipment like bulldozers and wood chippers. This section explores large equipment commonly used with "whole-tree" or "cut-to-length", "mastication" and "chipping" methods of fuel reduction. However, ecological, management and regulatory considerations are often the same with any mechanized logging method. Specific attention is given to the equipment's design, ground pressure, and operability.

Context

Ecological Considerations

- Displacement– removal of duff , formation of ruts
- Compaction—impacts on infiltration, runoff and erosion
- Slope influence on erosion
- Soil moisture influence on compaction and runoff potential
- Vegetation recovery post-treatment
- Proximity and connectivity of treatment areas to water body

Mechanical Treatment Overview Video
CLICK HERE

Rubber-tired harvester/forwarder in operation.

Management Considerations

- Access to the site
- Project site slope
- Proximity to a waterbody/stream zone
- Track vs. rubber tire equipment

Regulatory Considerations

- Early season soil moisture levels and project start?
- Steep slopes?
- Stream zones?
- Is mitigation necessary? If so, what and where?

TOOLKIT

3.3: Mechanical Treatment

Mechanical Equipment Overview

Table 7. Overview of common mechanical equipment for fuels reduction projects.

Equipment Type	Description	Tracked or Rubber Tired	Ground Pressure (psi)	Operability	Photo
Harvester	A machine that fells, delimbs, tops, and crosscuts (bucks) the tree at the stump area. Configurations include single-grip and double- grip machines. Multi-function harvesters are equipped with a boom-mounted felling device, and sometimes have the ability to transport the material to the landing (Kellogg et al. 1992).	• Tracked, • Rubber-tired • Rubber tired with tracks	4-18psi	• Pivots turns can create erosion potential; wide arc turns are less impactful. Some are self-leveling and/or rotating cabs. • Rubber-tired version are articulating and create less soil displacement	
Forwarder	A machine used for transporting shortwood or cut-to-length logs clear of the ground. The forwarder is equipped with a grapple loader for loading and unloading (Kellogg et al. 1992).	• Rubber-tired • Rubber tired with tracks on larger equipment • Tracked ASV (can forward)	• 4-22psi (unloaded) • Up to 43psi (loaded)	Pivots turns, wide arc turns, articulating, some are self-leveling	

3.3: Mechanical Treatment

Table 7 (continued). Overview of common mechanical equipment for fuels reduction projects.

Equipment Type	Description	Tracked or Rubber Tired	Ground Pressure (psi)	Operability	Photo
Masticator	Small or large machine with mulching attachment; grinds forest understory brush, limbs, and tree tops into woody mulch; intended to reduce fire hazard by transferring standing biomass to ground mulch, prepare for reforestation, and/or improve habitat. Rotory and drum masticators produce different results.	Generally tracked (masticator head mounted on boom of excavator or smaller skid steer)	3psi-16psi	• Pivot turns and wide arc turns, front or boom mounted head • Front mounted masticators (on skid steer) are lower ground pressure but tracks over much more ground	
Chipper	A machine equipped with rotating disk-mounted or drum-mounted knives that mechanically reduce logs or whole trees to small pieces or chips of more-or-less uniform dimension (Kellogg et al. 1992). Small chippers can be loaded by hand but larger chippers often have a grapple for self-loading the material into the chipper.	Tracked or rubber-tired	3psi-25psi	• Pivot turns and wide arc turns. • Pull behind chippers also require a tow vehicle which also adds compaction potential	

3.3: Mechanical Treatment

Wheels vs Tracks

Wheels or tracks are used to propel forestry equipment. Wheeled equipment generally uses 4, 6 or 8 rubber-tires which are generally very large in size. Wheeled machines are often built on articulated chassis for improved mobility. In contrast, tracked equipment has a continuous band of treads driven by two or more drive wheels. The band is typically made of steel but some are designed with rubber reinforced with steel. Tracked machines are slower than wheeled machines, but often have the advantage of being more stable on steep slopes. Tracked machines can operate on slopes up to 55%. Tracked machines are capable of operating on wet and loose soils. Rubber tired machines may be prevented from operating on wet or loose soil and are limited to less than 40% slope.

Each design has strengths and weaknesses. While soil compaction generally tends to be lower with tracked equipment, displacement of soil and vegetation tends to be greater. Pivot turns with tracks can create berms and cause displacement of soil organic matter. Reducing the frequency and spatial extent of pivot turns can reduce the amount of ground disturbance created with tracked equipment. The greater contact pressure of wheeled equipment tends to result in greater changes to soil density and porosity than with tracked equipment (Kamaruzaman, 1991). Both soil moisture content and the number of machine passes affect the magnitude of impacts to soil physical properties. Traffic with all logging machines may be concentrated on a minimum number of skid tracks to decrease the extent and severity of soil disturbance. Restricting operations with machines during wet periods when soil water content is high may decrease the possibility of soil damage by compaction. Knowing equipment strengths and weaknesses can greatly reduce watershed impacts.

Table 8. Comparison of tracked and wheeled equipment.

	Advantages	Disadvantages
Tracked Equipment	• Typically more stable on steep slopes • Can operate on slopes up to 55% • Capable of operating on wet and loose soils • Lower ground pressure per given weight	• Slower than wheeled machines • Pivot turns create berms and can cause displacement and/or removal of duff and vegetation
Wheeled Equipment	Faster moving than tracked machines	• Limited to slopes less than 40% • Higher ground pressure per given weight • Limited operability on wet or loose soils

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Rubber tires (left) and metal tracks (right).

3.3: Mechanical Treatment

"Low Ground-Pressure"

Ground pressure refers to the amount force exerted from the machine to the ground surface. Ground pressure is estimated by dividing the total weight of the machine by the length of track shoes or contact area of the wheels. Ground pressure is measured in the United State in pounds per square inch (psi). Equipment with low ground pressure, has a greater floatation over the soil surface than high ground pressure equipment. The famous Abrams M1 military tank has a ground-pressure of 15psi. Less than 5 psi is the legal definition of low-ground pressure in Canada. In the US, low ground-pressure ranges from 6.3-15 psi. Common forestry equipment ground-pressures ranges from less than 4 psi of light weight tracked machines to over 40 psi of heavy loaded wheeled machines (see Table 9).

Discussion

The term 'Low Ground Pressure' is commonly used without a specific definition in forestry practices. The table below presents a number of ground pressures, all of which are based on a number of assumptions. Assumptions are listed below. One of the primary assumptions that most likely leads to an underestimation of ground pressures is the assumption of surface contact. For this exercise, we assumed a certain flat contact area and did not calculate the higher contact pressures in the middle of the contact area due to the curvature of a rubber tires. The second factor leading to underestimates of ground pressure is that the actual lug area of the 'low ground pressure' tires was not calculated but instead a flat, no-lug surface was assumed. While this is the standard procedure used in estimating ground pressures, if actual ground pressures at the primary or leading contact points (the lugs) were measured, the actual contact areas would be less and therefore would result in an actual ground pressure that may be 2 or 3 times greater.

Soil Disturbance Variables

Of primary consideration, even assuming these conservative ground-pressure estimates, is that ground-pressure for the loaded forwarder greatly exceeds the US and Canadian definition of 'Low.' Many forest thinning projects in the Lake Tahoe Basin rely on the combined use of a harvester and forwarder followed by masticator. Forwarders loaded as well as some wheeled harvesters exceed the 'low ground pressure' definition. Many observers believe that the 5-6.3, is a more useful definition of true low ground pressure. Given that an Abrams M1 Military tank a mentioned above has a GP of 15, it may be more useful to use 5psi as the standard.

The main point of this discussion is to demonstrate the various ground pressures of specific equipment and discuss those ground pressures relative to impacts from forestry activities. We suggest that while some machines meet the 'low ground pressure' definition, the combination of equipment used on forest thinning projects do not meet the 'low ground pressure' definition.

We propose that ground pressure in one of a number of variables that need to be considered when addressing the questions:

- What is the impact of a specific piece of equipment on soil compaction and disturbance?
- Can the impact be minimized?

These questions lead to the critical discussion of what exactly are the variables involved in soil compaction and disturbance from forestry equipment. Obviously, psi or ground pressure is one of those variables. Other critical variables include:

- Type of ground contact (steel tracks with out without lugs)
- Number of machine passes
- Condition of the ground surface (mulch, duff, other cover, depth of cover)
- Soil moisture
- Type of soil (granular decomposed granite, volcanic, meadow soil, etc.)
- Tracked vehicle operation technique (pivot turns vs wide-arc turns)

3.3: Mechanical Treatment

Table 9. Comparison of estimated ground pressures of common fuels treatment equipment.
Sources: Day and Benjamin 1991; Kellogg et al. 1992; Simonson 2002.

Type of Equipment	Brand	Model	Weight (tare)	Weight (loaded)	PSI empty	PSI loaded	Wheeled	Tracked
Harvester	Valmet	901.3	31,945	n/a	17	n/a	6	
Harvester	Valmet	EX10	54,002	n/a	7.6	n/a		2
Forwarder	Tigercat	1085	60,240	115,240	22	43	8	
Masticator	Caterpiller	320c	47,973	n/a	5.5	n/a		2
Track Chipper	Morbark	M20R	14,700	n/a	3.4	n/a		2
Skid Steer	ASV	100	10,150	12,200	3.9	4.7		2

Rubber-tired forwarder.

Front-mounted masticator on tracked skid-steer.

Tracked harvester.

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3.3: Mechanical Treatment

Potential Impact: Soil Compaction

- Soil compaction tends to increase as the number of vehicle passes increases. At three different North Tahoe sites, 6 passes with a rubber-tired harvester/forwarder led to 38-69% reductions in cone penetrometer depth-to-refusal (DTR); 4 passed led to a 79% reduction in DTR (Highlands only—Figure 22); and 2 passes led to a 3-32% reduction in DTR. This data suggests that 4-6 passes was the threshold for lasting compaction at these sites (Highlands, Skylandia).
- A soil's resistance to compaction can be very site-specific. At another site (Granlibakken), as few as 1-3 passes by a harvester/forwarder led to a 67% reduction in penetrometer DTR, which was the same change in compaction as that measured at an adjacent plot with 5-10 equipment passes (65% reduction). Another plot at the same site with 50-100 passes exhibited the greatest compaction—an 83% reduction in penetrometer DTR (as shown in Figure 23).
- Soil compaction from equipment operations can persist for long periods of time. Penetrometer DTR at a landing near Truckee averaged only 1.8 inches 15 years after the fuels reduction project was complete (Waddle Ranch).
- As the number of equipment passes increases, the width of the travelway (impacted area) tends to increase. Increasing the number of passes from 2 to 6 increased travelway width by 75% (Highlands) and 142% (Granlibakken).
- With other site and soil factors being equal, equipment tends to produce less compaction where a robust mulch/duff layer is present and more compaction where soil is bare (Hatchett et al. 2006).
- Operating equipment over a slash mat can minimize soil compaction when heavy slash layers are used (~40.0 kg/m^2), but thinner slash mats tend to get crushed and provide minimal soil protection, especially with increasing machine passes (Han 2006).

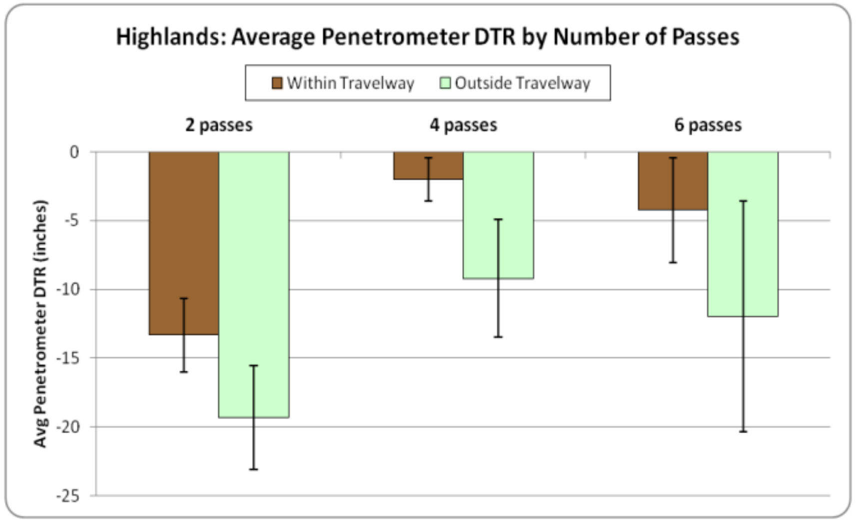


Figure 22. Comparison of soil compaction and number of equipment passes at Highlands site, North Lake Tahoe. *Error bars represent one standard deviation from the mean.*

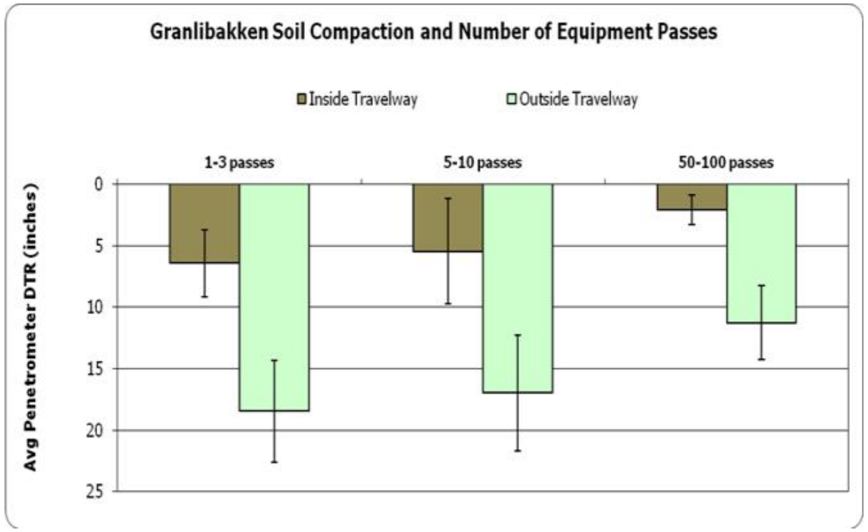
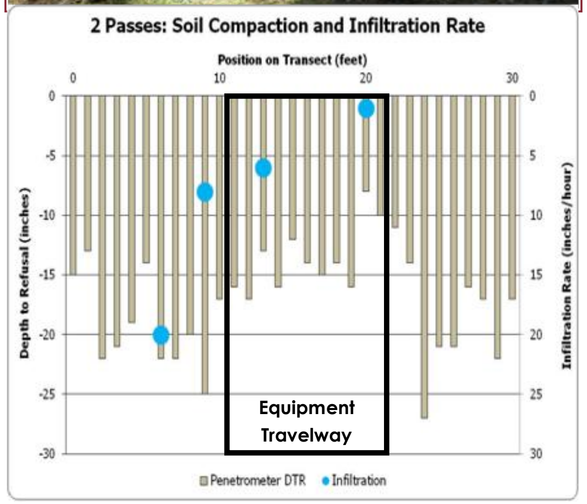


Figure 23. Comparison of soil compaction and number of equipment passes at Granlibakken site, North Lake Tahoe. *Error bars represent one standard deviation from the mean.*

3.3: Mechanical Treatment

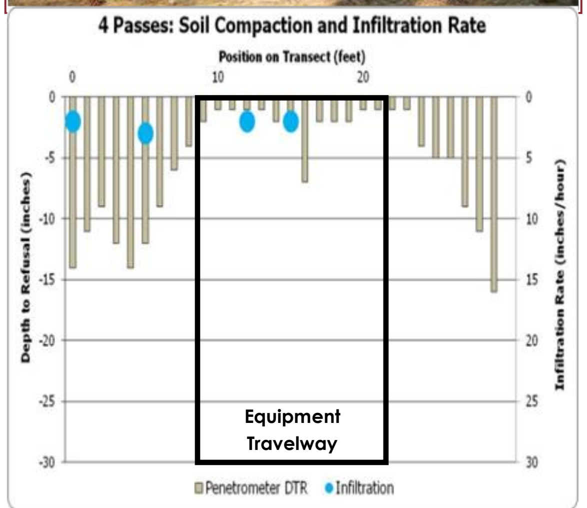
Cut-To-Length Compaction and Infiltration Case Study: Highlands Project, North Lake Tahoe

The purpose of this study site was to assess the effects of different numbers of equipment passes (cut-to-length equipment) on soil compaction and infiltration. For soil compaction, 2 passes reduced penetrometer depth by 32% whereas 4 and 6 passes reduction penetrometer depth by 79% and 69%, respectively. Infiltration rate was reduced by 71% for 2 passes, 20% for 4 passes, and 89% for 6 passes. This assessment suggests that as few as 2 passes can decrease infiltration rates and 4-6 passes can leave behind persistent soil compaction. This type of simple assessment should be conducted on more forest management projects to increase our understanding of mechanical impacts and our ability to both prevent and mitigate such impacts.



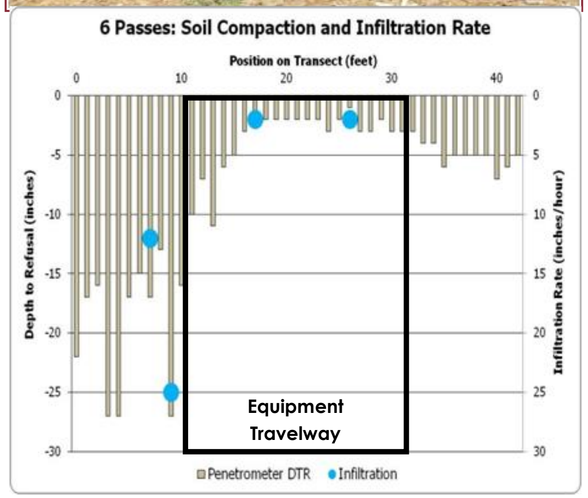
Average Travelway Penetrometer Depth: **12.9 inches**

Average Travelway Infiltration Rate: **3.5 inches/hour**



Average Travelway Penetrometer Depth: **1.9 inches**

Average Travelway Infiltration Rate: **2 inches/hour**



Average Travelway Penetrometer Depth: **3.7 inches**

Average Travelway Infiltration Rate: **2 inches/hour**

3.3: Mechanical Treatment

Potential Impact: Soil and Duff Displacement

Overview

Impacts of mechanized equipment varies widely. Specific impacts can be additive or even multiplicative, such as soil displacement and compaction, which allows displaced soil to more easily reach water courses. Most if not all impacts can be minimized or eliminated if planning and oversight is done fully and adequately and mitigation measures are applied where needed. While there is seldom a direct cost ascribed to these impacts, time spent during the planning phase can address most impacts when carried out during implementation.

Pivot Turns—Tracked Equipment

Tracked equipment requires some displacement of soil and soil surface material. When soil is disrupted, a number of potential impacts can take place. Protective surface mulch and duff is removed, exposing soil to erosive forces. Soil itself can be mounded and made available for increased erosion. Combined with potential depressions in the surrounding ground surface caused by tracked vehicle travel, this sediment and nutrient-rich organic material (mulch and duff) can more easily find its way into nearby watercourses.

Displaced and dislodged soil and soil organic matter is also more likely to produce excess available nitrogen in the form of nitrate and ammonium, since those nutrients are known to be liberated when soil is disturbed and thus can find their way to streams through overland flow even when sediment is not moved. Phosphorus is also transported with soil particles.

Surface Mulch

As previously stated, surface mulch is perhaps the most important protective element of the forest floor. Harrison (2012) reported that erosion rates were cut in half by adding (or preserving) as little as 25-50% mulch cover compared to bare soil conditions in forest thinning projects in Lake Tahoe. When mulch and duff are displaced, erosive forces are free to work on bare soil. However, duff and mulch can also be a mitigation component so that when those elements are displaced during operations, they can often be replaced through simple hand work following operations or can be replaced during mastication through the leveling and mulching process.

Vegetation Removal/Displacement

Vegetation removal can be considered a potential impact of mechanical treatment. However, since vegetation removal is one of the main objectives of treatment, it is often not detrimental and helps meet project goals. Further, most forest understory species are disturbance tolerant if not disturbance obligate. Thus, disturbance of most understory shrubs generally results in a positive response (re-growth) within 1 to 3 seasons.

Drainage Alteration

Drainage alteration and associated disturbance may be, aside from roads, one of the most potentially destructive impacts of mechanical soil treatment but one that can generally be avoided or mitigated. Further, old drainage disruptions from previous projects and activities can be improved when planned for and mitigated as part of the vegetation management process. Drainages can

Deep wheel ruts created through a meadow from unauthorized equipment access during the wet season.

3.3: Mechanical Treatment

be altered by simply tracking through them with equipment or by disrupting them by any number of mechanical equipment travel patterns. Often, disruption may not even be apparent and only becomes an issue when drainages start to carry water, in some cases years after the project has been completed. Thus using 2.5 Flow Accumulation Analysis and assessing the treatment site pre-treatment can minimize drainage alteration or at least allow that alteration to be mitigated if the drainage is identified and mitigation included in the plan.

Roads and Travelways

Roads and travelways (equipment travel paths) usually represent the highest potential for soil impact. Existing roads are obviously pre-existing. Old dirt roads tend to produce less sediment than newly built or recently graded roads and thus when a road is re-opened to equipment traffic, even where it previously existed, sediment yield has been shown to increase, sometimes by orders of magnitude (Drake and Hogan 2013). However, there are a number of tools that can be used to minimize road runoff. Further, if proactive planning is used, soil impacts can minimized through carefully planning travel routes (see 3.4 Road and Travelway Management). Further, in cases where roads already exist, it is sometimes possible to remove or fully mitigate runoff from those roads if a cost effective manner. This can be a critical consideration if overall sediment loading must be reduced in the Lake Tahoe basin and anywhere else that sediment is a pollutant of concern. We present tools in 3.4 Road and Travelway Management that describe how to accomplish those goals in a cost effective manner.

3.3: Mechanical Treatment

Success Criteria

Project goals for mechanical thinning are to remove forest biomass with a minimum of soil disturbance and compaction. Where excessive compaction occurs, such as on main and secondary travel routes, decompaction should take place if the ground surface angle exceeds 5 degrees and/or is connected to a road or drainage. The list of success criteria below is not exhaustive but can be used as a basis for determining whether impacts are significant and whether those impacts carry with them a high probability of accelerated runoff. The primary water quality goal of mechanical thinning should be to leave the soil in the treated area in a condition that is equal to or better than the initial pre-project soil condition or in a condition that the soil can recover within 3 seasons.

Table 10. Mechanical Thinning Example Success Criteria Matrix

Success Criteria Indicator	Year 1	Year 2	Year 3	Response to Unmet Success Criteria
Visible Erosion	None	None	None	Determine cause or source of erosion and apply appropriate treatments (*soil loosening, mulching, rerouting water, disconnect water flow, etc.*)
Disturbed/displaced soil	<5% of site	n/a	n/a	Rake and smooth displaced soil, mulch; reduce pivot turns
Compaction: Penetrometer Depth (inches/psi)	12"/250psi (or no reduction greater than 50%)	12"/200psi	12"/200psi	De-compact
Surface Cover (%)	90% (or no reduction greater than 10% bare areas)	90%	90%	Add surface mulch; redirect mulch from chipping/ mastication
Surface Cover Thickness (in)	>1"	>1"	>1"	Add duff, chips or needles
Total amount of project area compacted	<5%			De-compact to 12"

3.3: Mechanical Treatment

Mechanical Treatment Mitigation Tools

Table 11. Mitigation Alternatives for Mechanical Equipment Impacts

Mitigation Type	Description	Purpose	Tested?	Additional Cost
De-compaction	Remove compaction using mechanized treatment such as an excavator bucket or ripper tines.	Re-develop infiltration, reduce runoff, increase soil oxygen exchange and plant rooting depth.	Yes	Varies, can be done cost-effectively using onsite equipment during de-mob or project exit.
Add mulch or duff	Rake or otherwise distribute mulch, duff and/or wood chips to areas of bare soil.	Slow surface runoff; protect soil surface from raindrop impact and surface sealing; reduce evaporative water loss; reduce dust.	Yes	Low, when on site materials can be used.
Directing masticated debris or chips over machine tracks	A form of re-mulching. Masticator can sometimes be directed to 'throw' mulch onto bare areas. Chips can easily be directed over tracks when using chippers.	Slow surface runoff; protect soil surface from raindrop impact and surface sealing; reduce evaporative water loss; provide surface cushion from human and other impacts; reduce dust.	Yes	Low
Travel over slash mat	Placement of limbs and other woody material in front of machine in travelway. Complete surface cover should be achieved.	To cushion and protect soil surface from compaction and soil disturbance.	Yes	Low
Minimize number of equipment passes (or concentrate in defined areas)	Plan equipment access and travelways so that large numbers of passes are limited to certain areas that will be decompacted post-project.	Minimize soil impacts in most areas and limit high-impact areas to minimize post-project mitigation requirements.	Yes	Minimal cost if planned in advance; can reduce amount of mitigation necessary.
Minimize pivot turns	When turning tracked machines, turns should be made in arcs, which both tracks moving forward. Strategic travel paths into and movement through treatment areas can minimize or eliminate pivot turns.	To minimize or eliminate soil displacement, which increases exposure to erosive forces.	Yes	None

3.3: Mechanical Treatment

Mitigation Treatments and Effectiveness

The purpose of mitigation is to address impacts of mechanical treatment sites to original or pre-project conditions. Those conditions include soil density/compaction, surface cover (mulch, duff, slash) and surface soil condition (displacement). Adequate mitigation allows soil disturbing activities to take place while leaving the site in a condition that does not create water quality impacts or decrease ecosystem function.

Tahoma Trials: Mitigation and monitoring trials were conducted in Tahoma on bare/compacted equipment travelways.

- The addition of 2-3 inches of wood chips on the soil surface reduced runoff velocity by 60% and runoff distance by 54% compared to bare/unmitigated conditions.
- Incorporation of wood chips into the soil by hand tilling led to the same reduction in runoff velocity as mulching (60%) but a more substantial reduction in runoff distance of 85% due to much high infiltration rates.
- Incorporation of wood chips into the soil also led to a large (779%) increase in penetrometer depth and 230% increase in wetting depth.
- Wood chip mulch has been observed to be displaced by concentrated runoff when not incorporated into the soil, particularly in dirt roads.
- Results suggest that mulching alone can provide hydrologic and sediment reduction benefits in lower-angle conditions and that incorporating wood chips into soil via physical loosening provides the greatest and longest lasting improvements.

Operating Equipment Over Slash Mats (from Han 2006)

- The buffering effect of slash is highly dependent on quantity of slash and diminishes quickly with increasing machine passes.
- Heavy slash (40.0 kg/m^2) was found to result in less than half as much soil compaction as light slash (7.5 kg/m^2),
- Slash is rarely evenly distributed on the trail and portions of trails with lower amounts of slash can get very compacted.
- Higher soil moisture levels tended to correspond to greater compaction with the same number of machine passes.

For additional information on mitigation treatments for soil compaction and displacement, see 3.4 Road and Travel Management.

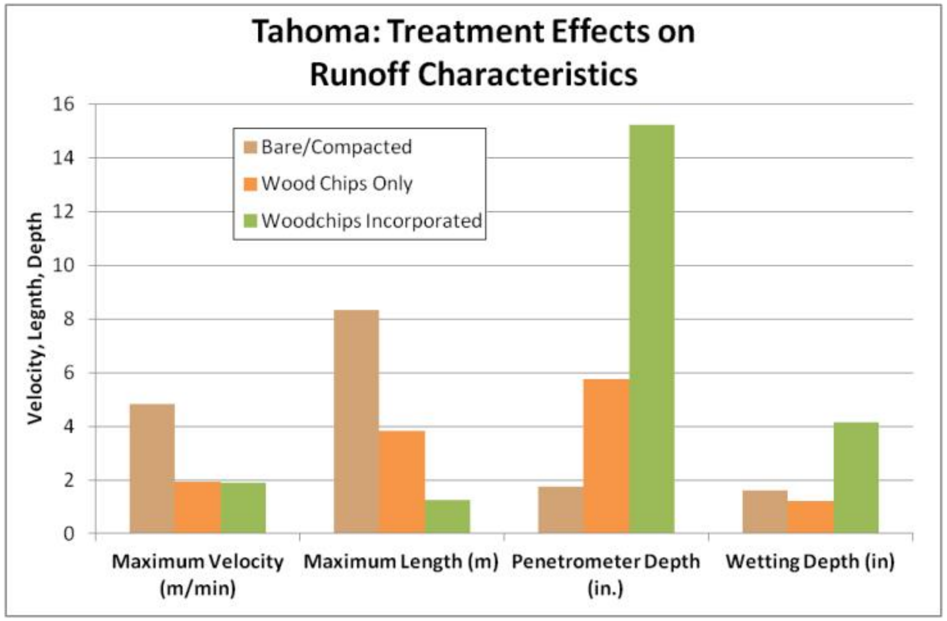


Figure 24. Mitigation treatment effects on runoff characteristics from Tahoe West Shore runoff simulation trials.

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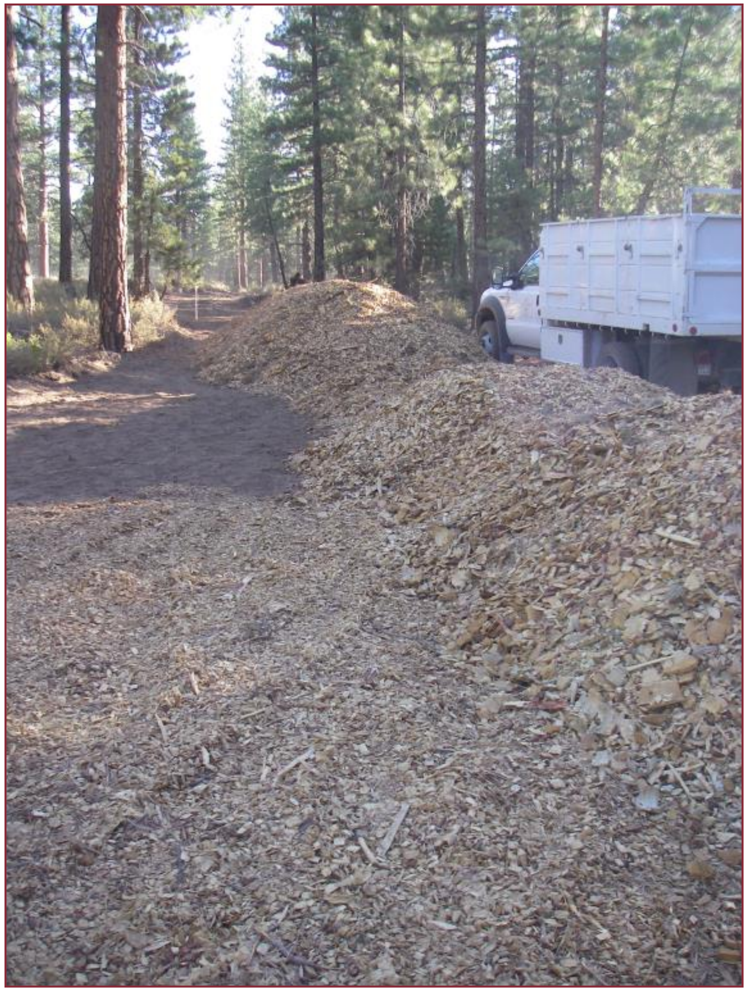
3.3: Mechanical Treatment

Recommended Actions

- Assess and document soil conditions prior to implementation (compaction, soil cover, duff depth, soil moisture).
- Assess and document soil conditions during and after project implementation to determine if and where mitigation treatments are needed. *See Achieving (Step 4) for information on field assessment methods.*
- Use stratified entry approach: use main travel way to enter and exit project area; use spur access off main travel way and specify a maximum number of trips per spur where mitigation is not intended to be required post-project (4 trips is a good starting point). *See 3.4 Road and Travel Management for more information.*
- De-compact main travel way when demobilizing (use separate bucket or ripper attached to masticator head).
- Spread wood chips and/or masticator shreds over bare soil areas.
- Incorporate wood chips into soil in compacted areas for greatest hydrologic benefits and erosion resistance.
- Minimize or eliminate pivot turns (operators can make arced turns).
- Aim to conduct mechanized thinning treatment once soil moisture is less than 10%. If operating equipment during higher soil moisture conditions is necessary, concentrate trips to main travelway(s) and implement appropriate post-treatment mitigation measures (such as soil decompaction and mulching).
- Identify legacy sites (e.g. old landings, skid trails) that can be decommissioned as part of forest fuels reduction projects.



Wood chips staged on haul road for post-harvest mitigation treatments.

3.3: Mechanical Treatment

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3.4: Road and Travel Management

Definition

Road and travel management refers to strategies, tactics and tools used to minimize or eliminate water quality impacts from mechanized equipment used to manage forest vegetation. This can range from simply eliminating equipment travel in a particular sensitive area to road surfacing. Some road and travel management tools are pro-active and employ travel strategies that minimize and/or concentrate equipment travelways. Other tools are reactive and employ treatments such as soil decompaction, road surfacing, or road decommissioning following use.

Purpose

The purpose of road and travel management tools are to minimize or eliminate impacts from roads and mechanical treatment travelways, such as increased soil compaction and surface runoff.

Overview

Road and travel management includes an expansive set of tools and approaches to addressing known or potential impacts from mechanized equipment. Strategies include planning where equipment will travel in order to minimize equipment footprints (fewer trips in the same place, less need to mitigate) to concentrating travel so that soil compaction from repeated trips can be more easily removed if necessary. Active road treatments include surfacing with gravel, wood chips, recycled asphalt grindings or other suitable and non-erodible material.

Since roads are the primary sources of erosion and sediment loading to streams in forested watersheds (Croke and Hairsine 2005), carful attention to roads before, during and following forest management is likely to provide the greatest return on investment in planning and/or mitigation dollars.

Context

Ecological

- Potential for disruption and/or concentration of water flow paths by roads and other equipment travelways.

Abandoned haul road near stream with no mitigation.

- Spatial distribution of soil and vegetation impacts.
- Connectivity between erosion source areas and streams.

Management

- Equipment types and operating requirements/capabilities.
- Presence of existing roads and landings.
- Locations of staging and landing areas.
- Upfront effort/cost vs. ongoing maintenance effort/cost.

Regulatory

- Sensitive area restrictions and/or success criteria for mitigation (stream zones, steep slopes, etc).
- Creation of new roads or re-opening/expansion of existing roads.
- Soil moisture and early-season equipment access restrictions/criteria.
- How to incentivize restoration of legacy sites during forestry projects?

TOOLKIT

3.4: Road and Travel Management

Access Planning

Mechanical treatment impacts can be minimized and/or concentrated and then mitigated through proper access planning. As we have shown, four or more passes by cut-to-length equipment can add significant and lasting compaction to soil. Pre-project planning and an outcome-oriented management strategy during project implementation can assist managers to minimize or reverse those impacts.

"Concentrate then Mitigate"

Primary travelways (trunk lines) can be identified and large numbers of equipment passes are then limited to these areas, which can then be efficiently mitigated during demobilization (e.g. decompaction, mulching). In this strategy, the number of equipment passes on secondary travelways off the main trunk line are limited to a maximum number of passes (Tahoe-area research suggests that 4 passes is a good starting point), in order to minimize soil impacts and avoid the need for post-project mitigation.

Drainage and Water Flow Planning

Water flow paths should be taken into account when planning locations and alignments of roads, travelways and landings. Stream setbacks are a common requirement in most forestry projects, but conducting a pre-project Flow Accumulation Analysis (see 2.5 Flow Accumulation Analysis) can help to reveal less obvious drainageways that could be impacted or interrupted during forestry operations if not properly addressed during both planning and implementation. Impressions or ruts along equipment travelways can capture and concentrate surface flow from subtle drainages and quickly become threats to water quality if not avoided or properly mitigated. Avoiding flow paths tends is the preferred option, but where they cannot be avoided, careful attention should be paid to temporary and permanent protection/mitigation measures and their effectiveness. Mitigations may include during-project tools such as applying a thick mulch layer, slash mats, log bridges and others. Ultimately, the process of achieving water quality protection requires checking to make sure that drainageways are not impacted, or where they are, appropriate and effective mitigation measures are employed.

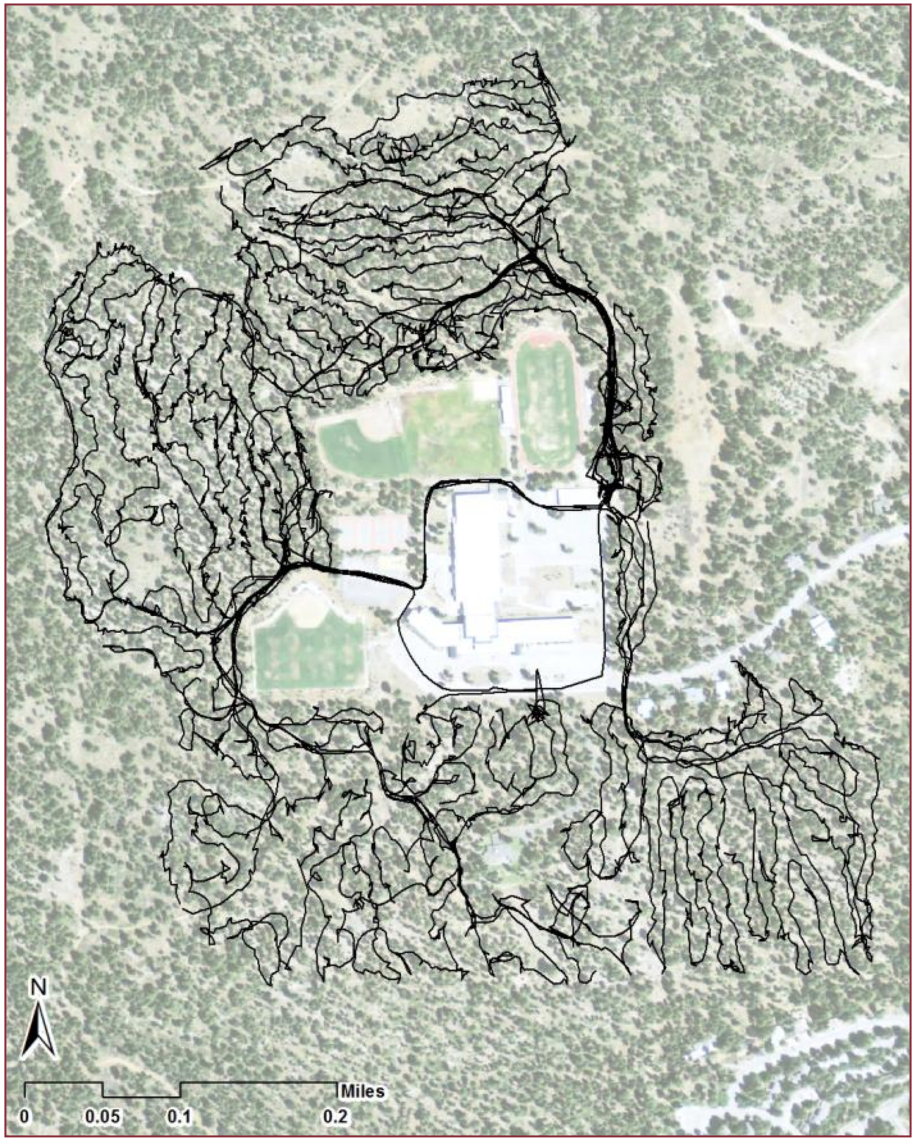

Figure 25. Cut-to-length equipment travelways mapped using a GPS unit. Large numbers of passes were concentrated along a few main trunk lines.

3.4: Road and Travel Management

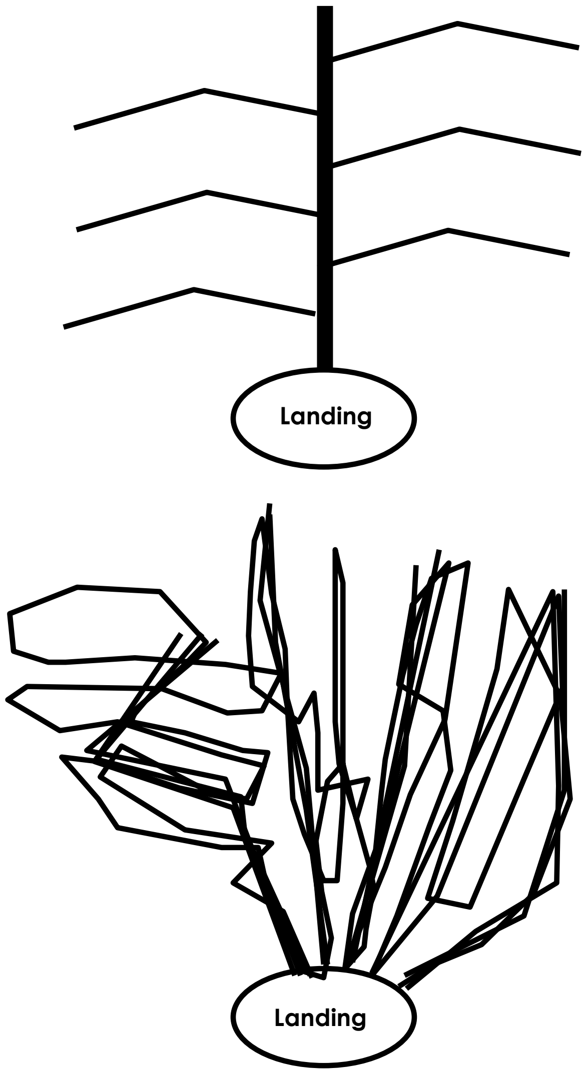

Figure 26. Simplified examples of different equipment access scenarios. Top diagram represents the recommended "concentrate and mitigate" approach. Bottom diagram shows example equipment travelways in a more disbursed and unplanned scenario.

Equipment Choices

One consideration in access planning is the operational requirements and capabilities of different types of equipment as they relate to ground disturbance. For example, equipment such as front-mounted masticators or tow-behind chippers have little to no reach and will therefore need to travel over more ground area in most projects. In contrast, boom-mounted masticators or cable yarding systems can allow ground disturbances to be concentrated is smaller areas.

Another option is to use modified attachments for standard forestry equipment to support cost-effective mitigation. For instance, ripping tines can be added to a boom-mounted masticator attachment, allowing operators to quickly decompact travelways or roads without requiring a separate equipment mobilization. For more information on multi-functional sub-soiling implements for forestry projects, see Archuleta and Baxter (2008).

3.4: Road and Travel Management

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 for active roads are summarized and compared below.

Table 12. 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 man-age, 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	

3.4: Road and Travel Management

Table 12, 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 on-site (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	

TOOLKIT

3.4: Road and Travel Management

Observed or Measured Results: Treatments for Active Roads

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 (Layh et al. 2012; see Figure 27).

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 and Hogan 2013). See case study on page 96 for additional details.

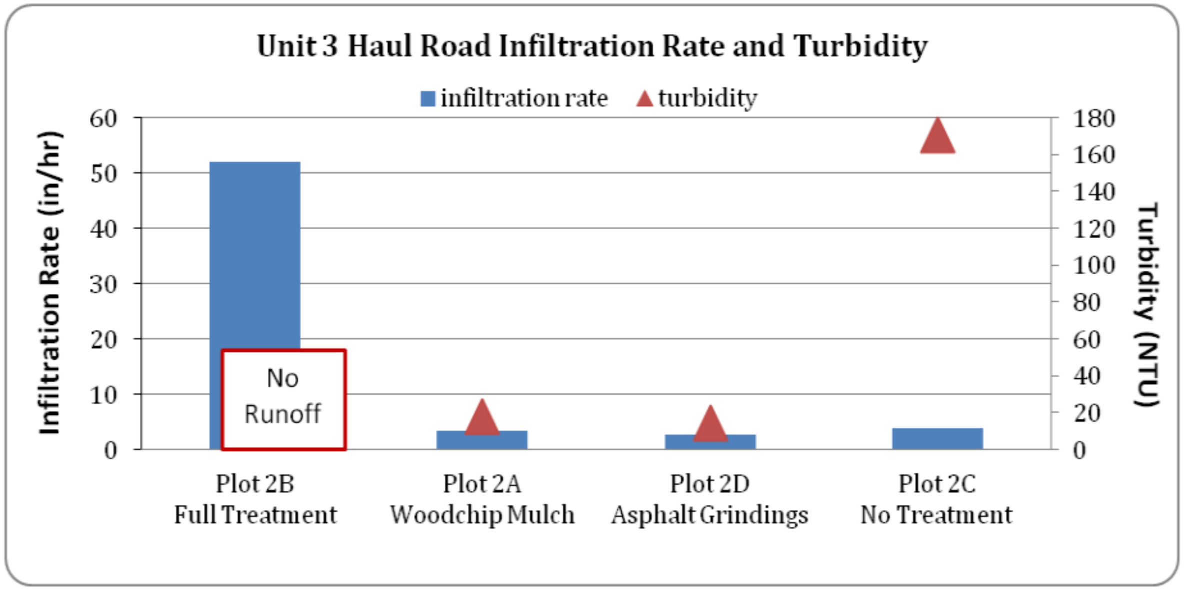

Figure 27. Infiltration rate and turbidity for different road treatment techniques measured using a runoff simulator two years after treatment at Waddle Ranch (Truckee, CA).

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 (Layh et al. 2012; see Figure 27).
- 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 and Hogan 2013).
- 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.

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. 2009).

TOOLKIT

3.4: Road and Travel Management

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. 2009; Grismer and Hogan 2005).

Truckee Haul Road – large gully present before smooth grading.

Truckee Haul Road – one season after smooth grading, rilling was observed in the exact same location as the gully.

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. 2009).

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 and Hogan 2013). Where road grading is necessary, application of gravel road base can substantially reduce sediment yield in runoff (see case study on next page).

Sediment Risk on Active vs Inactive Roads

Rainfall and runoff simulation studies on a variety of forest 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. (Drake and Hogan 2013).

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 forestry efforts

TOOLKIT

3.4: Road and Travel Management

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 28). However, after applying 1 inch of gravel to the road surface, 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.

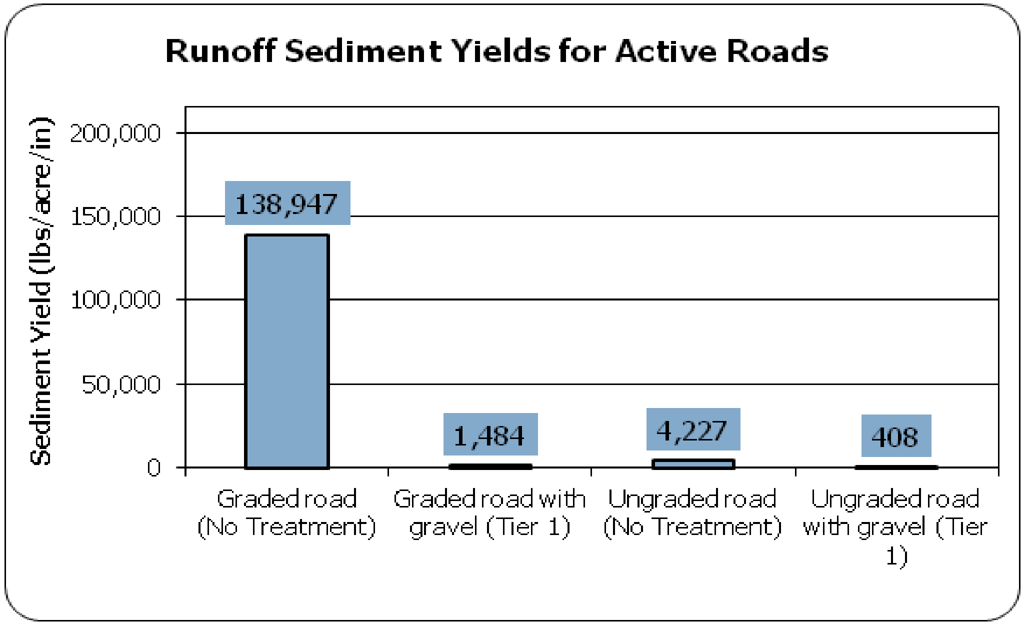

Figure 28. Runoff sediment yields for active forest roads.

Runoff simulation conducted on graded and ungraded roads. *Left fork graded, right fork not graded.*

Graded road (no treatment) during runoff simulation. Deep rill formation is visible.

Ungraded road with 1 inch of gravel. Water is dispersed and not able to erode the road surface.

3.4: Road and Travel Management

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.

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

TOOLKIT

3.4: Road and Travel Management

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 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 2.4 Water Flow/Connectivity Assessment and 2.5 Flow Accumulation Analysis). 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 management and maintenance of dirt and gravel roads. The following is a short list of some of these publications:

- Rural Roads: A Construction and Maintenance Guide for California Land-owners. 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

TOOLKIT

3.4: Road and Travel Management

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.

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 upland 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. 2013). 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 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 example:

- **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 and Hogan 2013).
- **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 and Hogan 2013).
- **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 and Hogan 2013).

TOOLKIT

3.4: Road and Travel Management

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 Road before (left) and after decommissioning (right).


Smooth Cruise Road before (left) and after decommissioning (right).

TOOLKIT

3.4: Road and Travel Management

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. IERS staff used cone penetrometer (see 4.4 Cone Penetrometer) to conduct 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.

Abandoned forest road with well-established shrubs and a very compacted soil.

Importance of Rebuilding Soil Function

Lloyd et al. (2013) conducted research assessing the functional differences between forest roads that had been abandoned or had a low-intensity surface treatment (e.g. scattering slash) and others that had been fully recontoured. They reported that recontoured and abandoned sites displayed similar above-ground properties but exhibited notable differences in below-ground (soil) properties, including infiltration, organic matter, total carbon, and total nitrogen, among others. They found that recontouring can dramatically accelerate recovery of key soil and hydrologic properties by hundreds to thousands of years, as compared with never-roaded reference areas. They ultimately concluded that low-intensity treatments that fail to restore both above- and below-ground properties (particularly soil hydrologic function) may lead to an altered ecosystem with different functional processes and lower resilience.

3.4: Road and Travel Management

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.

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.

Lower Lombard Road before treatment with compacted, bare soil.

Lower Lombard Road one year after recontouring and soil-based restoration treatment.

TOOLKIT

3.4: Road and Travel Management

Landings

Landings are a necessary element of many fuels reduction and timber harvesting projects. The size and physical condition of landings can vary widely, from upwards of 20,000 square feet with bare cut and fill slopes, to less than 5,000 square feet and covered in wood chips. Regardless of their size, compaction is seldom removed from landings in the Tahoe-Truckee area and therefore, they remain a source of runoff in the watershed. For operational reasons, landings tend to be connected with roads and skid trails, which can act as conveyances for runoff to or from landings, compounding the hydrologic sediment delivery impacts of all these features. The good news is that landings can be quickly transformed from runoff sources into reservoirs using soil-based mitigation techniques lined out in this section. Below are a few key findings from assessment and restoration research trials conducted on abandoned landings near Truckee, CA approximately 15 years post-thinning (Layh et al. 2012):

- Infiltration rate increased more than 700% from 0.4 in/hr before treatment to 2.9 in/hr one year after soil loosening, wood chip incorporation, seed and mulch (hereafter referred to as "full treatment").
- Penetrometer depth increased from 1 inch to an average of 13 inches one year after full treatment.
- Plant cover increased from 1-5% before treatment to 20-30% one year after full treatment.
- Plots that were loosened with wood chips incorporated (no seeding) produced the same hydrologic characteristics as those plots that were seeded (high infiltration and penetrometer depths) but no measurable increase in plant cover.

These findings demonstrate that, much like with road decommissioning, soil-based restoration treatments can restore resilience and erosion resistance to drastically disturbed landing sites in one year or less, using equipment and materials that are already onsite for most forest management projects.

Landing Density: Threat or Opportunity?

A high density of landings were observed and mapped in the East Martis Creek watershed near Truckee, CA in 2012. In one afternoon of assessment, 27 landings were visually identified along 8.6 miles of road. That equates to 3.1 landings per road mile assessed. Assessment in a nearby watershed yielded a very similar landing density of 2.8 landings per road mile. Many of these landings appeared to have been created and/or actively used over the past 10-20 years. The landings observed were generally flat, many with bare cut slopes on the uphill side, moderate to high levels of soil compaction and supporting limited vegetation (mostly trees, minimal herbaceous plants). With limited infiltration and waters storage capacity and high runoff connectivity to the road network, the cumulative impact of landings on the timing and volume of watershed-wide runoff is worth considering. For example, using only the 27 landings identified in one afternoon of assessment, at an average size of 10,000 square feet, they account for a total area of 270,000 square feet (6.2 acres). Assuming the compacted soil in these landings can currently store approximately 8% water by volume and that water storage in an undisturbed forest soil is approximately 40% (which can be achieved at disturbed sites though low-cost soil restoration treatments), water storage capacity in the top 24 inches of soil of these landings could be increased by nearly 400%, from 43,200 cubic feet to 216,000 cubic feet (roughly 5 acre-feet). ***Treatment of landings to reduce runoff and increase water storage and groundwater recharge is a key restoration opportunity in this and most other Sierra Nevada watersheds.***

Examples of abandoned landings assessed near Truckee, CA in 2012.

3.4: Road and Travel Management

Recommended Actions

- Create a base map showing flow paths (not just streams) and legacy erosion source areas such as old roads and landings. Use this to create an access plan including protection/avoidance areas, temporary BMPs, and post-project mitigation areas. See 2.5 Flow Accumulation Analysis tool.
- Use stratified entry approach: use main travel way to enter and exit project area; use spur access off main travel way and specify a maximum number of trips per spur where mitigation is not intended to be required post-project (4 trips is a good starting point).
- Require contractors to submit GPS tracking data to document equipment travelways. Use this information to determine if and where mitigation may be required, and if other contract conditions were met (e.g. stream buffer restrictions).
- Spread wood chips and/or masticator shreds over bare soil areas.
- De-compact main travel way when demobilizing (use separate bucket or ripper attached to masticator head).
- Incorporate wood chips into soil in compacted areas for greatest hydrologic benefits and erosion resistance.
- Minimize or eliminate pivot turns and associated displacement of duff and topsoil (operators can make arced turns).
- Assess and document soil conditions during and after project implementation to determine if and where mitigation treatments are needed. See Step 4: Achieving for information on field assessment methods.
- Aim to conduct mechanized thinning treatment once soil moisture is less than 10%. If operating equipment during higher soil moisture conditions is necessary, concentrate trips to main travelway(s) and implement appropriate post-treatment mitigation measures.

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

--George Bernard Shaw

STEP 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.

4.1: Developing a Monitoring Plan

Definition

A 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 (1998): "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 belief 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.

Intention of Monitoring

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.

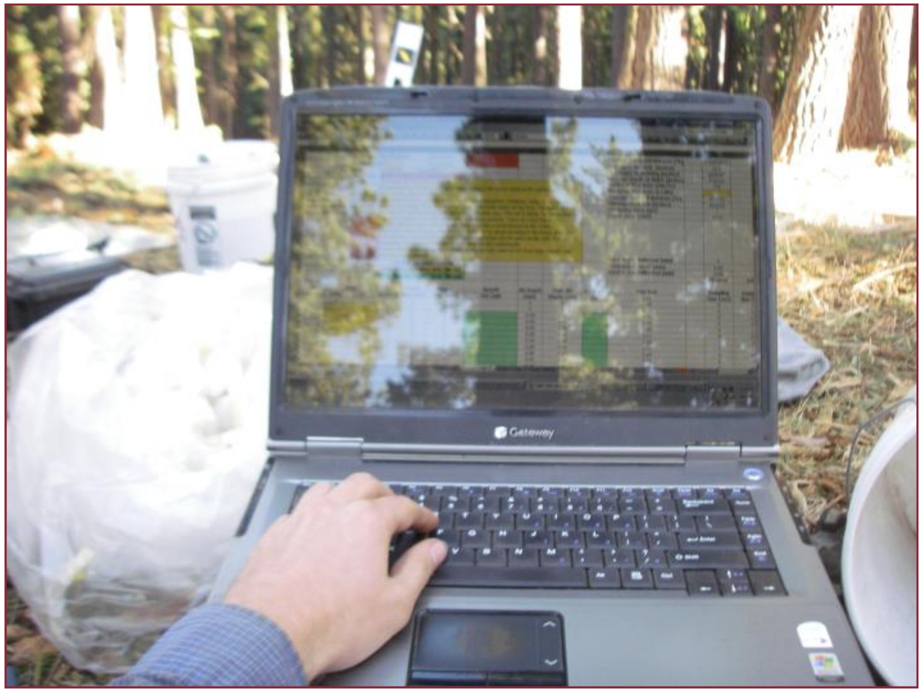
4.1: Developing a Monitoring Plan

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 often 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.

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



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.

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

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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.

4.1: Developing a Monitoring Plan

Outcome-Based Management in Action: Celio Ranch Defense Zone Project Example

By Martin Goldberg, Fire and Fuels Manager, Lake Valley Fire Protection District

Located in the Upper Truckee River watershed of the Lake Tahoe Basin, the primary purpose for the project was to protect lives and property. The tree species composition within the project area was predominantly lodgepole pine, followed by white fir. A portion of the project area was classified as a stream environment zone (SEZ). Quaking Aspen were suppressed by lodgepole within the SEZ. Thickets of lodgepole pine in SEZs are of particular concern to forest practitioners in the Lake Tahoe Basin because they can ignite easily and burn rapidly.

Regulations prohibited forestry activities in SEZs that may cause "permanent soil or vegetative disturbance" and such activities were to be completed solely by means of helicopter, balloon, over snow, or other minimal impact techniques. A common method for regulatory staff to assess "permanent soil or vegetation disturbance" was by evaluating whether the site would return to background conditions within one year and by utilizing their best professional judgment. This may or may not have exactly fit the definition of "no permanent soil or vegetation disturbance".

As manager of fire and fuels for the Lake Valley Fire Protection District, I had a project that needed to be permitted. To do so, I proposed using innovative techniques based on scientific evidence, monitoring the outcome with proven and easy assessment methods, and mitigating any impacts beyond our success criteria.

Through research, I determined that soil and vegetative disturbance could be avoided, reduced or mitigated. To reduce compactive forces on the soil, equipment operations in the SEZ took place in the fall when soil strength was at its highest (low moisture level). Crews cut and limbed trees using gas-powered hand equipment (i.e. chainsaws). All boles greater than 10 inches were carried out of the SEZ by a skid steer and chipped using a track chipper (see photos). To avoid impacts, watercourses were crossed using downed logs to form Humboldt crossings. We committed to using only low ground pressure equipment (5 psi or less), and limited the number of equipment passes. Chips were thinly spread outside defined watercourses and wet meadows. Where feasible, we operated equipment on material that could absorb or spread out a load, such as a layer of wood chips or a layer of slash.

I committed to assessing the soil and vegetation cover pre- and post-project and to mitigate areas using decompaction and mulching if needed. A cone penetrometer was used to measure soil resistance to force (a proxy for compaction). To measure vegetative impacts, we used cover-point monitoring following monitoring protocols for revegetation projects in the Lake Tahoe Region.

Skid steer loader transporting logs across a Humbolt crossing.

4.1: Developing a Monitoring Plan

Based on monitoring results, the fuels treatment techniques used (hand crew, skid steer, and track chipper) did not result in permanent soil disturbance in violation of the Basin Plan, nor did the project disturb or remove vegetation causing an impact to the health and diversity of the SEZ.

The project demonstrated the use of ground-based mechanical equipment in an SEZ. Beyond the fire hazard reduction, my hope was to develop the practice and the necessary trust for implementation of future projects slowly, carefully and intentionally. The project was small in comparison to much larger SEZ fuel reduction and restoration projects recommended in the Lake Tahoe Basin. Using the outcome-based management process, we can learn to implement a wider range of treatments on forestry projects that meet our common goal of watershed protection and reducing the threat of a catastrophic wildfire.

Monitoring transects for taking cone penetrometer measurements.

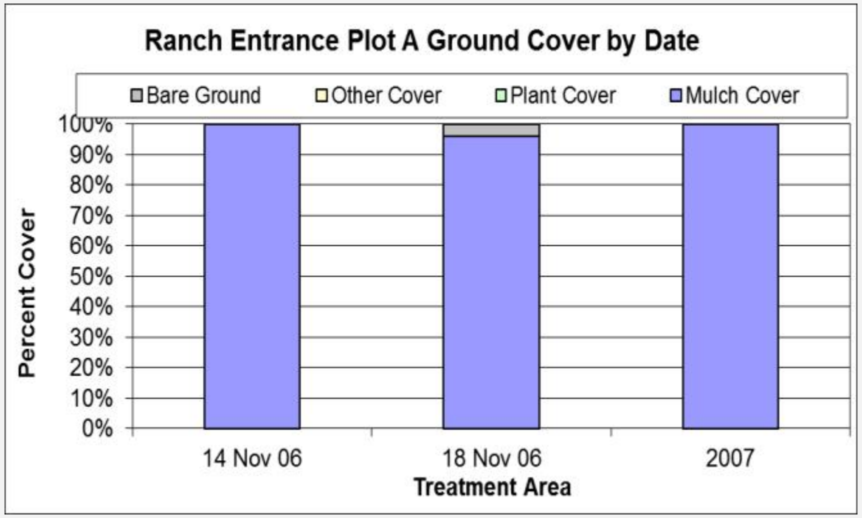

Figure 29. Graph showing results of pre– and post-project ground cover assessment.

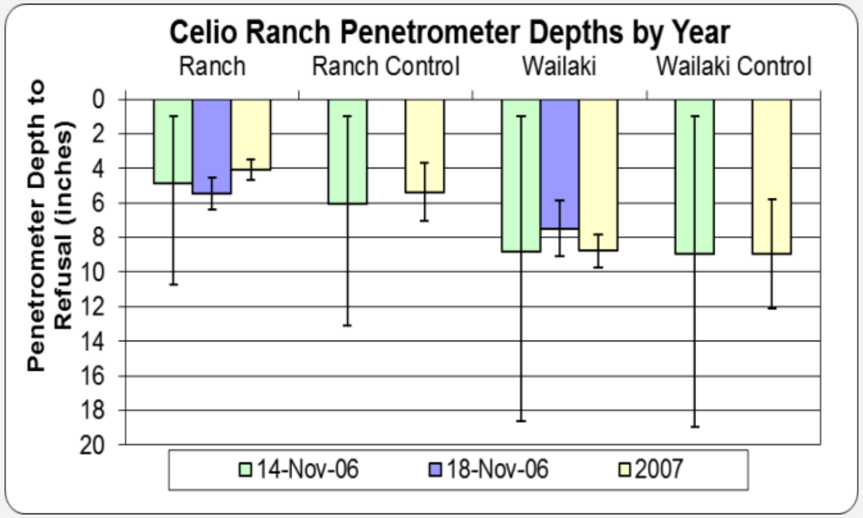

Figure 30. Graph showing results of pre– and post-project soil compaction assessment, measured with a cone penetrometer.

4.2: Photo Point Documentation

Definition	Purpose	Output Data	How to Use it
Taking photographs at fixed locations over time utilizing GIS technology to mark locations and photo points	To document visual changes over time	1. "Before" and "After" photos of treatment area 2. Success criteria indicators 3. Visual documentation	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

Input	Output	Equipment Needed
$	☆ ☆	Digital camera and a tracking spreadsheet

TOOLKIT

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

4.2: Photo Point Documentation

Data Interpretation Example

Before Treatment

After Treatment

Example of 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.

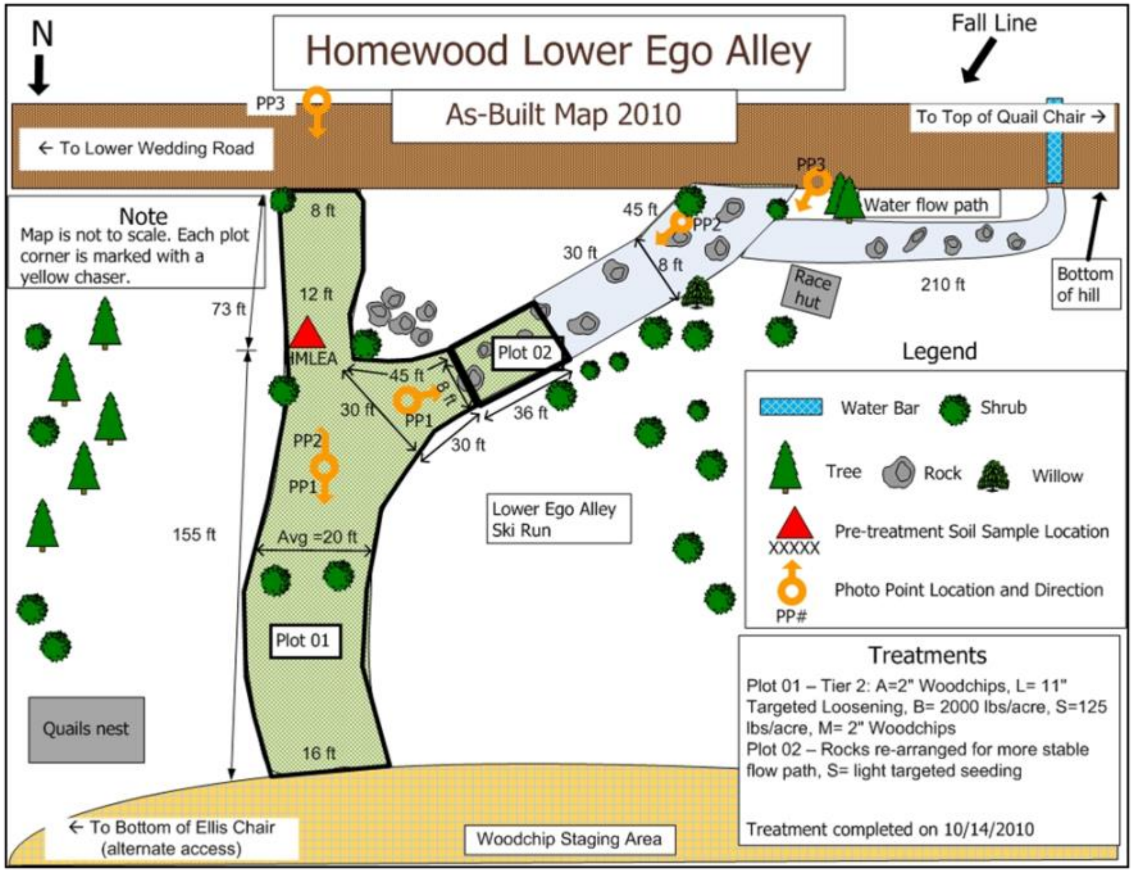

Figure 31. Example as-built map showing photo point locations and directions.

TOOLKIT

4.3: 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 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 erosion areas

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

4.3: Visual Erosion Assessment

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.

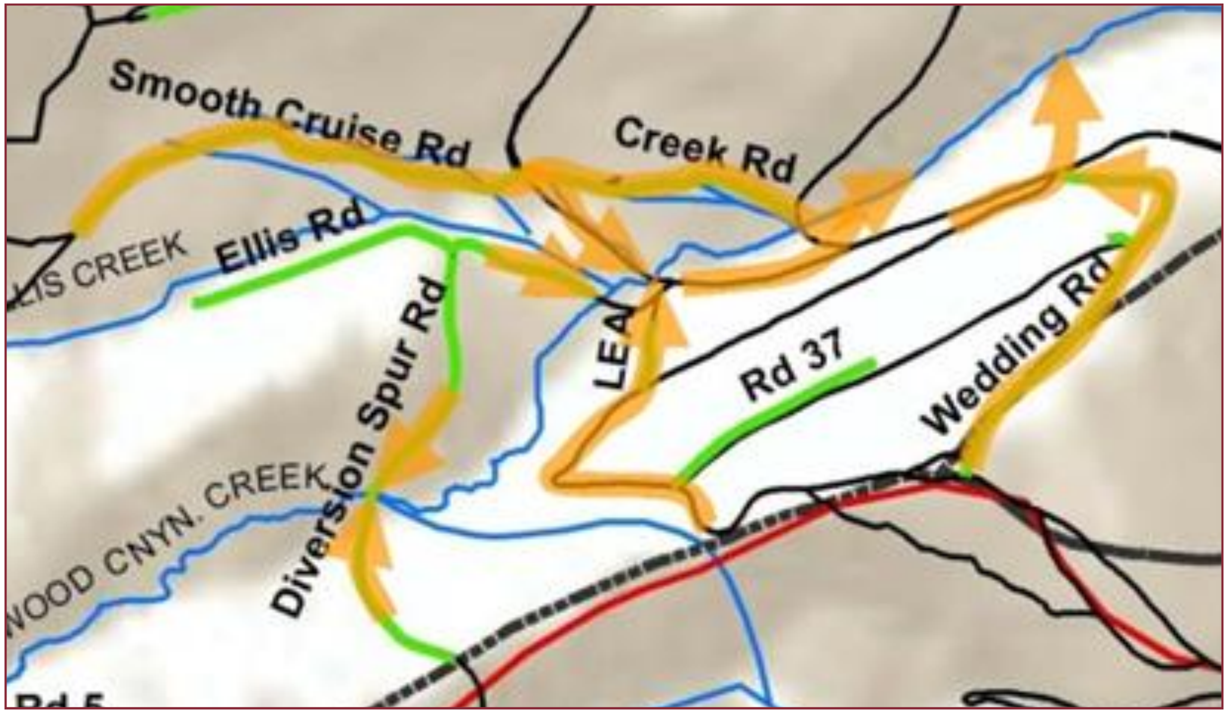

Figure 32. Map showing erosion problems and water flow paths, produced using visual erosion assessment in field.

4.4: Cone Penetrometer (Soil Compaction)

Definition	Purpose	Output Data	How to Use it
Measures a soil's resistance to force, which can be used as a surrogate for compaction, soil compaction, 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, 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 rod 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	Equipment Needed
$	☆ ☆	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

Cone Penetrometer Assessment Video
CLICK HERE

4.4: Cone Penetrometer (Soil Compaction)

Data Interpretation Example

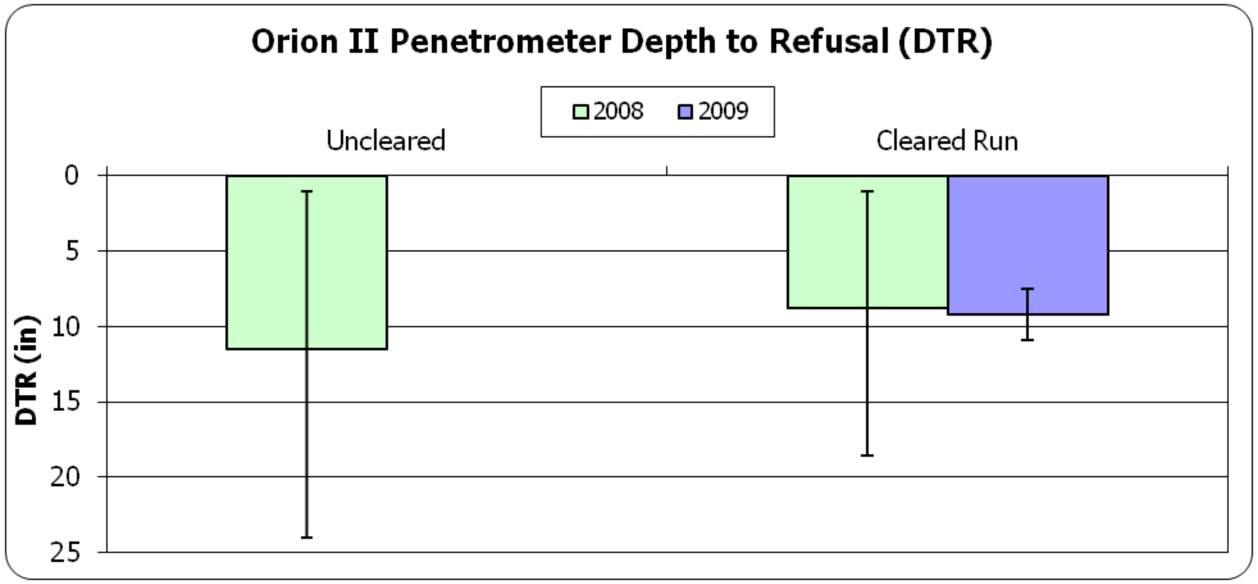

Figure 33. Average penetrometer depth to refusal graph. *The error bars denote one standard deviation above and below the mean.*

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.

TOOLKIT

4.5: Soil Moisture

Definition	Purpose	Output Data	How to Use it
Measures soil water content by volume	Assess sensitivity to compaction; assess changes in water holding capacity after treatment; compare to cone penetrometer readings	1. Percent soil water content by volume	1. Position soil moisture probes vertically. 2. Push into soil until probes are fully covered with soil. Measurements taken without probes fully inserted into soil will not be accurate. 3. Press the "read" button on the display and record the percentage shown 4. Repeat this process to collect the required data

Input	Output	Equipment Needed
$	☆ ☆	Order from Campbell Scientific: www.campbellsci.com/hs2

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

Soil Moisture Assessment Video
CLICK HERE

4.5: Soil Moisture

Data Interpretation Example

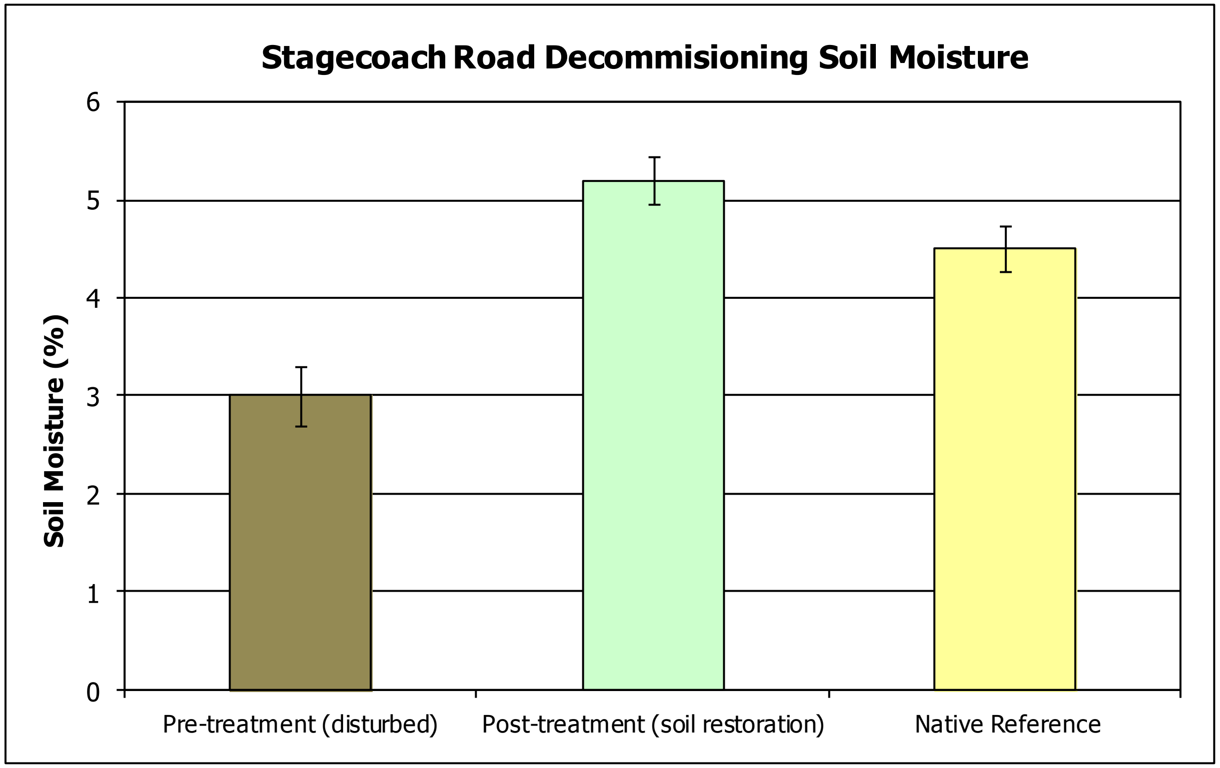

Figure 34. Average soil moisture graph. *The error bars denote one standard deviation above and below the mean.*

What does the data suggest?

The example graph above shows soil moisture readings taken before and after a road restoration/ decommissioning project, and compares those readings to a nearby undisturbed native reference site.

This data indicates that the restoration treatment (loosening, wood chip incorporation, seed and mulch) increased soil water holding capacity to a level slightly higher than the native reference site. For a more complete assessment of how effective the treatment was at rebuilding ecosystem resilience at this site, soil moisture measurements could be accompanied by cone penetrometer readings (soil compaction), soil organic matter assessment and cover measurements of vegetation and mulch.

TOOLKIT

4.6: 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 water at different flow rates to measure and visually assess infiltration, 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: • 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	Equipment Needed
$$	☆☆☆	Must be custom built—no known commercial sources

TOOLKIT

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

Runoff Simulator Assessment Video
CLICK HERE

4.6: Runoff Simulator

Data Interpretation Example

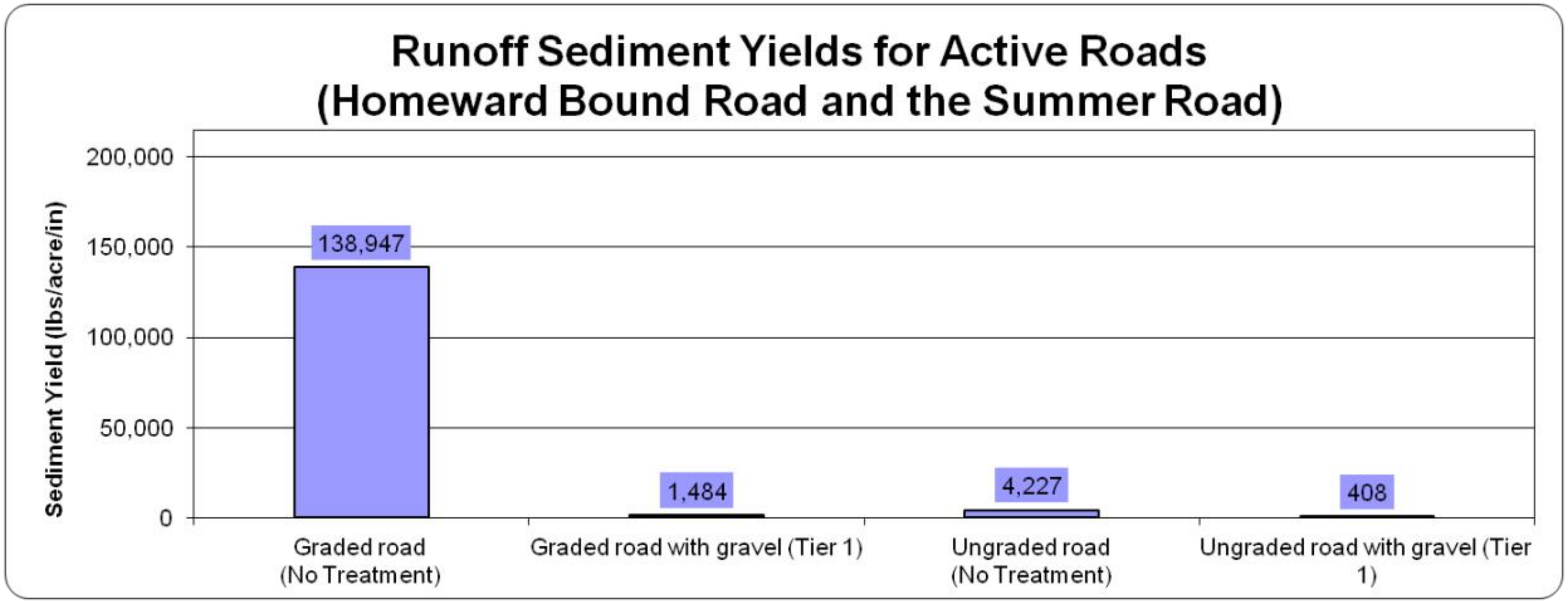

Figure 35. Example runoff sediment yield graph from active dirt roads with different management and mitigation treatments.

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 4 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

4.7: Constant-Head Permeameter (Infiltration)

Definition	Purpose	Output Data	How to Use it
Measures the saturated hydraulic conductivity of soils, or the permeability of soils	To measure relative soil permeability	Permeability; long-term constant infiltration rate when the soil is saturated.	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 5. Difference between readings at one minute intervals is equivalent to infiltration rate in inches per hour.

Input	Output	Equipment Needed
$	★ ★	Build from PVC piping, ball valve and water gauge.

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

Constant-Head Permeameter Assessment Video

CLICK HERE

4.7: Constant-Head Permeameter (Infiltration)

Data Interpretation Example

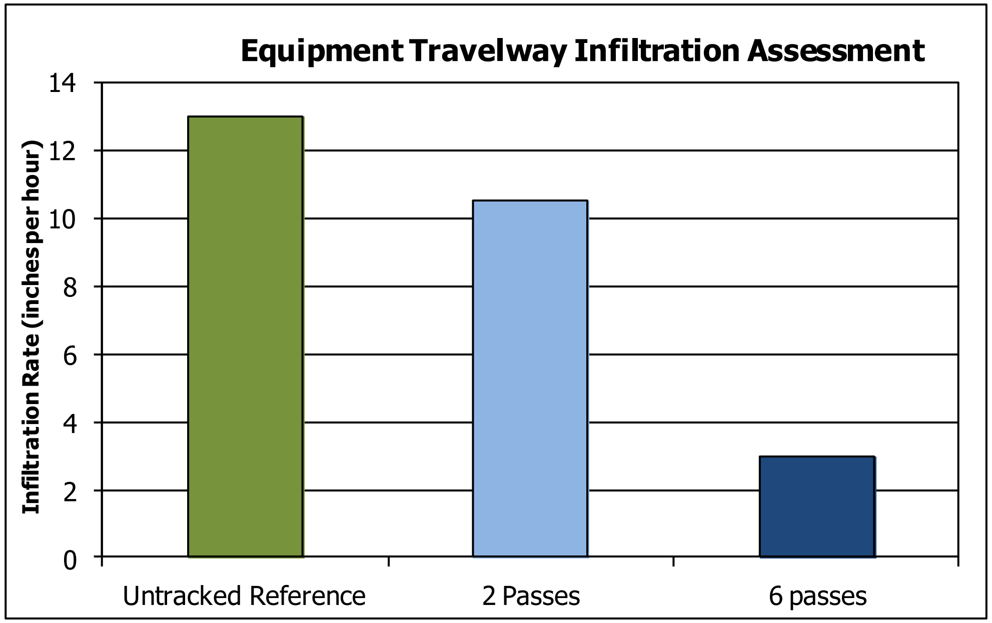

Figure 36. Constant-head permeameter graph showing infiltration rate for different numbers of passes by a tracked masticator.

What does the data suggest?

The constant-head permeameter (CHP) measures the constant rate of infiltration into soils, which is also sometimes 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 soil after 2 and 6 passes by a tracked masticator for a forest fuels reduction project. Infiltration results for the tracked areas were compared to an untracked reference area.

CHP infiltration results show that 2 passes resulted in a slight reduction in infiltration rate compared to the untracked reference area, while 6 passes resulted in a stark reduction in infiltration rate.

These results suggest that limiting the number of equipment passes can help to prevent soil compaction on forestry projects. Additionally, the 6 pass travelway should be decompacted and covered in mulch to reverse the impacts of soil compaction from the tracked masticator.

4.8: Cover Assessment—Measurement

Definition	Purpose	Output Data
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

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

How to Use it

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

Alternatively, cover can be estimated visually using a reference card that shows actual cover and associated percentages. This method is much quicker but less accurate or defensible (see 4.9: Ocular Estimate).

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

4.8: Cover Assessment—Measurement

Data Interpretation Example

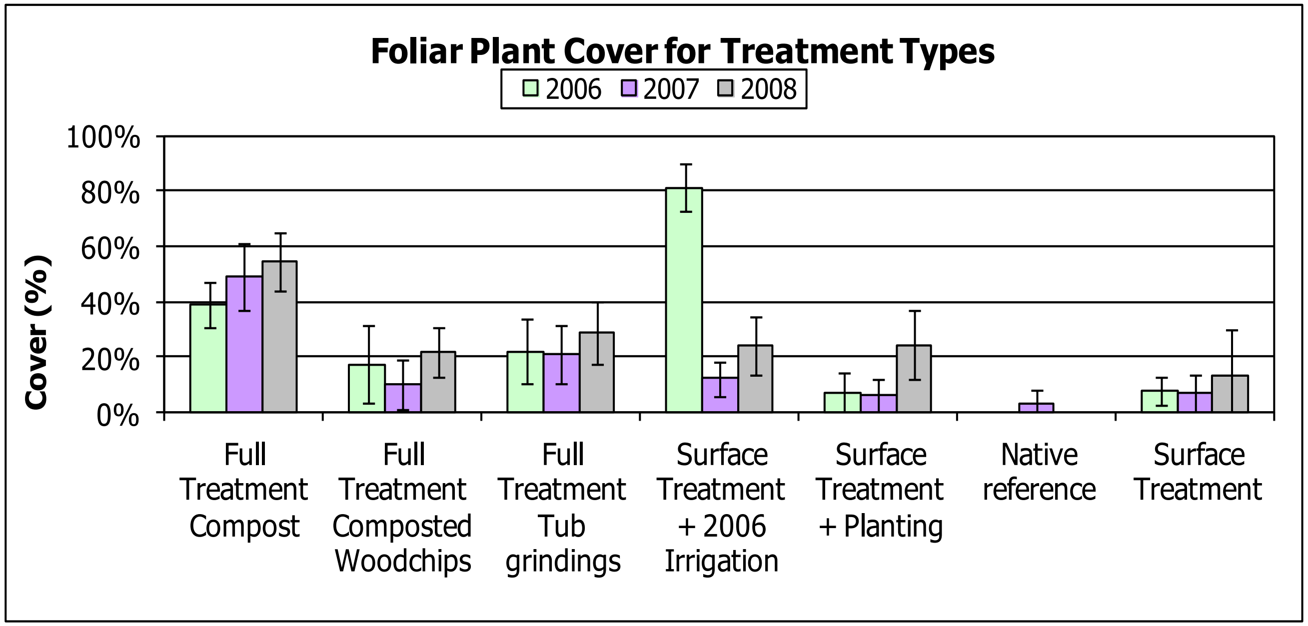

Figure 37. Example foliar plant cover percentage graph. *The error bars denote one standard deviation above and below the mean.*

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.

4.9: Cover Assessment—Ocular Estimate

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 general 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

4.9: Cover Assessment—Ocular Estimate

Data Interpretation Example

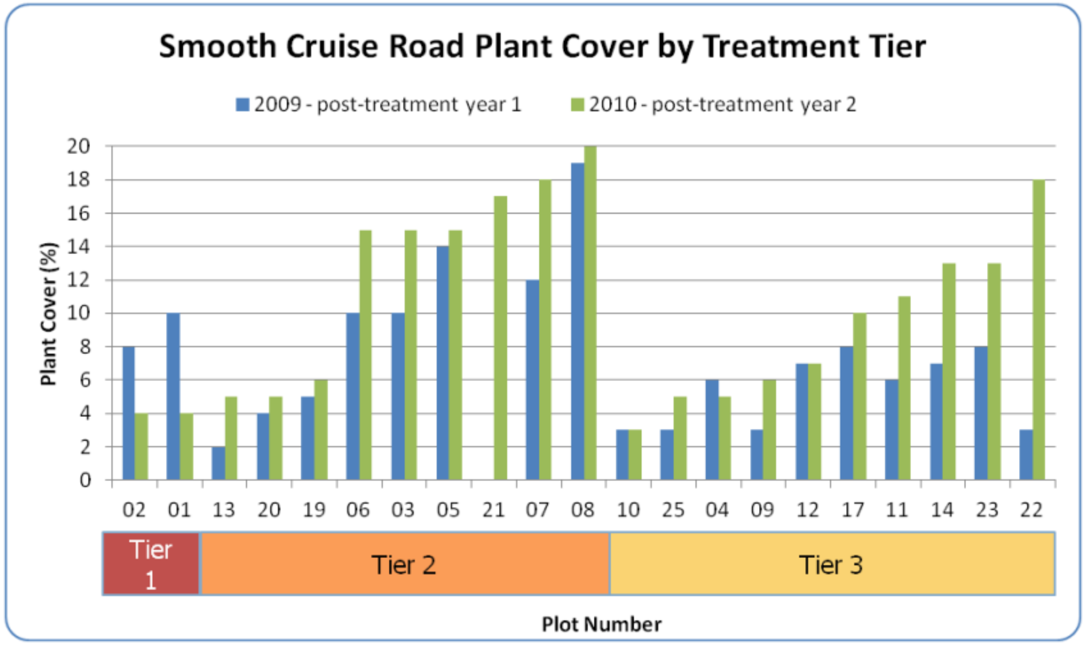

Figure 38. Ocular estimates of plant cover following different "tiers" of treatment on a forest road. Tier 1 is mulch-only treatment; Tier 2 is targeted loosening; Tier 3 is bucket tilling.

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.

TOOLKIT

4.10: Soil Sampling

	Definition	Purpose	Output Data	How to Use it
	The collection of soil samples, for subsequent lab analysis, to measure specific nutrient and physical parameters	Soil organic matter and nutrient levels can be used to develop appropriate restoration treatments and assess site resilience (e.g. ability to support vegetation, infiltrate and store water, etc.)	1. Nutrient content 2. Organic matter content 3. Physical properties 4. Chemical properties	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
	Input	**Output**	**Equipment Needed**	
	$	☆ ☆	Buy a trowel, soil sieve, and Ziploc bags	

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

4.10: Soil Sampling

Data Interpretation Example

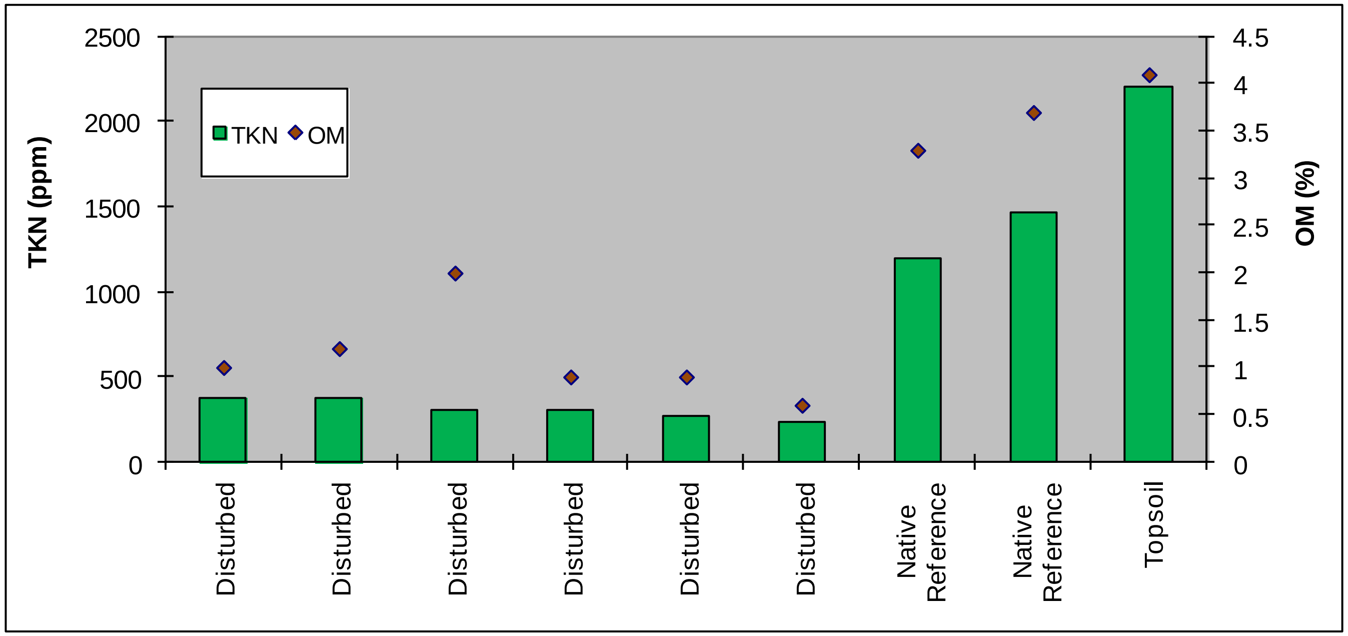

Figure 39. Soil organic matter (OM) and total Kjeldhal nitrogen (TKN) levels.

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 before grading), 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, 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.

TOOLKIT

4.11: 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.

4.11: Management Response

In the following example, note how the management response is embedded within the planning process.

Step 1: Identify the Need for Action

Mechanical equipment will be used in stream zone and compaction is a concern.

Step 2: Set Goal

No net increase in soil compaction post-project.

Step 3: Develop Plan

- The main travelway will be located outside of the stream buffer zone.
- Equipment travel within stream zone will be limited to no more than 4 passes.
- Pivot turns will not be allowed (to minimize soil displacement)

Step 4: Define Success Criteria and Monitoring Methods

Success criteria include no more than 10% increase in soil compaction, as measured by depth to refusal at 350 PSI using a cone penetrometer.

Step 5: Develop Pre-Defined Management Response

If soil depth to refusal is reduced by more than 10% after forestry treatment, these areas will receive the following treatments:

- Soil loosening and wood chip incorporation
- Seeding (native grass blend)
- Duff replacement (using duff collected from nearby areas)

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 if success criteria are not met. And project implementers can either use creative measures during implementation to avoid impacts or plan to implement post-project mitigation treatments to in order to meet success criteria. Additional management responses can be developed during monitoring if other issues or 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."

STEP 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**.

5.1: Exchanging Information

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

Outcome-based management workshop at Ward Canyon.

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 13. 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

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

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 Support 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 outcomes 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 on West Shore of Lake Tahoe, California.

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

--Mark Twain

Part Three
Annotated Bibliography

Annotated Bibliography

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Introduction to the Annotated Bibliography

This annotated bibliography includes a collection of research publications and other technical reference documents that were cited earlier in the Guidebook and that we (the authors) considered to be most relevant to this Guidebook's subject matter. Each citation is followed by a brief overview and a synopsis of relevant findings. The citations are organized by the sections in the Toolkit in which they were cited.

We hope that this unconventionally formatted annotated bibliography provides useful guidance and hopefully serves as a starting point for asking and answering your own questions.

Annotated Bibliography

Pile Burning

Busse, M., Shestak, C., Hubbert, K. 2013. Soil heating during burning of forest slash piles and wood piles. International Journal of Wildland Fire, Vol. 22, Issue 6, pp. 786–796.

Overview: The intent of this study was to measure the magnitude, duration and penetration of the soil heat pulse generated during burning of forest fuels burn piles in the Lake Tahoe Basin. The piles varied widely in size and fuel composition, ranging from slash to large wood.

Relevant Findings:

- The soil heat pulse depended primarily on fuel composition, not on pile size.
- Burn piles dominated by large wood produced lethal heating lasting up to 3 days in the top 10cm of soil. In contrast, the heat pulse was moderate beneath piles containing a mixture of fuel sizes.
- Soil impacts associated with the heating effects of large wood piles include destruction of the soil seed bank, reduced microbial biomass, volatilization of soil C and N, and detrimental changes to soil physical properties.
- Considerable spatial variability was noted. Soil temperatures were generally greatest near pile centers and decline sharply toward the pile edges.
- Soil and vegetation recovery following burning of large wood piles is likely to take considerably longer than after burning of slash piles, but no monitoring data was available to inform this prediction.
- Long-term impacts to soils and water quality from most pile burning projects are likely to be negligible, except at sites with an abundance of large-diameter fuels and in areas in close proximity to live streams and surface waters.

Korb, J., Johnson, N., Covington, W. 2004. Slash Pile Burning Effects on Soil Biotic and Chemical Properties and Plant Establishment: Recommendations for Amelioration. Restoration Ecology, Vol. 12, No. 1, pp. 52-62.

Overview: This study investigated the effects of slash pile burning on soil biotic and chemical properties and early vegetation succession on burned slash pile areas in a ponderosa pine forest in the Coconino National Forest near Flagstaff, Arizona, which is similar in elevation and climate to the Tahoe Basin. The study sampled across a gradient of burned piles for arbuscular mychorrhizal (AM) propagule densities, the soil seed bank, and soil chemical properties. In addition, they assessed the effect of treating burn scars with different combination of salvaged topsoil, sterilized topsoil and seeding on early herbaceous succession.

Relevant Findings:

- Adding both seed and salvaged topsoil more than doubled total native plant cover and decreased ruderal and exotic plant cover.
- Direct seeding on ash resulted in lower native species richness and less than half the native plant cover compared to burn scars treated with both salvaged topsoil and seed.
- They recommend that slash be piled and burned on existing forest roads whenever possible to minimize ecological impacts, including discouraging the establishment of exotic species.
- They also stress the importance of using locally-collected seed and topsoil in the mitigation of burn pile scars.

Annotated Bibliography

Broadcast Burning

DeBano, L.F., G. Nearly and P.F. Ffolliott. 1998. Fire's Effects On Ecosystems. John Wiley and Sons.

Overview: The authors addressed fire effects on ecosystems and especially concentrated on fire effects on soil. This work was an attempt to update work done in the 1970 by the (then) Soil Conservation Service (now the Natural Resource Conservation Service).

Relevant Findings

- Fire effects depend on fire intensity [thus broadcast burns can be expected to have more widespread but lower intensity effects.]
- Above ground temperatures correspond to fire intensity but below ground temperatures rise slowly due to soil moisture.
- Above ground flame length is a poor indicator of soil heating and damage; soil damage is more dependent on duration than intensity of fire.
- Most of the heat, even in intense fires, is located in the surface 4 inches. However, this is where microbes and organic matter (activity) exist and thus damaging that layer produces most of the damage associated with a fire.
- Organic matter (OM) provides a great deal of the 'services' in a forest floor. Thus, when that OM is burned off, function is severely limited or eliminated for some period of time.
- Fires release nutrients directly through mineralization as well as stimulating microbial activity. Vegetation absorbs (and adsorbs) some of those nutrients IF vegetation is present. Thus, vegetation can offset nutrient leaching and runoff.
- Ammonium increases immediately after a fire. Nitrate increases threefold within 0.5 to 1 year due to microbial breakdown and is very mobile. Vegetation can convert this NO_3 into NH_4 again.
- Erosion can be increased if roots are burned (soil burned to >4" depth).
- Erosion post fire depends to a large extent on the rainfall regime, particularly the 1st year.
- Erosion wanes with increased vegetation, litter and debris post fire.
- When more than 75% of the surface is covered by vegetation or plant litter, only 2% of a storm is likely to become runoff.
- When less than 10% is covered, more than 70% of precipitation may become runoff.
- Increase in runoff tends to fully wane within the first 1-2 years following fire (not burn piles).

Elliot, W. J., Page-Dumarose, D. and Robichaud, P. R. (1996) The Effects of Forest Management on Erosion and Soil Productivity. Proceedings of the Soil Quality and Erosion Interaction Symposium, The Soil and Water Conservation Society of America, Keystone, Colorado

Overview: The authors address mechanical treatment of forests through a combination of summarizing field research and modeling. They focus on disturbance and productivity with a primary emphasis on erosion.

Relevant Findings:

- Most erosion from managed watersheds comes from roads.
- Background hydraulic conductivities are in the range of $^{+/-}$ 15mm/hr.
- Roads hydraulic conductivities are approximately $^{+/-}$ 1 mm hr.
- Background erosion rates average 0.1 mg/ha
- Erosion rates from roads can be 100 mg/ha or higher.

[Reviewer Comment: Roads sediment yields can be 3 orders of magnitude higher than non-roaded areas (Drake and Hogan 2013). Thus, sediment reduction efforts in forested areas should be focused on roads.]

- WEPP was used to model sediment yield.

Payne, D. 1999. Prescribed fire effects on water quality in the Lake Tahoe Basin, California. Master's Thesis. Paper 1835. San Jose State University.

Overview: The author investigated how broadcast/prescribed burning impacted water quality, specifically calcium, phosphate, nitrate, in ephemeral streams in the General Creek drainage after State Parks implemented a prescribed fire regimen in the General Creek watershed on the west shore of Lake Tahoe.

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Relevant Findings:

- Relatively minor changes in nutrient loading occurred following broadcast burning.
- No adverse impacts to water quality were measured.
- Most effects, when discernible, were short term.
- Water sampling during this sampling period included an extremely high flow year, which would have been more likely to mobilize nutrients of concern. The author suggests that during a 'normal' or lower flow year, surface material would be much less likely to mobilize and would have an opportunity to 'settle' and stabilize.

Mechanical Treatment

Han, Sang-Kyun. 2006. Impacts on soils from cut-to-length and whole tree harvesting. Master's Thesis. University of Idaho. August 2006.

Overview: This study investigated the soil compaction effects of cut-to-length and whole tree harvesting methods in Northern Idaho, as well as the compaction amelioration effectiveness of slash mats, as part of the author's Master's Thesis.

Relevant Findings:

- The buffering effect of slash is highly dependent on quantity of slash and diminishes quickly with increasing machine passes.
- Heavy slash (40.0 kg/m^2) was found to result in less than half as much soil compaction as light slash (7.5 kg/m^2).
- Slash is rarely evenly distributed on the trail and portions of trails with lower amounts of slash can get very compacted.
- Higher soil moisture levels tended to correspond to greater compaction with the same number of machine passes.

Harrison, N. 2012. Understanding the effects of soil exposure in fuels treatments that balance fuel reduction and erosion control in the Tahoe Basin. Masters Thesis. Humboldt State University. http://www.fs.fed.us/psw/partnerships/tahoescience/documents/p019_HarrisonThesis.pdf

Overview: The author evaluated post burn areas, particularly the Angora Fire (Lake Tahoe) and other 'controlled' or broadcast burn areas with the intention of determining how fire and fire treatments affect erosion, specifically in relation to how much surface cover is required to mitigate fire effects. Field observations were compared with WEPP model outputs.

Relevant Findings:

- As little as 25% surface cover mitigated some of the fire erosion effects.
- Significant increases in erosion were noted at the threshold of 54% burned surface.

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- The greatest increases in erosion occurred at 66-100% burned surface.
- WEPP model and field observations were most similar with scenarios that WEPP could model (large, contiguous hillslopes).
- Both the field observations and the model output suggest that fire effects (on erosion) can be mitigated by using mastication to mulch areas where fire impacts are high.

Hatchett, B., Hogan, M., Grismer, M. 2006. Mechanized mastication effects on soil compaction and runoff from forests in the Western Lake Tahoe Basin. California Agriculture 60: 77-82.

Overview: The authors investigated the impact to soil and runoff of an excavator-mounted rotary masticator. Two types of measurements were taken: one was a cone penetrometer which measured an analogue of soil density/compaction and the other was a rainfall simulator which directly measured infiltration and runoff on masticated areas.

Relevant Findings:

- Most of the measurements taken in tracked area did not show a significant increase in soil density.
- Where compaction was found, compaction in excavator tracks increased with depth up to 18" and decreased away from the tracks.
- Tracked areas typically were completely mulched with woody debris from mastication.
- Low amounts of mulch cover in tracked areas produced similar runoff and sediment yield amounts as nearby 'undisturbed' native soil areas that lacked surface cover, suggesting that tracked equipment did not significantly increase runoff.
- Where mulch was present in the tracked areas, runoff was comparable to native areas with duff cover

Road and Travel Management

Archuleta, J. and Baxter, E. 2008. Subsoiling promotes native plant establishment on compacted forest sites. Native Plants Journal 9(2):117–122.

Overview: The authors look at 3 implements that can be used for mitigating soil compaction on forestry projects. These implements are custom-designed and suggest that a number of creative solutions can be developed to address compaction and thus reduce erosion in forest vegetation management projects. While the authors did not present any data or findings from the use of these tools, the paper presents obvious uses and applications where tilling/decompaction is understood to be effective.

Relevant Findings:

Three tilling or soil loosening implements were investigated including:

- ***Subsoiling gapple rake***- a special item that can be used during or after vegetation thinning projects and can be mounted on a tracked vehicle to loosen soil.
- ***Subsoiler excavator bucket***- a specially modified excavator bucket used specifically for restoration projects that uses tines attached to the sides of the bucket and a coulter blade.
- ***Subsoiling brushcutter hitch***- a specially designed addition to a brushcutter head that can be added after brushcutting that allows one implement to be used, through this simple addition, to loosen soil following mastication.

Croke, J. and P. Hairsine. 2005. Sediment delivery in managed forests: a review. *Environmental Reviews.* Vol. 14. pp. 59–87.

Overview: Synthesis paper focusing on runoff delivery pathways and connectivity and connectivity between roads (and other timber harvest travel paths) and streams. The authors stress the importance of understanding hydrological connectivity and managing runoff pathways as the key to limiting impacts of forestry activities on in-stream water quality.

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Relevant Findings:

- General tendency for elevated sediment concentrations and/or turbidity following periods of logging and road building.
- Roads may occupy less than 1% of watershed area but contribute a disproportionate amount of sediment and runoff during low to moderate rainfall events.
- Authors identify three key elements to reducing sediment delivery: 1) identify key erosion sources; 2) understand sediment delivery pathways and connectivity; 3) monitoring the effectiveness of source control treatments and BMPs.
- The understanding required to implement effective erosion control does exist, but the means or desire for holistic strategies is absent.
- Most empirical models address rill and gully erosion but fail to address many key sediment sources.
- Our gap in understanding of sediment delivery processes has limited the application and utility of many sophisticated, physically-based models in predicting catchment sediment yield.

Drake, K. and M. Hogan. 2013. Watershed Management Guidebook: An Outcome-Based Guide to Watershed Management. Prepared for the California State Water Resources Control Board.

Overview: This Guidebook is a compilation of many years of field research and demonstration projects in the Lake Tahoe area on the effectiveness of various watershed management and restoration practices. The authors put forward a process called *Outcome-Based Management*, which calls for a shift from modeling and predictions to checking actual project outcomes and adjusting outcomes when goals are not met. In addition to specific treatment and monitoring tools, the authors introduce a watershed assessment approach called *Erosion-Focused Rapid Assessment* (EfRA) as well. This document is considered the parent document to the *Forest Management Guidebook*.

Relevant Findings:

- 80-100% reductions in runoff and sediment yield can be achieved on disturbed sites using soil-based restoration treatments.
- Targeted, "rising limb" stream monitoring methods can be used to detect a "signal" of water quality improvement from watershed restoration work in as little as 3-5 years.
- Erosion-focused rapid assessment (EfRA) can be used to target field time and prioritize erosion hot spots for treatment to maximize water quality benefits.
- Outcome-based management can actually save money since regulatory requirements can often be achieved in a more direct and streamlined manner.
- Outcome –based management can reduce the probability of legal battles compared to relying on predictive models and compliance-based project implementation strategies.

Foltz, R.B.; Copeland, N.S. 2008. Evaluating the efficacy of wood shreds for mitigating erosion. Journal of Environmental Management 90(2):779-785.

Overview: The authors evaluated the efficacy of wood shreds (a lumber production by-product) as an erosion control mulch on a coarse and fine grained soil. Using a rainfall simulator, they attempted to determine whether specific amounts of mulch (30, 50 or 70% cover) can be related to significant reductions in sediment. The study used both simulated rainfall, which produced sheet flow, and additional concentrated flow in order to determine hydrologic differences.

Relevant Findings:

- They found that 50% wood shred cover seemed optimal for sediment reduction in sheet flow. That is, 50% cover showed the largest relative reduction of sediment yield in simulated rainfall.
- The percentage of cover is more important than the type of cover in terms of controlling erosion.

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- Cost effectiveness, long-term durability, and impacts on revegetation are considered important factors in erosion control material selection.
- Concentrated flow reduced mitigation effectiveness overall.

Grismer, M.E., C. Schnurrenberger, R. Arst and M.P. Hogan. 2009. Integrated Monitoring and Assessment of Soil Restoration Treatments in the Lake Tahoe Basin. Environ. *Monitoring & Assessment.* Volume 150. Issue 1.

Overview: The authors investigated a range of monitoring techniques based on the hypothesis that direct functional assessment of revegetation and restoration projects is a critical step in determine what techniques work and which need to be improved.

Relevant Findings:

More than 120 plots, monitored over a 3 year period, showed these results:

- Treatments that loosened soil showed the greatest infiltration increases.
- Adding coarse organic matter to the soil, in addition to loosening, resulted in the greatest overall sediment reduction.
- Pine needle mulch of at least 51mm depth was the most effective mulch cover in reducing sediment, though mulch did not increase infiltration. Rather it slowed surface flow.
- Compost increased total N levels as well as total organic matter in soil.
- Compost and wood chips produced the highest increase in soil organic matter when applied together.
- Tilling of compost into the soil produced the highest vegetation cover over 2 seasons.
- Wood chips produced similar vegetative results to compost.
- Increase in organic fertilizers increased weedy growth but not desired native growth.
- Native plant cover was highest in tilled, amended, non-irrigated sites when compared to irrigated, non-tilled sites.

Grismer, M.E., and M.P. Hogan. 2005. Evaluation of Revegetation/Mulch Erosion Control Using Simulated Rainfall in the Lake Tahoe Basin: 3. Treatment Assessment. *Land Degradation & Dev.* 16: 489-501.

Overview: The authors state that little monitoring of effectiveness of erosion control treatment has been done in the Lake Tahoe basin. Using a rainfall simulator, they measured runoff rates from two soil types (volcanic and granitic) in bare, mulched and vegetated states.

Relevant Findings:

- Sediment yield was correlated to slope angle; that is, the steeper the slope, the greater the sediment yield on both soil types.
- In bare conditions, volcanic soils produced an order of magnitude more sediment than granitic.
- Pine needle mulch was an effective method of reducing sediment.
- Soil restoration that included tilling of wood chips into the soil, revegetation with native grasses and use of a woody surface mulch resulted in little to no runoff in both soil types and persisted for at least two years.

Layh, G., Hogan, M., Downing, L. 2012. Waddle Ranch Monitoring Report. Prepared for Lahontan Regional Water Quality Control Board. March 2012.

Overview: The authors investigated the persistence of compaction in roads and landings and potential mitigation tools and responses to treatment of roads and landings in a watershed in the Waddle Ranch area of Martis Valley near Truckee, California. Landing treatments included tilling with a mini-excavator and ripping with a deep ripper implement, addition of organic matter and a range of tests on seldom-used roads.

Road treatments included full soil restoration (tilling, organic matter addition, seeding and mulching), wood chips mulch on compacted road, asphalt grindings on compacted road and measurement of untreated conditions. These tests were done to determine if seldom-used roads could be stabilized and still handle some minimal seasonal traffic. Tests were done to determine change in infiltration, runoff, erosion and plant growth.

LID or 'low impact development' treatments were applied to a primary haul road in an attempt to determine whether these treatments showed promise as low-cost sediment reduction tools.

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Relevant Findings

Landings:

- Compaction in landings can persist for more than 15 years with little loosening of soil, even when shrubs are present.
- Tilling and ripping produced similar results in terms of soil looseness, as measured with a cone penetrometer.
- Tilling to 12" with addition of 4" of high carbon soil amendments increased soil 'looseness' from 1" to 13 inches.
- Tilled/ripped soil increased water infiltration rate six-fold (600%).
- High rates of wood mulch (5+") can reduce grass growth response on landings.
- Plots that were not seeded produced little vegetative growth, suggesting that there is a very poor seed bank present in old landings.

Roads:

- The full treatment road restoration resulted in no runoff compared to a low infiltration rate and various rates of erosion for less intensive treatments.
- Woodchip mulch and asphalt grinding treatments produced no additional infiltration over the untreated area but decreased turbidity in the runoff by 10 times or an order of magnitude.
- Plant cover was enhanced drastically on the full treatment plot (+/- 30% cover) compared to the wood chip, asphalt grindings and bare plots.
- Roads can be made to be erosion resistant when only occasional vehicle use is required by using specific treatments that are tailored to use frequency.

LID Road Sediment Treatments:

- LID runoff capture treatments can be extremely effective in infiltrating water when linked with appropriate water bar design such that the water bar delivers water to the LID capture/infiltration basin.
- The LID basin infiltrated all runoff water from a 150 gallon runoff event.

Lloyd, R., Lohse, K., Ferre, T. 2013. Influence of road reclamation techniques on forest ecosystem recovery. *Frontiers in Ecology and the Environment.* Vol. 11, Issue 2, pp. 75-81.

Overview: The authors examined how two road reclamation methods (recontouring and abandonment) affect above- and below-ground ecosystem properties relative to "never-roaded" areas.

Relevant Findings:

- Recontoured and abandoned sites displayed similar above-ground properties but exhibited notable differences in below-ground properties, including soil hydraulic conductivity, organic matter, total carbon, and total nitrogen, among others.
- Recontouring can dramatically accelerate recovery of key soil and hydrologic properties by hundreds to thousands of years, as compared with never-roaded reference areas.
- Land managers should weight initial economic costs with both short- and long-term ecosystem benefits when planning watershed restoration projects.
- Low-intensity treatments that fail to restore both above- and below-ground properties may lead to an altered ecosystem with different functional processes and potential.

Luce, C. 1997. Effectiveness of Road Ripping in Restoring Infiltration Capacity of Forest Roads. *Restoration Ecology*, Vol. 5, No. 3, pp. 265–270.

Overview: Rainfall simulation used on small plots to evaluate the effects of road ripping and straw mulch cover on hydraulic conductivity and surface runoff on forest roads in Northern Idaho.

Relevant Findings:

- Ripping alone caused modest increases in saturated hydraulic conductivity, but do not represent "hydrologic recovery" relative to undisturbed forest areas.
- Where a contractor had inadvertently incorporated some of the organic layer from the surrounding forest soil during the ripping operation, the ripped road retained its looseness.
- Presence of mulch on soil surface allowed soil to sustain relatively high hydraulic conductivities across simulated rainstorms of increasing intensity, likely because mulch prevented surface sealing of soil macro-pores.

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- Although it was not quantified, surface runoff from the mulched-ripped plots was visibly cleaner than that flowing from the ripped-unmulched plots.

Main Conclusion: Ripping and subsoiling alone provide only temporary and marginal improvements. Tilling organic matter amendments into the soil appears to enhance both the short-term effectiveness and long-term infiltration capacity, greatly accelerating restoration of the road's hydrologic and ecological function.

Madej, M. A. 2001. Erosion and sediment delivery following removal of forest roads. Earth Surface Processes and Landforms 26:175-190.

Overview: The author assessed and modeled sediment yield from a number of roads that had been 'rehabilitated' in Redwood National Park and compared those results to 'untreated' roads. She reported on long term modeled sediment yield (1978 to 1998) and estimated sediment loads from a 12 year recurrence interval storm that occurred in 1997.

Relevant Findings:

- Post treatment erosion from roads and stream crossings was highly variable.
- On average, treated roads were estimated to contribute 480m^3 of sediment per kilometer of road, which was about ¼ of that contributed by untreated roads.
- Only 20% or the treated stream crossings accounted for 73% of the post treatment sediment from roads.
- Almost 80% or the treated roads showed no detectable erosion in the 12 year storm.
- Hillslope position was important in explaining post treatment road erosion.
- The highest erosion came from steep, lower hillslope position sites.

Assessment Tools

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.

Overview: The authors of this landmark publication not only provide a range of technical guidance on developing monitoring plans, but they make a clear case for the importance of monitoring—and the use of monitoring results—for effective adaptive management. The publication addresses common pitfalls in monitoring projects and provides detailed guidance on everything from sampling design to statistical analysis to data presentation. In the opinion of these reviewers, this is the most comprehensive and important monitoring guidance document currently available and should be required reading for anyone practicing ecological monitoring.

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

Overview: This is a comprehensive guidance document for developing water quality monitoring plans to evaluate the effects of forest management activities on water quality. The document begins by covering topics such as types of monitoring, regulatory drivers, study design, statistical analysis and a step-by-step process from creating monitoring plans. The second half of the document focuses on review and selection of monitoring parameters relevant to assessing the impacts of forestry activities on water quality. Although this publication focuses on Pacific Northwest forests and forest practices, the majority of its content and guidance is readily transferable to watersheds in other geographic areas.

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Targeted Water Quality Monitoring

Grismer, M.E. 2014. Soil Disturbance/Restoration effects on Stream Sediment Loading in the Tahoe Basin – Detection Monitoring. Environmental Monitoring & Assessment. Volume 186, Issue 7.

Overview

The author examines the use of continuous flow monitoring on three West Shore Lake Tahoe streams to determine whether that type of water monitoring can be used to accurately determine changes in water quality from upper watershed restoration. The paper suggests that accuracy is critical in order to determine cost effectiveness of restoration efforts.

Relevant Findings:

- Mid range daily flows can be used to detect changes in water quality with $^{+/-}$5% of the watershed treated.
- The study confirmed a relationship between total suspended solids and flow rate.
- A 1.5-fold reduction in sediment was detected from restoration work implemented in 2012-2013.

Grismer, M.E. 2012. Detecting Soil Disturbance/Restoration effects on Stream Sediment Loading in the Tahoe Basin – Modeling Predictions. Hydrological Processes. Volume 28. Issue 2.

Overview: The author used an existing model to attempt to predict the amount of 'disturbance' from both forest vegetation management (fuels thinning) and restoration of disturbed soils (roads and ski runs) that would be measurable in stream monitoring from several different Lake Tahoe west shore watersheds. This work was done in an attempt to support what was considered the need to actually quantify sediment reductions to comply with the Lake Tahoe TMDL. [*Reviewers note: the Lake Tahoe TMDL has since moved away from direct measurement of impacts or benefits to primarily activity reporting and model-based crediting.*

Relevant Findings:

According to the modeled results:

- More than 30% of the watershed would need to be impacted by fuel reduction work before those impacts would show up in stream sediment monitoring.
- $^{+/-}$ 5% of the watershed would need to be treated before that sediment reduction work would result in a measurable decrease in sediment in streams.
- A few years of pre-and post restoration stream monitoring should be able to be used to quantifiably assess improvements from watershed restoration work.
- Actual stream monitoring of sediment and nutrient yield changes is critical for any TMDL crediting program.

"This Guidebook is a useful tool for protecting water quality during forest health and restoration projects that address excessive fuel loads. The specific practices and the outcome-based management process outlined in the Guidebook are useful to both professionals and laypeople, and have the support of regulatory agency personnel".

—Doug Cushman, Chief – Nonpoint Source Unit, Lahontan Regional Water Quality Control Board

"For forest managers, this toolkit is the last resource you will ever need to ensure that your projects achieve results and multiple benefits. Thank you to Michael Hogan and Kevin Drake who are true believers and true experts in the field of outcome-based management and watershed protection."

—Martin Goldberg, Fire and Fuels Manager, Lake Valley Fire Protection District

"This guidebook/toolkit is focused on outcome-based management, which is definitely a move in the right direction. Forest managers will find it practical and useful for implementing fuels reduction/forest health projects and non-forest managers (homeowners, interested public and future foresters) will find the information accessible and educational."

Mike Vollmer, Environmental Improvement Program Manager, Tahoe Regional Planning Agency

"This toolkit is for people who are passionate about managing forests to protect communities, watersheds, and ecosystems. It provides a common framework for learning from each other's successes, challenges, and opportunities."

—Forest Schafer, Forester, North Lake Tahoe Fire Protection District

"A great guide for anyone involved in the restoration of forested landscapes. Clear and tangible results can be achieved by utilizing a simple, yet effective outcome-based management approach".

—Kim Boyd, District Manager, Tahoe Resource Conservation District

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