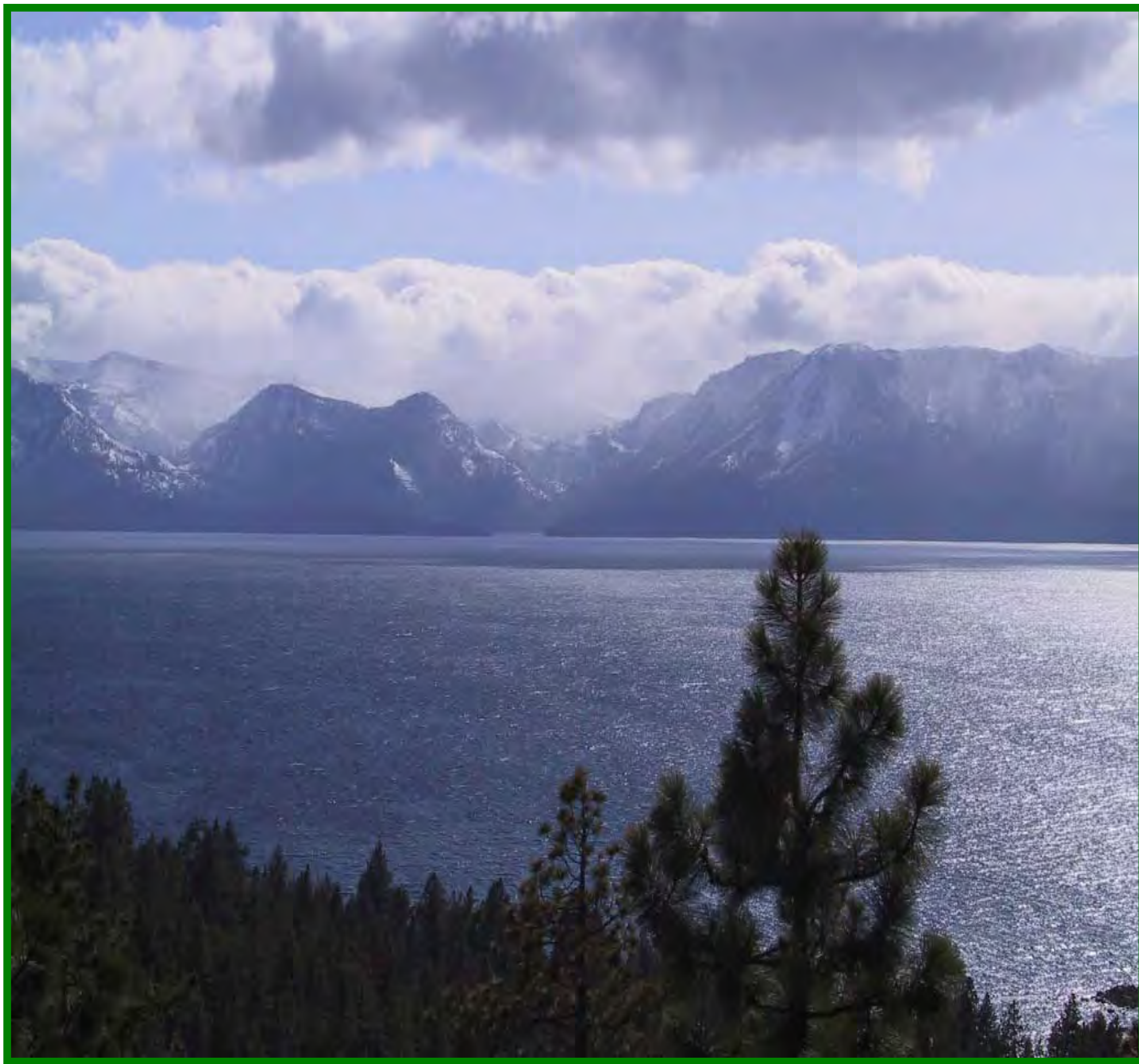
Cave Rock Revegetation Monitoring Program-
Improving Sediment Source Control Projects
in the Lake Tahoe Basin
Final DRAFT

JULY 2005



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EXECUTIVE SUMMARY

Sediment delivery to watercourses is a major cause of water pollution in the Western United States. This is especially apparent in the Lake Tahoe Basin where lake clarity has been reduced approximately one foot per year for over thirty years. Sediment source control treatment can be a highly effective tool to reduce or eliminate sediment movement and delivery downslope. Monitoring provides a bridge to understanding whether and to what extent sediment source control projects are functioning. Monitoring, when properly applied and combined with appropriate success criteria, can also form the basis for regulatory consistency and effectiveness. However, effective, standardized monitoring protocols and processes have not been adopted for these projects. This report has been prepared in an effort to further monitoring efforts and monitoring effectiveness in the Lake Tahoe Basin.

Most monitoring, when it occurs, has been focused on measuring actual water quality. While water quality monitoring is important, it provides very little information on how individual projects perform with respect to reducing sediment production. So we are left with scant information on the performance of individual projects or the specific elements within those projects. This situation may be likened to investing ones savings into untested or unrated investments and never again checking to see if those investments are producing dividends. Without a more complete knowledge of project performance, we are extremely likely to repeat past mistakes. Furthermore, as other areas within Nevada and California vie for funds from a limited funding base, the ability to quantify success will become even more important since those funding these projects are increasingly requiring 'proof' of successful outcome to assure that their funding has been effectively spent and to assure subsequent funding.

While this monitoring project was underway, a substantial increase in our understanding of erosion control processes and treatments occurred. Through research carried out by UC Davis researchers under Dr. Mark Grismer, a steady shift from a vegetation focus to a whole soil focus as the foundation of sediment source control has occurred. Initially, this project concentrated on developing and using plant cover monitoring as a primary tool. However, Grismer and others have shown that specific soil parameters are much better indicators of whether a site will erode during runoff periods or not. Therefore, this project has included more than was originally expected. While we were not able to do extensive rainfall simulation work on the Cave Rock project due to funding constraints, we include a great deal of information in the literature review that reflects our recent findings on other projects. These findings shed considerable light on the success of the Cave Rock project in terms of sediment source control. During the summer of 1999, shortly after the Cave Rock project was constructed, a large summer thunder shower produced an estimated one inch of precipitation in less than 30 minutes. Sediment was displaced from many of the East Shore slopes as evidenced by loose soil along many of the subdivision roads and the State Highway. However, the Cave Rock project produced no soil movement whatsoever. While common wisdom would suggest that uncompacted soil on a 1.25 to 1 slope would easily fail, visual inspection showed otherwise. Our data and

related research explains this mechanism. Accurate monitoring helps describe the conditions that must occur in order for soil to remain in place in this type of event.

In 2002, the United States Forest Service and the Nevada Division of State Lands cooperated in funding this project with the goal of developing the foundation of a set of monitoring protocols to address the lack of protocols on upland, sediment source control (erosion control) projects. This report has as its goal the development of useable monitoring protocols. However, in order to make these protocols meaningful, they must be used within a context. The context that we present is one known as 'Adaptive Management'. Therefore, the expanded or more comprehensive goal of this report is to develop and define a framework for planning, implementing, monitoring and, if needed, retreating sediment source control projects so that those projects can achieve maximum effectiveness.

This report is divided into seven sections plus appendices. Section One provides an introduction, purpose statement and project overview. Section Two develops a framework for this project which is known as adaptive management. Adaptive Management can take a number of forms. We have defined adaptive management within a context of sediment source control projects. We have been developing, using and iterating this form of adaptive management for over seven seasons. Adaptive management offers an ideal format from which to consider and use monitoring in an actual project.

Section Three is a literature report that attempts to describe and discuss various elements of erosion, restoration and control of erosion. We include a broad range of ideas, concepts and physical research in order to better understand how erosion takes place and what can be done to actually control it in a systematic manner. We suggest that erosion is actually a systematic symptom rather than a strictly plant related issue, as is currently accepted by a number of entities.

Section Four presents potential success criteria from which to assess projects. Success criteria is critical to monitoring in that without clearly stated and usually numerical criteria, success is difficult or impossible to determine in an objective manner. We suggest that success should be linked to function rather than strictly form and set forth a number of criteria for consideration.

Section Five presents some methodologies for success base on the Cave Rock and othe projects throughout the Tahoe Truckee region. This section may be considered the 'toolbox' from which actual practices can be drawn. This section is not completely inclusive or exhaustive but is based on experience and research results from Integrated Environmental and other collaborators.

Section Six is the actual monitoring protocol section and includes a number of elements and methodologies. When the Cave Rock Monitoring Project was originally funded, the main monitoring emphasis was on plant and cover point monitoring. Since that time, advances in monitoring understanding has clearly led to other types of monitoring that may be more cost effective and at the same time more useful to determine whether a project will actually be protected from erosion. This is especially true with penetrometer monitoring. We include some initial penetrometer monitoring information from Cave Rock. Other penetrometer monitoring results will be available in related publications.

Section Seven includes some Cave Rock monitoring data and interpretation. We have collected a great deal of monitoring data which is included in a data disc for further use and interpretation as the need arises.

Section Eight includes lessons learned and recommendations. We have provided a partial list. We hope to add to this list on other projects as they develop.

The appendices include the following:

-Cave Rock Construction Revegetation Specifications

-Soil data table

-cover data table

-site assessment forms

-A monitoring publication from UC Davis that describes the types of monitoring since monitoring includes a great number of actual practices and approaches and can be used for a number of various reasons

Briefly, we suggest that for monitoring to occur, it must be linked directly to project goals. This requires clear and specific project goals to be set. Further, we suggest that once those project goals are set, a number of processes must take place in order for the goals to be met. Specifications must be produced that aim to meet project goals and accurate oversight of installation must occur. Follow up inspections and monitoring must take place and the ability to re-treat areas that are not performing must exist. Monitoring must be quantitative to the greatest extent possible. Qualitative monitoring may have limited usefulness but it is generally not repeatable, accurate or defensible. With careful planning and an understanding of project goals and different types of monitoring, cost effective, quantitative monitoring can be developed and used. We have found that penetrometer and total cover monitoring, linked to soil nutrient analysis can be done quickly, efficiently and can provide a great deal of information about potential infiltration, surface cover (mulch and plants) and soil sustainability. With this type of information available, and when interpreted and used effectively, sediment source control projects in the Tahoe Basin can be improved greatly. This process is already occurring due to this and related projects. We can now measure sediment yield potential much more directly and can input that information into future projects. Cave Rock Erosion Control project was an early step in that direction and has provided us with a great deal of foundational information regarding what type of treatments and material can keep sediment on the slopes, out of local water courses and ultimately out of Lake Tahoe. We hope this report helps further the overall goals of reversing the clarity and water quality issues in the Lake Tahoe Region and beyond.

SECTION ONE

INTRODUCTION

PURPOSE STATEMENT

PROJECT OVERVIEW

SECTION ONE: INTRODUCTION, PURPOSE STATEMENT

Sediment delivery to watercourses throughout the Lake Tahoe Basin is a known contributor to water quality degradation. However, efforts to keep sediment from entering Lake Tahoe have met with mixed results. Such efforts have included a wide range of treatments such as installation of curb and gutter, drainage pipes, settling ponds and revegetation treatment. Very little site-specific monitoring has been done on any of these treatment types and therefore it is not well known how effective these projects have been on any timescale. Assessing the 'success' of revegetation projects has been especially problematic for a number of reasons. One of the primary difficulties in assessing or improving erosion control projects is the lack of a robust monitoring program that is linked to project goals. This project (the Cave Rock Monitoring Project) attempts to address the current monitoring limitations by developing and/or identifying a functional set of monitoring protocols within the context of adaptive management. These protocols can be used together or individually to answer specific project-related questions. The Cave Rock Monitoring Project attempts to achieve the following goals:

1) Develop and identify monitoring protocols that can be used to assess sediment source control projects in the Lake Tahoe Basin (Monitoring Protocol section)
2) Identify a user-accessible process within which those protocols can be used (Adaptive Management section)
3) Develop specific success criteria against which monitoring data can be compared (Success Criteria section)
4) Develop a partial knowledge base relative to sediment source control (Literature Review section)
5) Identify the current state of the art sediment source control practices
6) discuss recent progress in project approaches and planning

Note that one of the main purposes of monitoring is usually to determine whether a particular site has the potential to erode or not. We usually monitor indirect indicators of erosion rather than erosion itself since direct measurement of erosion in practically impossible to achieve in a realistic manner.

PROJECT OVERVIEW

Cave Rock Erosion Control Project

1) **Description of project**

   The Cave Rock Erosion Control Project was initiated in 1999 as a partnership between the Nevada Division of State Lands, The Nevada Tahoe Resource Conservation District, Cave Rock General Improvement District, KB Foster Civil Engineering and Integrated Environmental Restoration Services (IERS). This project was considered extremely difficult in that it consisted of large, steep, eroding cut slopes that had been treated previously in 1991. Very little stabilization had occurred and during large thunderstorms, sediment was observed to run from the slopes and along the existing curb and gutter toward the waters of Lake Tahoe.

Figure 1.1: Aerial view of Cave Rock and Cave Rock Estates to the right of Cave Rock

a. Initial Adaptive Management Process

In 1999, IERS-applied soil restoration test plots were installed at Cave Rock slopes 4, 5 and 8 (see map) in an attempt to determine whether stabilization could in fact, take place on these steep, barren sites. In 2000, Cave Rock GID, NTRCD, KB Foster, Douglas County and IERS met on site to assess the outcome of the test. The group decided that since the initial test plots were, in fact, stabilizing slopes 4, 5 and 8, the project would move forward into full planning and construction, using the approach already developed and the lessons learned during construction of the test plots. This approach set the groundwork in developing an adaptive management process for this project.

b. Construction specifications and construction

Specifications were prepared during the summer, fall and winter of 2000-01. Construction began during the summer of 2001. Construction specifications are included in Appendix A.

c. Follow up treatment and monitoring

This project was unique in that it included a three year soil-vegetation treatment element. Unlike many projects that include a plant replacement clause, we believed that the primary protection against erosion is found in the soil and soil surface elements. We therefore included a follow-up clause for the revegetation contractor that may be used as a model for other projects. When the project was initially bid, it included unit prices for most of the soils-revegetation treatments. We also included set amounts of funding for year 1 and 2. This money was to be used for follow-up work that the soils-revegetation inspector deemed necessary. During year 1 and 2, the inspector met with the erosion control contractor (Rob Kay from R&K Erosion Control Company) and directed him to perform specific tasks. This approach proved to be highly effective in that we were able to resolve some small problems before they became larger issues.

d. Specific lessons learned, observations

i. **Initial soil stability**: During August of 2001, a summer thundershower occurred along the East Shore of Lake Tahoe. On the way to inspect the Cave Rock project, as I drove along the east shore, a great deal of sediment was apparent along the road edges and onto the road. However, upon reaching the Cave Rock project area, there was absolutely NO MOVEMENT of soil from the recently treated areas, ***even though the treatment area did not have any vegetation yet established***. Rainfall estimates of 0.75 to 1.25 inches per hour were described. This outcome clearly suggested that loose soil will not necessarily slump, fail or otherwise move downslope in rainstorms that do not saturate the soil. It has been observed that loose, uncompacted soil is less likely to saturate and more likely to encourage through-flow of rainfall during these brief summer showers. Observations on other projects suggest that during the winter season, saturated conditions can result in mass failures when unconsolidated soil is combined with lack of plant growth. In this case, no plant growth was evident since the project had been completed approximately one week earlier. (Note that on site 8.1, germination took place from this single rainstorm prior to the beginning of irrigation.)

ii. Irrigation: Irrigation was essential for stability of the steep slopes of Cave Rock. However, due to watering late into the season, as late as October, root development was very low and shallow. Since roots did not need to penetrate deeply into the substrate to seek out water, during the second season, roots had apparently not stored enough starches and many of the grasses did not reemerge. We would not recommend irrigating past September and would recommend reducing irrigation cycles and volumes beginning in September.

iii. **Follow-up treatment**: Follow-up treatment resulted in a number of highly effective, small fixes throughout the project. Most of those fixes were required due to incorrect construction (tilling not deep enough) or to rodent or pet damage. We found that ground-dwelling rodents produced a great deal of disturbance, especially below the pine needle wattles which they used as protection and as runways. Ground-dwelling rodent populations seemed to swell rapidly following construction due to the establishment and/or enhancement of their habitat. We have concluded that follow-up treatment is a critical element of projects such as this one and can successfully be written into contracts, as was done here.

iv. **Initial stabilization:** Initial stabilization, provided by grass roots, is thought to be essential to steep slope erosion control projects. This project has been shown that the soil strength, usually provided by compaction, can in fact, be provided by plant roots on slopes over 1.5 to 1 if sufficient soil material is present. In areas where the bedrock is exposed, ongoing erosion is taking place. In areas where plants were initially able to grow, even when those plants were not alive in subsequent seasons, the root network provided continued stabilization and allowed other plants to move in and add to the diversity of the vegetation community.

v. **Replanting/second season planting**: We found that placement (planting) of plants may be most effective during the season following initial seeding. This is due to the fact that seeding is not completely even and in year 1 (the season following treatment), some areas may not exhibit as much growth as others. These bare, un-vegetated areas provide perfect sites for placement of seedlings since competition is reduced for both nutrients and water. Grasses are highly competitive and it is believed that this competition may be responsible for the lack of establishment of seedlings on marginal sites.

2) Description of monitoring done

The following types of monitoring were employed in this project:

a. Cover point monitoring for vegetation and mulch

b. Soil nutrient sampling for nutrient sustainability

c. Penetrometer monitoring for soil density, infiltration

d. Solar exposure

3) Project outcome

a. Summary of data, high points

i. Time of plant monitoring is important; monitor at peak standing biomass of the dominant species

ii. Soil moisture is important in understanding penetrometer data; measure soil moisture and soil density

iii. Some sites met proposed success criteria, others did not.

iv. Follow up treatment will be critical for those areas not meeting success criteria

v. Soil nutrients are likely low in some sites, suggesting that robust plant growth may be limited.

vi. Soil depth is shallow. More depth (12-18”) would have been preferable. However, in this project, conservative soil depth was chosen due to the uncertain nature of soil stability.

vii. Soil stability has been extremely high, suggesting that more soil depth would have been possible on this and similar sites.

viii. Soil stability has been compromised by ground dwelling rodents such as gophers and ground squirrels. These rodents use wattles as runways and shelters, concentrating disturbance directly below those wattles

ix. Ants have been extremely active in some of the project areas. Ants and ground dwelling rodents are key species in an ecosystem suggesting that, while they create short term disturbance, this project area has increased habitat for those groups of organisms. The bio-turbation or soil mixing that has resulted from these organisms is known to be a critical element of soil ‘tilth’.

b. Monitoring lessons learned

i. ***Time of monitoring***: we monitored during several different time periods from May through August. The data and site observations strongly suggest that time of monitoring should be directly tied to plant growth stage. That is, monitoring should be done during peak standing biomass (PSB) of the dominant species and that this stage will occur at different times for different sites. For instance, on site 8, a very different cover level was observed on the north side of this site in June from that which was observed during August due to the different aspects and thus the different growth periods. The north side was snow covered until May while the south side was snow free much of the winter, resulting in quite different maturity times. If both sides of this site were monitored at the same time, perhaps June, the northerly exposure would generally have its cover underestimated. We have further discovered that with the type of grasses grown, it may be possible to monitor after maximum standing biomass has occurred since many of these grasses remain standing and appear much the same as they do at PSB. This assumes, of course, that little or no grazing occurs. Due to the large amount of monitoring that may need to occur during a season, this may provide a wider window of opportunity for monitoring duration.

ii. ***Measurement of mulch***: one misleading numerical value for cover monitoring is the amount of mulch listed. It must be mentioned that the amount of mulch that is measured is the result of not measuring a plant for a given cover point measurement. However, with the type of single layer cover monitoring that we do, if we encounter a plant measurement, or 'hit', we do not also measure what is under that plant, resulting in a gross underestimate of total mulch cover. This can be rectified by a more complex, dual layer monitoring process. However, in an attempt to define a simple monitoring procedure, we do not recommend using this type of monitoring at this point.

iii. ***Importance of vegetation cover monitoring***: while this project has been progressing, other related projects using a rainfall simulator have shown that vegetation cover does not always assure a reduction in erosion. For that reason, we suggest that cover point monitoring be used where total vegetation is of primary importance. And while it is not within the purview of this project, it seems likely that other types of monitoring beyond cover point may be more effective in directly addressing whether a site has the potential to erode.

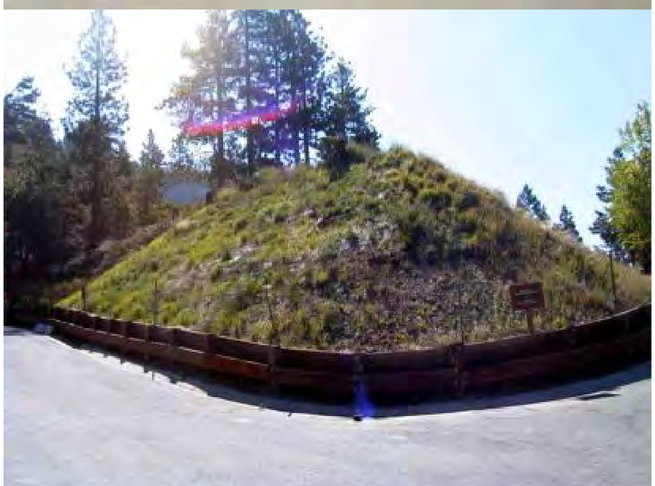
iv. ***Potential for soil density/penetrometer monitoring***: related research has shown that penetrometer measurements, which assess soil density, have proven extremely useful as indicators of infiltration. Infiltration is a primary variable in the erosion process. Linking penetrometer measurements to future monitoring will likely provide a more cost effective method to assess erosion potential, especially when linked to other monitoring elements such a plant and total much cover and soil nuteints.

c. Suggested protocols for future projects

i. Reduction in importance of plant/vegetation cover monitoring

ii. Penetrometer/soil density measurement as surrogate for infiltration

iii. Simulated runoff as direct measurement of surface erosion potential



Figs 1.2, 1.3, 1.4: before and after photos of Cave Rock site 8

PROBLEM STATEMENT

Programmatic limitations

Revegetation holds a great deal of potential for stabilizing eroding and disturbed areas throughout the Tahoe Basin. However, revegetation practices have met with poor to moderate success over the past 25 years in the Lake Tahoe Basin and elsewhere in the arid, mountainous West (Benoit and Hasty 1994). During the past twenty-five years there have been a number of studies aimed at answering specific vegetation-related questions in the Lake Tahoe Basin (Edmunson 1976; Kay 1976:p 16; Kay 1988:pp 268-272; Leiser et al. 1974; Nakao et al. 1976; SCS 1975; White and Franks 1978). Unfortunately, these studies are not widely known and have limited availability as well as applicability. These studies by and large use an agricultural (dose response) approach to revegetation (see literature report for a complete discussion of 'dose response'.) Recently, an increasing emphasis has been placed on addressing revegetation projects in a different context: that of a 'natural' or in-tact wildland system. For instance, native, undisturbed sites are known to minimize runoff, maximize infiltration and control erosion while supporting self-sustaining plant communities. However, until recently, revegetation practices on drastically disturbed sites in the Tahoe Basin have generally not been able to produce outcomes that approximate native conditions. The purpose of this program is to develop a process whereby revegetation/sediment source control and upland restoration projects can provide outcomes that not only reduce sediment yield, ideally to background levels, but also to ***quantify*** that reduction. The ability to measure potential sediment reduction on source control projects moves us beyond opinion-based statements and proclamations to a more sound, scientifically-based position. The application of scientific principles within an adaptive management context will move us (and is moving us) into a new phase of water quality and ecosystem protection. We hope that this program report will assist in these efforts.

Types of Studies

A great deal of essential research has been carried out in the Lake Tahoe Basin that has attempted to identify water quality conditions and causes of water quality and ecosystem degradation (See Goldman and related studies). Studies aimed at solving problems are far less common. For instance, the Claassen and Hogan 1995-96 study was the first to look at nitrogen pools throughout the Basin as a foundation for restoration of disturbed systems (Claassen and Hogan 1998). Further work with Caltrans and others by Claassen, Grismer and Hogan (various, and in prep.) have moved restoration and revegetation evaluation and field practices into a more science-based realm. However, a great deal of work remains to be done. This report first identifies limiting factors of past attempts at revegetation and second identifies suggested paths for improvement.

LIMITATIONS OF PAST PRACTICES

Lack of full consideration of erosion principles

Most past revegetation practices have been based largely or solely on the establishment of vegetation to the minimization or exclusion of soil parameters. However, erosion is widely understood to be a soil-based issue with plants playing an integral role. Since sheet or overland flow (and associated gully and rill formation) is the result of limited infiltration into the soil[1], soil physical factors such as infiltration, surface roughness, mulch cover, aggregate content and organic matter content tend to play major roles in the reduction of or protection against erosion (see literature report).

This document provides a summary report of scientific literature that describes these issues and helps establish a clearer understanding of erosive forces and the elements within a soil-plant ecosystem that provide protection against those forces.

Expert Opinion

Attempts to establish vegetation on previously disturbed sites in the past have proceeded largely without a framework for improvement or even direct accountability by any parties involved. Much of what is thought to be ‘known’ or understood about erosion control and revegetation practices is based on so-called ‘expert opinion’, provided by consultants, practitioners, product manufacturers/suppliers and even scientists. It is likely that this dependence on expert opinion has limited progress toward more effective practices, since not only has expert opinion seldom been held to a standard of any sort of scientific rigor, but often also is resistant to change and adaptation to new ideas and new science.

Lack of a Programmatic Approach

There has been no programmatic approach to improvement of revegetation practices and since expert opinion and lack of accountability have been the mainstays of revegetation practices, little attempt has been made at developing a program of improvement. In 1999, Caltrans, the Lahontan Regional Water Quality Control Board, the UC Davis Soils and Revegetation Group and Integrated Environmental Restoration Services joined to initiate the development of cover point monitoring protocols to measure revegetation outcomes and in 2000 Caltrans and UC Davis, building on that foundation, began an aggressive program of improvement called the Demonstration and Development Program. This document builds from that foundation and describes the application of that program to a built project, the Cave Rock Erosion Control Project.

Defining ‘Success’

It may seem odd that ‘success’ would need to be defined and yet the lack of a clear and widely accepted standard (or standards) of success may be a key limiting factor in

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[1] More specifically, overland flow results when precipitation rates exceed infiltration rates. Infiltration tends to be severely limited on highly disturbed, compacted or otherwise impacted soils.

revegetation practice improvement. Without a common understanding of what success is, one individual may deem a project successful while another may regard it as partly successful or worse. A number of disagreements regarding this issue have developed over the years, most likely because no clear or commonly accepted definition of success has been articulated. It must be noted that success criteria will be somewhat subjective and so will need to be defined in an inclusive manner. Furthermore, it is critical that success criteria be linked directly to the goals of the project or process (Cummings 2003, 4:S79-S82;Hobbs 2003, 4:S2-S3). The ability to articulate measurable success criteria for sediment source control projects is an essential foundation for moving those projects toward a higher level of effectiveness. To paraphrase a common saying: “If you don’t know where you’re going, any road will get you there!” These issues are discussed in greater detail in the Adaptive Management section.

Numerical Monitoring Protocols

Once success criteria are understood and agreed upon, these criteria need to be measured in such a way that observer bias is minimized. This approach to sediment source control project evaluation has not been used widely in the Tahoe Basin or elsewhere in the Sierra Nevada. Most of the so-called monitoring has been done by visual observation and is usually interpreted by an individual involved in designing the project. This sort of visual evaluation is highly prone to bias, as is demonstrated in the Monitoring section.

Follow-up treatment

Most erosion control projects that have been built in the Lake Tahoe Basin have not had any meaningful follow-up treatment. Typically, replanting to meet some survival criteria is the extent of follow-up. No attention has been paid to slope failure of other types of issues that commonly occur on newly constructed projects. This situation may be closely linked to the lack of accountability.

Solutions

This document and associated Adaptive Management Monitoring Program attempts to address these issues and offer solutions to them.

SECTION TWO: MONITORING IN AN ADAPTIVE MANAGEMENT CONTEXT

DEFINITION

Adaptive Management can be a powerful process for addressing erosion control and other environmental issues. Considerable attention has been paid to the concept of Adaptive Management recently. However, there is still a great deal of confusion about what exactly ‘adaptive management’ is and how it relates to monitoring. Adaptive Management has a dual nature. **First**, Adaptive Management is a philosophical approach toward resource management that acknowledges the fact that we do not completely understand the system that we are dealing with. It acknowledges that we must proceed with a project or program using existing information while we gather the knowledge that we lack. **Second**, Adaptive Management is a structured decision-making process that includes the following components, usually in stepwise fashion:

1. Clear articulation of project goals, outcome or success criteria
2. Collection of existing knowledge and practices relative to achieving that goal or those goals
3. Identification of information gaps and related research needs
4. Well-defined strategy to applying knowledge and relevant practices toward achieving that goal or goals
5. A clearly-defined and defensible monitoring program to determine whether that goal or those goals are being achieved
6. A pre-defined management response or responses if those goals are not met.

Given this definition of Adaptive Management, the need for monitoring becomes apparent. If we are to consistently improve sediment source control/revegetation projects, we must have a set of measuring tools that are precise within stated limits and are reproducible within those same limits. The following model illustrates graphically, the cycle of adaptive management and the function of monitoring within that model:

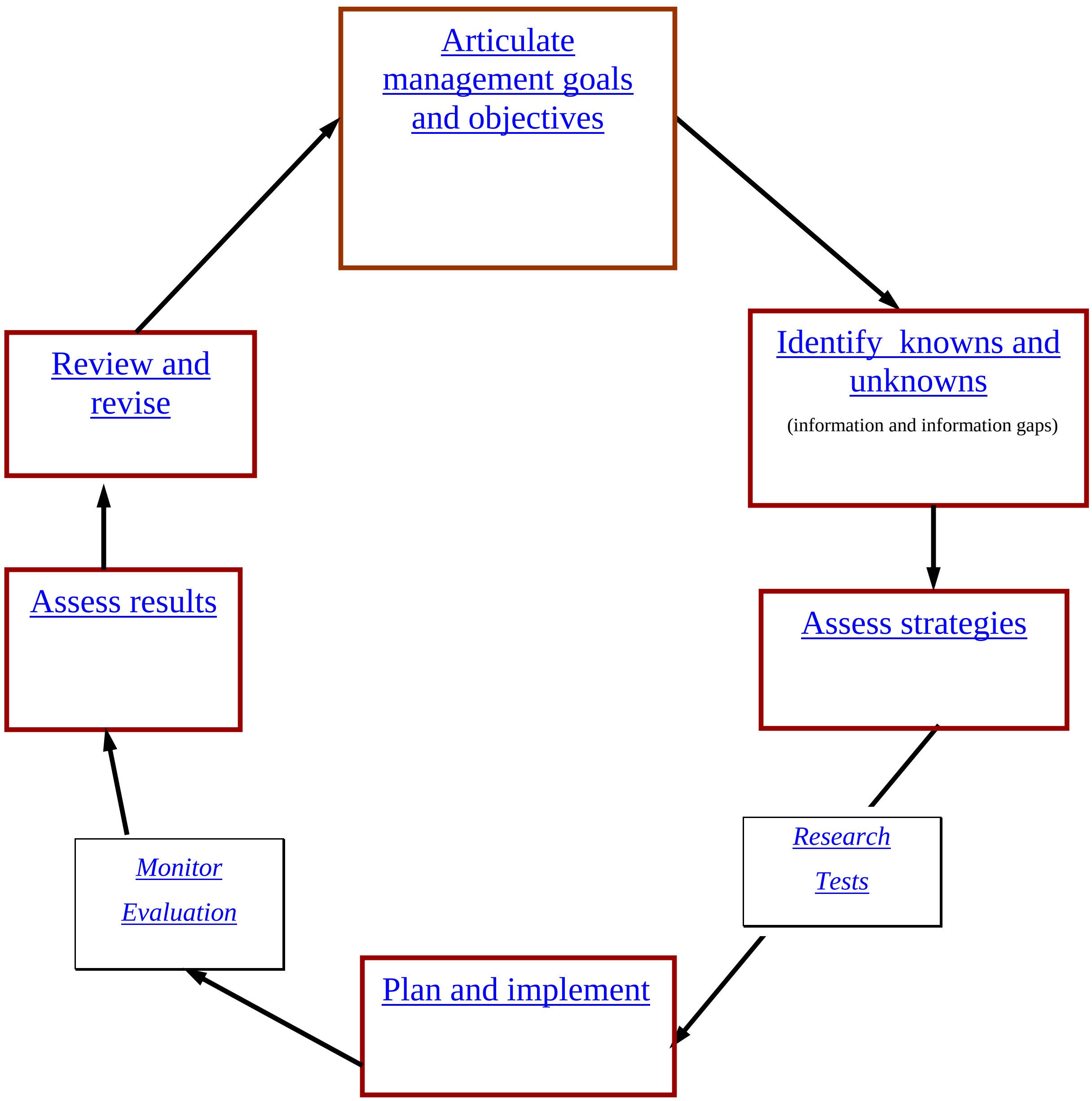
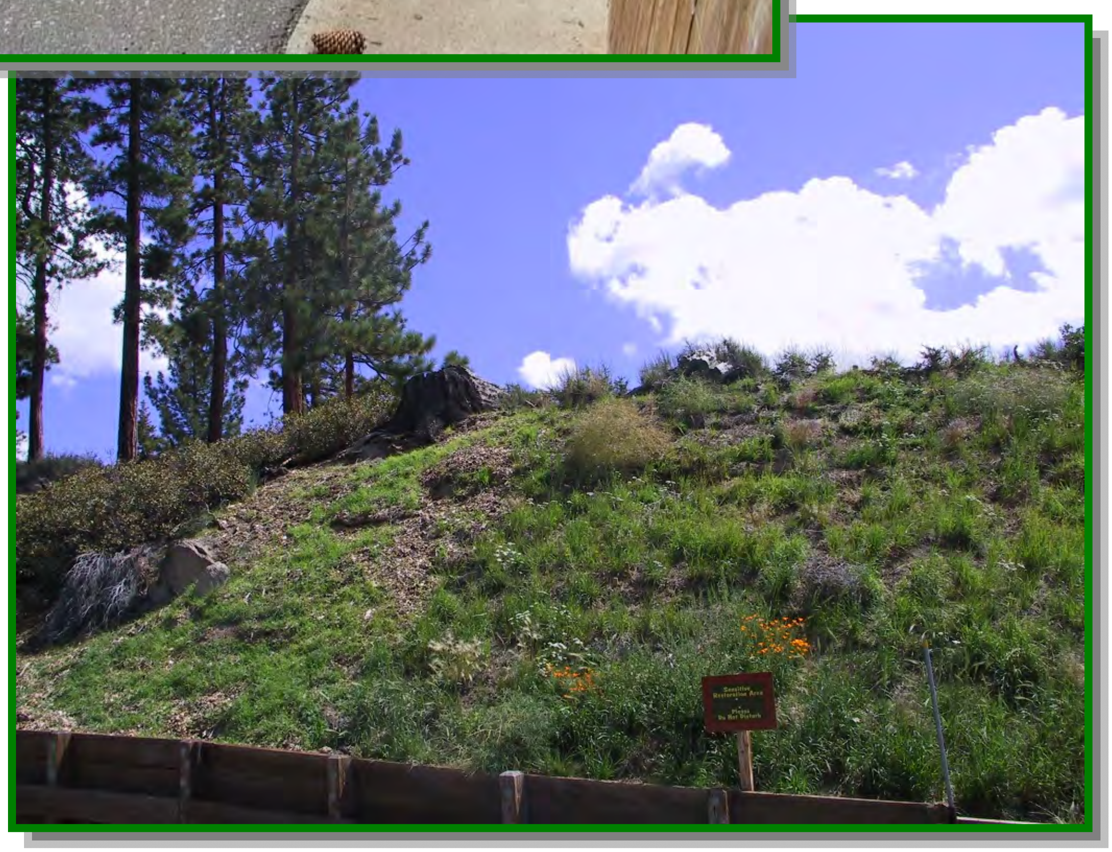


Figure 2.1: an adaptive management model (adapted from The Nature Conservancy with Craig Thomsen).

SECTION THREE: LITERATURE REVIEW:

EROSION, SEDIMENT SOURCE CONTROL



SECTION THREE: LITERATURE REVIEW: EROSION, SEDIMENT SOURCE CONTROL

ABSTRACT

Erosion and sedimentation are pervasive processes that are associated with land disturbance in all parts of the world. Most development is associated with a high level of ground disturbance. In order to effectively address the control of erosion and sedimentation in these highly disturbed sites, thus protecting water quality and other beneficial uses, information regarding (and understanding of) physical and biological processes will be of critical importance. This report discusses processes, paradigms and practices and is intended to offer the planner and practitioner with enough information to adequately plan and implement a revegetation, erosion control or water quality improvement project. Erosion and sedimentation include a number of related processes that involve movement of soil and organic matter particles from one landscape position to another. Site disturbance severely accelerates this process and often results in degradation of habitat, water quality and other environmental elements. Most of the currently accepted ‘erosion control’ practices, based on models such as the Universal Soil Loss Equation, focus largely on the ‘C’ or cover factor. Thus, emphasis has been placed on plants or ‘revegetation’ as the primary solution to erosion control on disturbed sites. This document presents a literature review that develops a conceptual and practical approach to erosion control based on *functional ecosystem processes* with ***time*** as a critical component. We define terms, describe processes and treatments (tools) and suggest a functional approach to control of erosion. Our framework for this approach is from an ecosystem rather than a point in time, agricultural approach. Sustainable, effective restoration of highly disturbed sites such as ski runs and road cuts will be dependant upon an understanding of how ecological systems function and what is required to rebuild those systems, once they are disturbed. The intent of this document is to help develop information about these processes and move standard erosion control practices toward developing stable ecosystems that are more sustainable, robust and functional.

LITERATURE REPORT OVERVIEW

This literature report is intended to be used to reference specific elements of erosion and erosion control. The content has been broken into three sections:

Section One: Erosion and Disturbance-A Conceptual Framework;

Section Two- Specific Erosion Issues and

Section Three- Control of Erosion-Approaches and Solutions.

Literature references are all placed at the end of the document.

INTRODUCTION

In addressing an issue as large and complex as erosion control, it is important to set a baseline for understanding. We need to determine what is currently known (what information is available), what we is not known and where information gaps exist. This is an essential element of the Adaptive Management cycle. Erosion poses a serious problem throughout the world. Any human-related ‘improvement’ or development is almost always associated with the potential for accelerated erosion and associated water pollution. This is especially true in mountainous regions where steep slopes and relatively young and/or poorly developed soils create ideal conditions for accelerated erosion once an area is disturbed. In order to take meaningful action to reduce or control erosion to acceptable levels, and thus protect water quality, it will be useful to develop an integrated, comprehensive understanding of what erosion is and what we currently know about controlling it. The goals of this report are:

1) to establish a common understanding of the main processes and variables which affect erosion

2) to describe some of the techniques or tools that can be used to ‘control’, reduce or limit erosion on disturbed sites and

3) to suggest where information is lacking so that further testing and experimentation can be identified.

Erosion is generally a ‘systematic’ or functional issue rather than a two-dimensional surface issue. That is, erosion is the product of an entire system of environmental interactions rather than simply the amount of plant cover on a site. When a system is ‘healthy’ or operating at a high level of function, erosion is likely to be low. When one or more components of the system have been disturbed, erosion is likely to increase. Background, or ‘natural’ erosion tends to take place in equilibrium with other watershed elements such as infiltration, stream flow, stream bank stability, vegetative community and so on. When disturbance takes place, this equilibrium is disrupted, resulting not only in increased sediment movement but in an increase in surface water flow, an increase in stream water volume and velocity, a decrease in steam bank stability and a decrease in watershed water storage (Selby 1993; Dudley and Stolton 2003). On a watershed-wide basis, accelerated erosion results in removal of watershed ‘capital’, or the carbon rich soil organic matter which drives so many important processes within a watershed. Carbon provides energy which drives ecosystem processes. Once this ‘capital’ is diminished, the ecosystem tends to function at a somewhat diminished level. While this function may be barely noticeable at small scales, when large areas such as roads or ski runs are developed, watershed function can be severely disrupted. When this happens, input and output erosion ‘variables’ are no longer in balance and often result in a downward spiral of ecosystem ‘damage’ or negative impacts (Daily, Matson, and Vitousek 1997).

DEFINITION(S) OF EROSION

The entire process commonly referred to as ‘erosion’ actually consists of two closely related processes: 1*)* **erosion**, or the *‘detachment or breaking away of soil particles from a land surface by some erosive agent, most commonly water or wind,* and 2) **sedimentation** or ”*subsequent transportation of the detached particles to another location”* (Flanagan 2002). It is important to understand the nature of these two processes since addressing them requires quite different techniques and approaches. Typically, controlling erosion requires keeping soil particles attached to one another and to the soil matrix. Native soils usually do this through the ‘aggregation’ process ((Kay and Angers 2002)) (see pg A-263 section 7.4.3). Soil aggregates are combinations of soil particles that are bound together. Typically this process is the result of physical and biological, especially microbial, processes (Horn and Baumgartl 2002). When soil is disturbed, aggregates tend to disaggregate, or come apart and are thus are more prone to erosion. Once soil particles begin to move, it is extremely difficult to capture fine silt and clay particles, which are typically responsible for a great deal of water quality pollution and degradation. Thus, this literature review focuses almost entirely on erosion or ‘sediment source’ control.

PART ONE

EROSION AND DISTURBANCE: A CONCEPTUAL FRAMEWORK

Section Overview: This section describes several concepts related to erosion. We discuss the concept of 'drastic' disturbance, sediment source control, wildland restoration, briefly discuss the state of erosion control knowledge and describe the world wide and specific extent of the erosion problem.

Drastic Disturbance as a defining concept

'Drastic disturbance' has been defined by Box (1978), as areas where "…the native vegetation and animal communities have been removed and most of the topsoil is lost, altered, or buried. These drastically disturbed sites will not completely heal themselves within the lifetime of [a person] through normal secondary successional processes." Drastically disturbed sites are typical of treatment areas that we must typically deal with, such as ski runs, road cuts and fills and building sites. These areas must be considered as functionally and biogeochemically distinct from the pre-disturbance (native) site condition and treatment must focus on restoring structure and function, especially in the soil, if long-term sustainable solutions to erosion are to be implemented (Kay and Angers 2002; Torbert and Burger, 1994; Torbert and Burger 2000a; Bradshaw 1992a; Whitford and Elkins 1986a). While some sites may be lightly disturbed and may subsequently support vegetation, drastically disturbed sites most often require soil amendments and tilling or loosening of soil.

Sediment source control vs. treatment

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

An innovative program has begun within the Lake Tahoe Basin, California and Nevada, where a consortium of entities, led by the California Tahoe Conservancy, have taken a significant step forward by developing what are being termed "Preferred Design Guidelines" (CTC 2002) which suggest that in project planning and implementation, the following design criteria are considered in this order of importance:

1) sediment source control
2) hydrologic design and function
3) conveyance and treatment.

This approach assumes that keeping sediment on site and in place is clearly more effective (both from a cost and environmental standpoint) than attempting to capture and treat it downstream. This approach is the outcome of an understanding that probably the most cost effective method of reducing sediment is to assure that it doesn't move in the first place.

A Dose-response (agronomic) vs 'capitalization' (wildland) approach to Erosion Control and Restoration

THE CONCEPT

It may be useful at this point to differentiate between agricultural and 'ecological' or wildland approaches to revegetation, erosion control and restoration. The two main approaches may be termed '**dose-response'**[2] and **wildland**. Dose-response describes what occurs in both agriculture and landscaping projects where fertilizer, water and other 'doses' of certain inputs are applied with an expected, short term response. Dose response systems can be seen for instance in a corn field or an urban lawn. A wildland approach is based on the concept of a one-time investment or re-capitalization of a disturbed site and attempts to take into account the overall ecological context of the project and the interactions between ecosystem elements. The desired outcome of a wildland treatment is typically a no- or low-maintenance, self-sustaining site. We therefore suggest that in order to be effective over the long term, erosion control implementation must be designed to be sustainable[3]. If this is the case, it is clear that addition of adequate amounts of materials as well as physical manipulation must take place in order to 'capitalize'[4] or 'invest' the system with nutrients as well as physical 'capital'.

A FUNCTIONAL APPROACH

The ability to develop and apply effective erosion control techniques and materials will depend to a great degree upon an adequate understanding of the processes of erosion over ***time***. If an erosion control practice is to be effective, it must directly address one or more of the processes (or variables) that are involved in erosion. For many years, plant cover (revegetation) alone has been used as a measure of erosion control effectiveness. While plant growth can be forced, through the ongoing use of adequate water and nutrients, the literature summarized here strongly suggests that: 1) an erosion resistant landscape is the result of a robust and well-functioning soil-plant ***system*** and 2) the effective control of erosion on disturbed sites depends to a large extent on re-creating and re-integrating ecosystem ***function***. Cummings (2003a) suggests that when assessing restoration or site 'success' we look not primarily at structure (the makeup of the physical plant community) as much as the essential functional elements such as nutrient cycling, infiltration (hydrologic function) and energy capture (plant growth/carbon storage) on those sites. This approach is gaining popularity since it is becoming more apparent that while a site may 'look' good, visual interpretation is prone to individual bias and that bias is largely dependant upon levels of training and experience, which

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

[3] An exception to this approach may be found where continual input and maintenance is planned. However, that is not usually practical or cost effective for most situations.

[4] The terms 'capital' or 'capitalization' are used to denote ecosystem capital such as organic matter, carbon, or other elements which drive the system, much as monetary capital drives economic systems.

varies widely between individuals. Further, simple visual observations cannot discern internal function such as infiltration or nutrient content of the soil and it is these two latter elements which drive so much of the erosion process.

State of Erosion Control Knowledge

It is important to discuss the existing state of 'knowledge' regarding erosion control. Some discussion of the existing state of knowledge has been described above (see introduction, this section). There has been a great deal of information put forth over many years regarding erosion and its control. Unfortunately, some portion of that information may be inadequate for planning and implementing erosion control projects. We suggest at least four reasons for this situation, based on Sutherland (1998a, 1998b) and {Benoit & Hasty 1994} :

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

2) **Site specificity**: studies and tests that are done somewhere else in different climates, soil types and types of disturbance may not be relevant to sites in the Sierra Nevada or the arid west.

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

4) **Time:** most studies are not considered over an extended, 3-10 year time period. Even Sutherland has only suggested that studies be more rigorous but does not consider ***effectiveness over time***. This is likely to be a critical consideration when designing and assessing projects, especially where soil restoration is important (Richter and Markewitz 2001; Bloomfield, Handley, and Bradshaw 1982a).

EXTENT OF THE PROBLEM

A primary question for consideration is how important or pervasive the erosion issue really is. One often hears the comment "But isn't erosion a natural process?" Several sources were considered in attempting to answer this question; According to Gray and Sotir (1996a) annual sediment yields for the US range up to at least 2 billion tons per year. Of the total amount eroded, about one-fourth to one-third reaches the ocean with the rest being deposited in flood plains, river channels, lakes and reservoirs. They report that "siltation and nutrients (nitrogen and phosphorus) from erosion impair more miles of rives and streams than any other pollutant (USEPA).

Erosion rates range from a low of 15 tons/mile^2/year for natural or undisturbed areas to a high of 150,000 tons/mile^2/year for highway construction sites, or a maximum difference of ***10,000 times*** (US EPA 1973). According to Scheidd (1967), roads may be associated with erosion rates 10-50 times above background. And according to Wark and Keller (1963), "Exposure of soil during the construction period can result in sediment production equal to 10 times the rate from cultivated land, 200 times the rate from a grassland and 2000 times that from forest land."

The California State Division of Soil Conservation found that roadways in the South Lake Tahoe area were the source of 78% of the total for sheet and road erosion. Further, they noted that "Ski slopes that are established by clearing mountainsides have marred the landscape and created erosion problems at the Heavenly Valley ski area in South Lake Tahoe. Erosion and land scars are noticeable, even though considerable effort has been expended to establish vegetation on the sterile granitic soil" (Resources Agency 1969)

Grismer and Hogan, in Tahoe specific research, found erosion rates on disturbed sites to be up to 530 times greater than similar native areas (Grismer & Hogan 2004; Grismer & Hogan In Press).

PART TWO

SPECIFIC EROSION ELEMENTS

This section describes and discusses elements or variables that are associated with erosion. These variables help define whether and to what extent erosion may occur on a given site. Erosion is dependant upon the level at which these variables are functioning. In other words, each variable will have an effect on erosion rates and when more that one variable is impacted, erosion is likely to increase. Some variables are obvious and others are more subtle. Figure 1 lists the various types of erosion, what they are caused by and what influences them.

TYPES OF EROSION

Water (liquid and frozen) erosion

Erosion is generally split into two categories: (liquid) water and wind. A third type of erosion, which is also related to water is referred to as 'frozen water' or 'winter' erosion, which includes snow and snowmelt erosion and frozen soil or 'freeze-thaw' erosion (McCool 2002).

Liquid water erosion is the most commonly cited and possibly best understood type of erosion. The linkage between this type of erosion and water quality is logical and relatively obvious. Classic splash detachment, transport, sheet flow, rill and gully concepts are part of the process known as water erosion. These and related processes are well understood. A great deal of literature has been developed to describe these processes such as in Torri and Borselli (Torri and Borselli 2000; Le Bissonnais and Singer 1993; Moore and Singer 1990; Wischmeier and Smith 1978) and many others.

This document will not describe these processes in depth since they have been well described elsewhere. An excellent and complete description of types of erosion and erosion processes is given by Gray and Sotir (1996a) in Biotechnical and Soil Bioengineering Slope Stabilization (pgs 19-30).

Table 3.1: types of erosional processes, their causes and influencing factors

Process	Cause	Influenced by
Splash detachment	Rain drop impact	Amount, size of droplets
Shear detachment	Surface flow	Amount of water
Freeze detachment	Water expansion upon freezing	Amount of water in soil, surface cover, air temperature, cloud cover
Transport	Water velocity	Amount and speed of water
Deposition	Slowing of water; filtering of water; exceeding waters capacity to suspend particles	Velocity change, filtration mechanism
Mass failure, rotational failure	Differential soil densities, sliding layer, differential pore pressure	Can be influenced by oversaturation of one layer relative to another

Freeze thaw

Soils subject to freeze/thaw conditions have different processes affecting erosion and runoff measurement. Edwards and Burney (1987) used a laboratory rainfall simulator to test three Prince Edward Island agricultural soils (varying in soil texture) for runoff and splash volume and sediment loss under varying conditions of freeze/thaw, ground cover and erosivity. With bare soil, freeze/thaw significantly increased sediment loss by about 90%. Using the same procedures, Edwards and Burney (1989) examined the effects of freeze/thaw frequency, winter rye cover, incorporated cereal residue, and subsoil compaction on runoff volume and sediment loss. Wooden soil boxes were subjected to simulated rain at the end of a 10-d freezing period, and (ii) at the end of the 5th 24-h freezing period of a 10-d alternating freeze-thaw cycle (freeze-thaw). Where the soil was continuously frozen for 10 d, there was 178% greater sediment loss and 160% greater runoff than with daily freeze/thaw over the same period, but there was no difference in sediment concentration. Incorporated cereal residue decreased sediment loss to 50% and runoff to 77% of that from bare soil, suggesting that mulch can significantly reduce erosion in freeze-thaw conditions.

Figure 3.1: Freeze-thaw erosion showing detached soil particles

Winter rye cover decreased sediment loss to 73% of that from bare soil. Simulated soil compaction caused a 45% increase in sediment loss. The loam soil showed 16.5% greater loss of fine sediment fractions >0.075mm than the fine sandy loam which showed 23.4% greater loss than the sandy loam. (Wilkinson, Grunes, and Sumner 2000b) Figure 1 shows a soil in the freeze portion of the freeze thaw cycle. Note the detached soil particles that have been detached and suspended by ice columns. When the ice melts, it will most likely flow overland, resulting in a high rate of sediment movement since all the soil particles are already detached.

Wind Erosion

Little research is available regarding the amounts and types of wind or frozen water erosion in the Sierra Nevada or other resort regions, even though the bulk of precipitation falls as frozen water (snow) in these resort regions. Further, wind may represent a more insidious (and effective) erosive agent on bare, disturbed areas than water. Evidence indicates that wind erosion is significant and can have devastating effects on soil quality, soil nutrient cycling and long-term soil productivity as well (Fryrear 2000a; Leys 2002; Stetler 2002a; Fryrear 2000b; Stetler 2002b). According to Fryrear, (2000a) “While the transport capacity of the wind is much less that that of water, wind erosion can remove the entire nutrient-rich soil surface regardless of field size or location.” Thus, wind erosion can be a highly effective degradation variable that should not be overlooked. Further, wind is less noticeable but possibly more constant that water erosion. Each time a gust of wind affects a bare area, the soil moved can, over time, be significant since it will be ongoing over an entire dry season.

Mass Failures

Mass failure involves a downward and outward movement of soil on a slope. According to Gray and Sotir (1996) “…mass movement [of soil] involves the sliding, toppling, falling, or spreading of fairly large and sometimes relatively intact masses.”(pg 20) Mass failure usually occurs along a failure plane, is the result of loss of shear strength and is exacerbated by positive pore pressure within the soil itself. Mass failures may be controlled, reduced or eliminated by plant roots. Mass failures have the potential to do a great deal of damage in a short period of time. Mass failures include rock falls, rotational slides, translational slides, lateral spreads, flows and

Figure 3.2: This photo of the American River shows a mass failure that blocked the river for some period of time. This slide is believed to be the result of lack of vegetation from a previous fire and defoliation efforts and from water associated with a 100 year precipitation event (1997)

creep. Figure 2 shows a mass failure that occurred along Highway 50 which crossed the American River and blocked the river. The damage that occurred to beneficial uses along the river has not been assessed but can only be considered major. This mass failure, which occurred on January 1, 1997 was partly the result of a forest fire and subsequent defoliation on the upland area adjoining the river. Several houses were completely destroyed. Property damage may have exceeded several million dollars. Ecological damage is difficult to estimate.

Colluviation

One other type of erosion that is not often discussed but may be significant on some bare areas is colluviation or erosion from gravitational forces. Saprolitic granite soils are especially prone to colluviation but all bare soils on steep slopes can be affected by gravity erosion. In fact, melt-freeze may act as the disturbing element that can make soil particles available for transport by gravity at some later time.

EROSION VARIABLES

The following discussion of erosion variables covers those elements which are known to effect erosion.

Soil Structure

Soil structure is defined as "The combination or arrangement of primary soil particles into secondary particles, units, or peds" (Brady and Weil 1996). Soil structure may be the most important element controlling erosion in upland sites since structure depends upon a great many physical and biological elements and processes (Kay and Angers, 2000). These interrelated elements include aggregate stability, infiltration, soil strength, pore space, soil density, water holding capacity, soil organic matter, plant growth and microbial 'activity'. Soil structure is a critical element of a sites predisposition toward erosion. According to Kay and Angers (2000): "Soil structure has a major influence on the ability of soil to support plant growth, cycle C and nutrients, receive, store and transmit water, and to resist soil erosion and the dispersal of chemicals of anthropogenic origin. Particular attention must be paid to soil structure in managed ecosystems where human activities can cause both short- and long-term changes that may have positive or detrimental impacts on the functions the soil fulfills". This statement and the research that supports it suggest very strongly that soil structure is of primary importance to control of erosion. When soil structure is severely disrupted (see 'drastic disturbance' Section One) that structure must be rebuilt if erosion is to be controlled. The following sections discuss some of the components of soil structure.

Infiltration

To the extent that water infiltrates into and through the soil, it does not run off (Radcliffe and Rasmussen 2000). In fact, runoff can be defined as the point at which water input exceeds the soil's capacity to absorb or infiltrate water {Eagelson 2002 #5100}. Infiltration is influenced by a number of factors including antecedent soil moisture, soil texture, surface relief, restricting sub-surface layers, organic matter, pore space and soil density (Battany and Grismer 20000; (Brady and Weil 1996; Radcliffe and Rasmussen 2002). High infiltration rates generally result in low runoff. Runoff rates and volumes are critical variables in the erosion process. Figure 3 shows a site in the Lake Tahoe Basin where the rainfall rate exceeded the infiltration rate and resulted in severe runoff. The erosion pictured occurred from one rainstorm that lasted for approximately forty-five minutes. The literature reported here as well as rainfall simulation underway in the Lake Tahoe area suggest that ***sediment source control projects will generally be successful to the extent that they can infiltrate water***. A primary goal of erosion control projects then, will be to develop a system of maximum, sustainable infiltration of water into the soil relative to a native and/or adequate reference site. This state of maximum infiltration is usually related to a high organic matter, low density soil and a robust, soil-plant community (Kay and Angers 2002).

Figure 3.3: This road cut photo illustrates lack of cover and infiltration capacity and resulting runoff.

Infiltration is heavily influenced by the density of that soil. Each 'native' soil has a density associated with it. Generally, the more dense a given soil, the lower the infiltration rate (De Vries and Craswell, 2002). When a soil is disturbed by any type of traffic, especially when wet, that soil becomes compacted, which essentially results in a higher density, lower pore space and a lower infiltration rate. The terms 'compaction' and 'high density' are used interchangeably although they are not always synonymous. A particular soil in its native or undisturbed state exhibits a particular density (also called 'bulk density') usually given in mass (or weight) per volume. (A soils bulk density is usually given in g/cm^3, kg/m^3 or Mg/m^3.) Once a site has been drastically disturbed and/or impacted with heavy equipment, that soils bulk density increases. This results in a loss of pore space. Lack of pore space results in increased runoff and thus increased erosion (Kay and Angers 2000; Radcliffe and Rasmussen 2000).

A compacted soil is by its nature high density. Subsoil and parent material tend to be high density by nature. In some cases where reconfiguration of a site results in subsoil being exposed, such as in a road cut or deeply incised ski run, soil density may be so high as to practically preclude infiltration. In all of these cases, some method of decompaction must take place if infiltration is to be increased to levels where plant growth can proceed and where runoff can be lessened.

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

Depth to restricting layer

According to Torbert and Berger :"Depth to a restrictive layer is an especially important physical property controlling productivity of trees [and by inference, other plants as well]. In a study to evaluate the effect of various mine soil physical and chemical properties…the most important mine soil property was rooting depth" (Torbert and Burger 2000b). While rooting depth is seldom considered in most erosion control projects, field experience and numerous measurements of unvegetated sites clearly suggests that shallow rooting depth is often associated with lack of vegetative. Two considerations for the connection between rooting depth and erosion are: 1) plants need a certain quantity of available nutrients and water. Water especially, is associated with the volume of pore space in a soil. A restricting layer tends to limit the amount of pore space in a soil, thus limiting water availability and 2) when water reaches a restricting layer, the infiltration rate is slowed, thus tending to saturate the soil. Two things can then occur. First, more water will flow over the surface as runoff and second, positive pore pressure in the soil and the different soil densities can tend to cause mass movements, such as landslides or other mass movements.

NUTRIENT CYCLING/SOIL ORGANIC MATTER

Soil organic matter has been linked to both establishment and persistence of plant communities in the Lake Tahoe basin and elsewhere (Claassen and Hogan 2002); (Baldock and Nelson 2002) (Reeder and Sabey 1987; Reeder and Sabey 1987; Bradshaw 1997a)as well as an increase in the soils ability to resist erosion. Torri and Borselli (2000) have found that "increasing organic matter content makes aggregates more resistant to sealing and consequently decreases runoff and erosion." And further "… those relationships indicate that soils with good granular structure (high Fe oxide and organic matter content) are less erodible. (pg G-189)". (McBride 1994) summarizes the functions of organic matter as follows: "In partnership with the clay fraction, organic matter has an extremely important influence on the chemical and physical properties of soils. Critical and beneficial functions of organic matter include:

1. Maintenance of good pore structure accompanied by improved water retention
2. Retention of nutrients (e.g. Ca2+, Mg2+, K+, NH4+, Mn2+, Fe3+, Cu2+) by cation exchange
3. Release of nitrogen, phosphorus, sulfur, and trace elements by mineralization[5]
4. Adsorption of potentially toxic organics (pesticides, industrial wastes, etc.)"

AGGREGATES

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

SURFACE COVER/MULCH

Cover:

Soil surface cover plays a critical role in not only erosion reduction but in other ecosystem processes as well. According to Pritchett and Fischer, "***Plant and litter cover***

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[5] Mineralization is the microbial process by which organic compounds are decomposed and carbon dioxide is released

is the greatest deterrent to surface erosion. The tremendous amounts of kinetic energy expended by falling rain are mostly absorbed by vegetation and litter in undisturbed forests. Disturbances caused by logging and other activities reduce infiltration rates and increase surface runoff and erosion."(Pritchett and Fisher 1987) pg 304).

Surface cover provides the following services:

- Reduces raindrop force (splash detachment)
- Reduces surface flow velocities (shear detachment of soil particles by both wind and water)
- Reduces evaporation (water loss reduction)
- Reduces radiation influx and efflux
- Increases soil nutrients (some mulches (Woods 1986)
- Increases seed germination at some levels (Molinar, Galt, and Holechek 2001)
- Protects soil from sealing and pore clogging (Singer and Blackard 1978).

Grismer and Hogan (in prep) showed that mulches alone could reduce soil erosion from bare slopes by an order of magnitude. However, the type, age and fiber length of the mulch material is important.

Plants

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

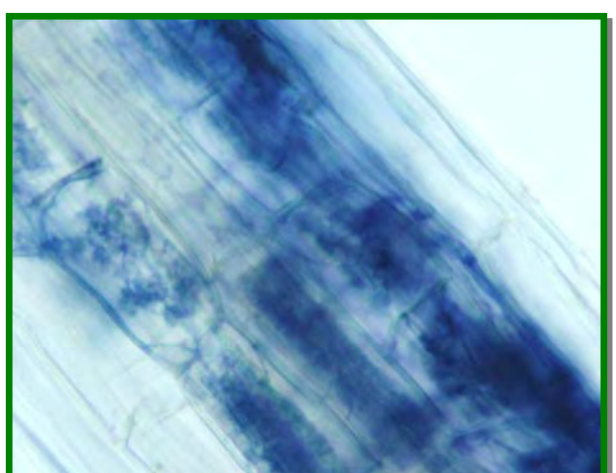

Figure 3.4: this scanning electron micrograph image shows mycorrhizal colonization in a plant root (photo courtesy of Dr. Vic Claassen, UC Davis.

While plants do play a number of essential roles in stabilizing soil and reducing erosion, plants alone do not always limit erosion to acceptable levels. (Elliot 2002a; Zhang 2002; Elliot 2002b).Grismer and Hogan, in recent rainfall simulation experiments on a range of cover types and amounts throughout the Tahoe region, found that plant cover did not always correlate with sedimentation rates and in fact, found that some sites with extremely high cover levels produced an extremely high erosion rate, similar to adjacent bare plots (Hogan 2004a).

Soil Microbial Communities/ Mycorrhizae

Microbial 'activity' is the chief driving force behind most soil function (McBride 1994); (Paul and Clark 1989a); (Reeder and Sabey 1987); {Huang & Schnizer 1986 }and {Whitford & Elkins 1986 }. Microbial populations are closely linked to and dependant on soil organic matter and soil quality, as discussed in earlier sections. The connection between the two cannot be overstated. Microbes contribute to nutrient cycling and availability, aggregate formation, erosion resistance, water holding capacity, disease resistance and so on. There are a number of microbial 'types' that coexist in the soil. A great deal is known about soil microbes and an even greater amount remains to be discovered. Soil microbes are grouped into broad categories of bacteria, actinomycetes and fungi. Soil microbial communities are known to convert most nutrients from an organic form into a plant available form (Blackmer 2000a; Killham 1994a; Paul and Clark 1989a; Tisdale and Oades 1982; Killham 1994b; Tisdale et al. 1993b; Buxton and Caruccio 1979b). In some cases, specific fungi are known to enhance uptake of both nutrients and water (Killham 1994a) (Allen 1991). These fungi are categorized as Mycorrhizal

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

Surface Roughness

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

Soil Surface Sealing/Pore Clogging

Surface sealing and pore clogging are two potentially related processes. When infiltration of water occurs, fine clays, silts, organic matter and other elements can contribute to clogging of pores. This process is especially related to splash detachment of fines and subsequent redistribution. In some cases, these fines are redistributed across the soil surface and subsequently dry into a hydrophobic layer called a soil crust. In other cases, this material makes its way into the soil and fills soil pores. In either case, the result is loss if infiltration and subsequent increase in overland flow and related erosion. (Moody 2002)

Predicting erosion

The ability to predict erosion has been important in designing and justifying many erosion control projects in the past. Erosion prediction is usually based on one or more currently used models. Many of the current model approaches to erosion control address erosion as primarily a surface phenomena. However, commonly used models such as the Universal Soil Loss Equation (USLE) and other related modes (RUSLE, CREAMS, GLEAMS, WEPP and so on), have proven inadequate to effectively predict erosion in wildland settings[6]. Therefore, these models may be misleading when used to quantify the impact of treatments such as plant cover, mulch treatment and so on. While models are useful as ways to envision erosive processes, a number of researchers suggest that actual control of erosion is likely to be enhanced by focus on physical processes in the soil and interactions between components than by focusing on model outputs (Bradshaw 1992a; Torri and Borselli 2000; Whitford and Elkins 1986a; Wilkinson, Grunes, and Sumner 2000a). For instance, Agassi suggest that “the successful design of soil conservation programs will be more easily achieved by studying the relationship between rainfall characteristics, sealing of the soil surface, and the ensuing decrease of infiltration rate than by studying and modeling erosion processes, as is currently being done.” (Agassi 1996). In the following section, we will address specific approaches to erosion based on ecological processes rather than model assumptions.

[6] Testing and calibration is being done to attempt to rectify this issue.

PART THREE

CONTROL OF EROSION: APPROACHES AND SOLUTIONS

Section Overview

This section describes and discusses various approaches and tools that can be used to control erosion. Rather than approaching erosion control as largely a ‘revegetation’ application, we describe the use of a ‘functional’ approach to erosion control and then discuss some of the basic considerations that sustainable, robust erosion control practices should be based upon. The term ‘functional’ refers to the various functions that exist in an ecological system. Many planners attempt to establish grasses and other plants on a highly disturbed site much as one would plant a lawn or pasture. However, recent research has clearly indicated that vegetation alone may not always be adequate to control erosion {Grismer & Hogan 2004 }{Grismer & Hogan In Press}. To create a self sustaining soil-vegetation community, we present the case that the most effective approach is likely to be one of understanding and restoring the actual functions that have been disturbed or destroyed during disturbance. These functions are described below. This section describes both concepts and specifics that contribute to successful long term control of erosion.

Background

A great many erosion control projects are designed and implemented with the project proponent assuming that specific BMP’s have been tested and ‘proven’ or that information gathered in various publications or conferences will actually perform as expected. Unfortunately, that is not usually the case. The purpose of this section is to suggest solutions (tools) that can be used to enhance understanding and provide information that can be used to as background to develop site specific erosion control and restoration implementation plans.

Restoration of *FUNCTION*: a model

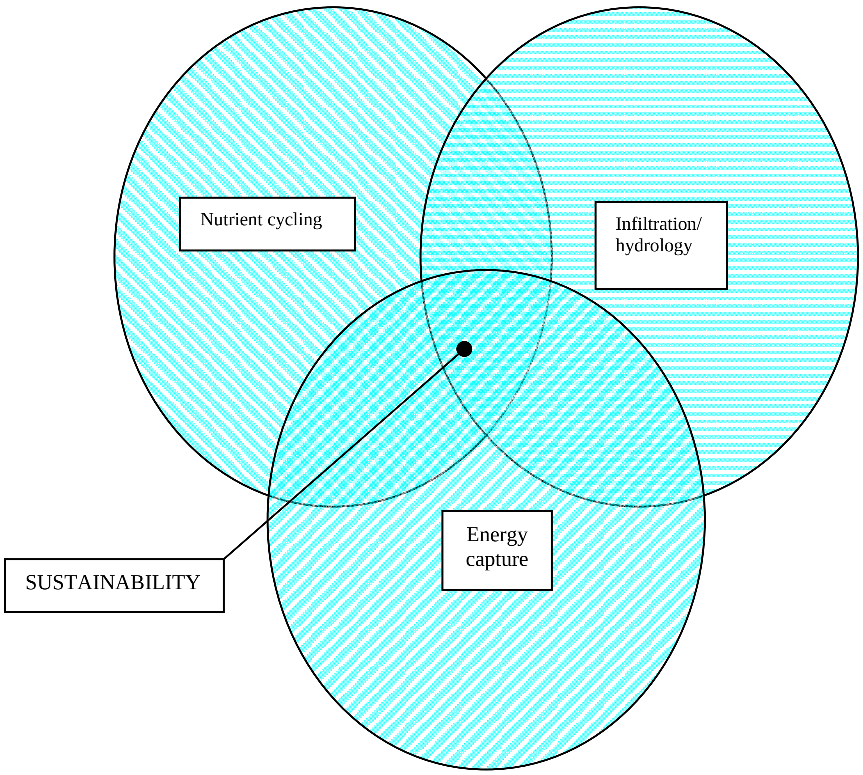

Figure 3.5: this diagram presents a conceptual model of the three critical elements of ecosystem function and the sustainability index, which occurs at the overlap of those elements.

Typically, when an erosion control project is undertaken, vegetation is considered as the first line of defense. Recently, information is being developed that suggest that a more comprehensive approach to erosion control may be more effective. Rather than using 'revegetation' as a primary approach, we present the concept of 'functional restoration'. The ability to restore function within the soil-plant ecosystem is likely to be the most powerful approach we can take to control sediment at its source. Cummings (2003b) suggests that the ability to restore function within a disturbed system should be a primary goal. The usefulness of this concept can be seen in some projects where surface treatments are aimed at plant growth as a primary objective. While it is possible to actually force plants to grow using a combination of fertilizers and irrigation, it has been shown that sometimes these projects do not actually control erosion since runoff is

Figures 3.6 and 3.7: the photo on the left shows the rainfall simulator being set up on a ski run in the Squaw Creek watershed. The photo on the right shows a distant view of that same slope. The well vegetated area produced similar amounts of runoff and sediment yield as a bare area while the areas on both sides of the person in the photo produced no runoff in simulated rainfall events of 2.4 inches per hour. Note that those areas, which are test plots, were all tilled, some with compost and some with wood chips. The approach on these test plots was to attempt to primarily restore hydrologic function and nutrient cycling. The relatively unvegetated area in front of the person absorbed over 5 inches of rainfall with no runoff. These results indicate that control of erosion is not primarily a plant function.

still quite high {Grismer 2004 }. According to Cummings and others, the main functions of concern are hydrologic function (infiltration, storage, transfer of water into and through the soil), nutrient cycling (cycling of nutrients within and through the soil) and energy capture (processing, storage and transfer of energy from the sun as well as capture and transfer of water energy within and through the watershed). By maximizing these three functions, soil will tend to remain in place and water within the watershed will tend toward a more natural or background behavior. For instance, if water infiltrates into the soil, it will move through the watershed more slowly, thus resulting in a lower runoff rate as well as lower volume and velocity of water in the streams. This attenuation of energy will lower overall erosive forces. Without restoring soil hydrologic ***function***, including infiltration, the goals of erosion control are not likely to be met, even though a site may support plant growth (at least as long as fertilizer and irrigation are applied). We therefore include the three main categories of function: hydrologic function, nutrient cycling and energy capture, as guiding principles for this portion of the literature review.

Water and wind erosion-some considerations

Water is probably the best known erosive force. However, there are other less obvious forces that may represent a high level of impact. While most sediment source control efforts focus on liquid water erosion, many of the same processes used to control liquid water erosion are also effective for wind and frozen water-caused erosion (McCool 2002; Fryrear 2000a; Tibke 2002; Fryrear 2000b). According to Reichert and Elemar (Reichert and Elemar 2002) “Water erosion is caused basically by raindrop impact and runoff of excess water, thus erosion and sedimentation control strategies must be based on ***covering the soil against raindrop impact, increasing water infiltration*** to reduce runoff generation and *increasing surface roughness* to reduce overland flow velocity.” The same techniques that are used to protect the soil surface against raindrop impact, namely mulch and live plants, are also effective for protection against wind erosion (by deflecting wind from the soil surface) and for protection against frozen water erosion (by insulating soil against freeze thaw and by providing additionally surface roughness for snow melt). Traditionally, live plant cover has been considered of primary importance in erosion control. However, a great deal of research has shown that total ground cover, and especially mulch, provides the most critical short-term impact or protection (Zhang 2002; Elliot 2002a){Grismer & Hogan In Press }.

WIND EROSION

Wind erosion is not generally considered when designing erosion control practices. However, wind erosion may be more , insidious and can have devastating effects on disturbed, bare areas. While wind erosion may not move as much sediment as water erosion, the material that is preferentially moved by wind is the lighter soil fraction; i.e. the organic matter and fine soil particles which have a much higher propensity for negative water quality impacts than do the more coarse particles. And wind tends to be ongoing and harder to notice. A significant body of evidence exists that indicates that wind erosion is significant and can have devastating effects on soil and water quality, soil nutrient cycling and long-term soil productivity as well (Fryrear 2000a; Leys 2002).

Therefore, we assume that the three main measurable attributes of a site[7] that indicate potential for erosion are: 1) cover (plant and mulch), 2) soil organic matter and associated nutrients and 3) infiltration.

Nutrient Cycling/organic matter

SOIL NUTRIENTS

Nutrients are critical for plant and microbial growth in the soil. There are a broad range of both macro (N,P,K), secondary (Ca, Mg, S) and micro (Zn, Fe, Mn, Cu, B, Mb, Mo, Cl, Ni) nutrients. Typically, in the Sierra Nevada and other western mountain ranges (in non-mined sites) macro and micro nutrients tend to be adequate on disturbed sites, except N. However, adequacy is not always adequate. It is difficult to generalize about adequacy of most nutrients in disturbed wildland settings. Therefore, the ability to gather soil nutrient data from surrounding 'reference' sites will usually be an important step in understanding what is required in a native or self-sustaining system.

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

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

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

[7] There are an extremely large numbers of attributes that actually define a site's ability to control erosion, such as microbial community, particle size distribution, plant type, and so forth. However, the three attributes chosen serve as indices or site indexes for erosion resistance. For instance, a healthy microbial community will depend on an adequate amount of organic matter for carbon, nitrogen and other elements. Infiltration can serve as an index of aggregation. So we have chosen the three most accessible attributes to serve as indices. .

project, an understanding of the soil nutrient content (load) is critical. In preparing project plans, it is important to understand three things:

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

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

Bradshaw et al (1982a) discussed the development of N cycling on mined land. They suggested that a pool of at least 1000 kg ha^{-1} (892 lb/ac) must be accumulated, after which N cycling by mineralization, plant uptake and litter fall will support a self-sustaining ecosystem. This value compares well with that suggested by Claassen and Hogan (Claassen and Hogan 2002) who found that well vegetated, previously disturbed sites in the Lake Tahoe Basin, was related to a pool of at least 1250 Kg ha^{-1} (1115 lb/ac) total N.

While N is understood as a critical limiting nutrient in most terrestrial semi-arid ecosystems, and that N is largely derived from organic matter in those ecosystems, the capacity for the total N contained in that organic matter to mineralize is not consistent or well understood (Baldock and Nelson 2002; Blackmer 2000a). Reestablishment of nutrient cycles on disturbed sites is seen as a primary cornerstone in the successful re-creation of a sustainable terrestrial ecosystem capable of reducing erosion, improving water quality, enhancing wildlife habitat and improving other beneficial uses (Haering, Daniels, and Feagley 2000; Macyk 2000; Marrs and Bradshaw 1993; Palmer 1990a; Reeder and Sabey 1987; Dancer, Handley, and Bradshaw 1977a; Palmer 1990b; Cummings 2003b; Bradshaw et al. 1982b; Bloomfield, Handley, and Bradshaw 1982b; Dancer, Handley, and Bradshaw 1977b; Dodge 1976; California. Division of Mines and Geology 1971). Woodmansee et al. (Woodmansee, Reeder, and Berg 1978) reported that N deficiency can affect long-term stability of a site by limiting plant growth, thereby increasing erosion from that site. Powers (Powers 1990) suggested that a decline in forest productivity is linked directly to losses of soil organic matter.

Organic Matter

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

The inclusion of organic material in a depauperate (low nutrient) soil may provide additional benefits beyond nutrient additions, such as increased water holding-capacity, increased microbial activity (enhanced cycling of pre-existing nutrients) increased infiltration rates, and an higher cation exchange capacity (Brady and Weil 1996).

Soil organic matter has been linked to both establishment and persistence of plant communities in the Lake Tahoe basin and elsewhere (Claassen and Hogan 1998); (Baldock and Nelson 2002; Bradshaw 1997a; Woodmansee, Reeder, and Berg 1978; Bradshaw 1997b) as well as an increase in the soils ability to resist erosion. There are a number of types of organic matter including compost, wood chips, manure and others. Each has its own strengths and weaknesses and should be considered carefully before use, especially for amounts and release rates of nitrogen and phosphorus.

The use of fertilizer for erosion control projects has been a standard practice for many years. Essentially, fertilizer is used to make up for inadequate amounts of nutrients in the soil. {Soil Improvement Committee 1998 #5410} Much of the information and the approach to fertilizer use comes from agricultural research. Much less research has been done on wildland system restoration. However, some work has been done by Bradshaw and other researchers working in the field of mineland reclamation. Much of this work has focused on rebuilding and re-capitalizing the nitrogen cycle in ‘derelict’ or drastically disturbed sites. These researchers generally found that adequate N cycling was directly linked to organic matter in the soil. {Roberts. R.D., Marrs, et al. 1980 }{Bradshaw, Marrs, et al. 1982 }{Bloomfield, Handley, et al. 1982 }{Marrs & Bradshaw 1982 }{Woodmansee, Reeder, et al. 1978}. Further, {Claassen & Hogan 2002} found that adeuate organic matter and mineralization of the N in that organic matter was directly linked to plant growth. And while some of this research has been available since at least 1980, little of its findings have been incorporated into ski area work.

Fertilizer

Bradshaw and others suggest that rebuilding of the nitrogen cycle is the underpinning of most reclamation or restoration on drastically disturbed land. {Reeder & Sabey 1987 #1450} and many others support the importance of this approach. Their findings clearly suggest that fertilizers alone are unlikely to rebuild these soil-plant systems to adequate levels of N in a reasonable time unless a very careful application regime is instituted. Yearly applications may increase nutrients to the point of self-sustainability, as Ray Brown was able to show on a mine site in Idaho. However, 25 years were required to do so. In this project, cost was not evaluated but estimates of labor alone could be as high as $25,000 {Brown & Johnson 1978}.

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

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

MYCORRHIZAE

Mycorrhizal fungi play an important role in most ecosystems. This paper is intended to address the issue of the use and function of mycorrhizae for upland revegetation projects.

A great deal of attention is currently being focused on mycorrhizal fungi. Mycorrhizal fungi are a group of fungi that have the ability to form a relationship with certain plants in an apparently mutualistic relationship. Mycorrhizae can be considered as an important subset of soil microbial components. We will not consider the broad range of mycorrhizal physiology, morphology, classification or other elements here. That information can be found in a great many publications including (1979; 1981; Walling, Davies, and Hasholt 1993; Paul and Clark 1989b; Killham 1994b; Israelsen 1980).

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

The microbial community within a soil are known to drive conversion of most nutrients from an organic form into a plant available form (Paul and Clark 1989a; Killham 1994a; Tisdale et al. 1993a; Buxton and Caruccio 1979a; Killham 1994b; Tisdale et al. 1993b; Buxton and Caruccio 1979b). In some cases, specific fungi are known to enhance uptake of both nutrients and water (Killham 1994a). A great deal of attention is currently being placed on mycorrhizal fungi and specifically, use of commercial, non-native or non-indigenous inoculum. Noyd (1997) and others reported that compost had a primary impact on reestablishment of both plant communities and mycorrhizal fungi colonization on taconite mine spoils in the Mesabi Iron Range in Minnesota while arbuscular mycorrhizae (AM) inoculation played a secondary role. Johnson (1998) in studying plant response to mycorrhizal inoculation across a phosphorus gradient reported that inoculation with arbuscular mycorrhizal fungi actually *reduced* growth at high soil P levels. This finding is relevant to most Tahoe and Sierra Nevada soils that tend to be high in P (Rogers 1974), suggesting that AM inoculation may not play an important role and may, in fact, *reduce* plant growth on some revegetation sites. This finding is further supported by an unpublished study of a variety of treatments on Tahoe granitic soil, including inoculation with non-native (cultured) mycorrhizae, where measurement of growth rates in a sixty day grow-out experiment showed that soil inoculated with mycorrhizae-only resulted in a growth rate *lower* than the control, while soil with compost and organic fertilizer additions resulted in growth rates over twice as high as either the control or the inoculated pots (Candice Longenecker, Senior Thesis, publication in prep).

Further, Johnson (Johnson 1998) suggested that manipulating edaphic factors through additions of soil organic matter may be more cost effective on low P sites than large scale inoculation. In support of this approach, Sylvia (Sylvia 1990) reported that, after initial infection by vesicular arbuscular mycorrhizae (VAM) on plants used in a mine reclamation site in White Springs, Florida, there was no plant effect at 18 months and that VAM inoculation had no effect on transplant survival. These soils were low in nutrients, thus supporting the nutrient addition findings of (Noyd, Pfleger, and Norland 1996), Johnson and others. In another study Noyd et al (Noyd et al. 1997) reports that adequate rates of compost added to taconite mine tailings produced biomass equivalent to or surpassing a native tallgrass prairie in three years and at the same time, organic matter accrual increased and litter breakdown rate decreased, inferring long-term plant community sustainability. In a greenhouse study, (Stahl et al. 1998) and others discuss the capacity of VAM-inoculated Big Sagebrush to better withstand drought than non-inoculated plants. However, the substrate used was collected from an undisturbed, nutrient-adequate site, thus further supporting the adequate nutrient concept. Weinbaum and Allan (Weinbaum and Allen 1996) showed that in a reciprocal transplant study between San Diego and Reno, that non-local mycorrhizal inoculum always declined at the exotic site and with exotic hosts, arguing for both locally collected inoculum and local plant source.

Energy Capture

The term energy capture refers to capture of solar energy as well as capture and storage of water energy within the watershed. That energy will largely be stored in the soil. A storm and/or runoff hydrograph represents an energy distribution graph. A hydrograph with a large peak early in the runoff cycle has a much higher probability of erosion than a lower peak later in the runoff cycle. This is also known as peak flow attenuation.

Plants and Cover

Traditionally, live plant cover has been considered of primary importance in erosion control. However, a great deal of research has shown that total ground cover, and especially mulch, provides the most critical short-term impact or protection (Zhang 2002) (Elliot 2002a) {Grismer & Hogan In Press}

Plants

Plants play an extremely important role in practically all ecosystems. Plant communities are linked to and supported by the soil resource/ soil community. The range of information available about plants is extremely large. We will not distill all of that information here. However, two very valuable and practical resources for native plants include the Native Plant Journal (http://muse.jhu.edu/journals/native_plants_journal/) and the associated Native Plant Network (http://nativeplants.for.uidaho.edu/). One consideration for plant use is that many claims seem to be made by manufacturers and suppliers, who typically have a great deal of information. However, site conditions widely and results from one planting or study may not be directly applicable to another.

A healthy, robust soil will be a critical path issue for planting of any kind. Drastically disturbed soil will have very different attributes from a slightly or non-disturbed site. Reestablishment of a sustainable plant community on severely disturbed upland sites in the Sierra Nevada has proven difficult (Erman and Others 1997; Nakao et al. 1976; Leiser et al. 1974). For many years, researchers and erosion control specification writers and practitioners have emphasized the plant or vegetative component of erosion control in revegetation and restoration projects (California Tahoe Conservancy 1987; U.S. Department of Agriculture 1982; Nakao et al. 1976; Leiser et al. 1974). We suggest that by linking the plant and soil elements, a much more effective outcome will be produced.

Plants play a great many roles in restoration and erosion control, especially on disturbed sites. Plants are closely linked to the elimination or reduction of erosion and have commonly been employed as the chief line of defense against surface erosion. While plants do play an essential role in stabilizing soil and reducing raindrop impact, they do not always limit erosion to acceptable levels. (Elliot 2002a; Zhang 2002). Aside from surface stabilization, plants are currently being studied for their ability to provide subsurface stabilization. For instance, an increase in root biomass typically results in an increase in physical soil stabilization through an increase in shear and tensile strength (Gray and Sotir 1996a). This fact can be especially useful in ski areas where some county or other 'engineering' agencies may require ski runs to be compacted in order to provide soil strength. However, when soil is compacted, infiltration is decreased and plant roots cannot penetrate easily, thus reducing plant growth to minimal levels see ('Infiltration, Soil Density' section, above). As Gray and Sotir have suggested, plant roots can provide adequate soil strength in uncompacted soils. Further, plants have been used successfully in the Lake Tahoe and Truckee areas to successfully hold loose soils of up to 1:1 slopes (Cave Rock Report, in preparation).

MULCH

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

Table 3.2: service and description matrix for various types of mulch

Service	**Description**	**Notes**
Surface protection-rain	Protects soil surface from raindrop splash detachment	
Surface protection-wind	Protects soil surface from detachment and transport of soil particles by shear forces	
Overland flow reduction	Reduces overland or surface flow of water by creating a maze of	Longer fiber length provides

Service	Description	Notes
	'mini-dams'.	better protection; Blown on mulch results in better soil surface contact
Temperature protection	Mulch reduces solar input to the soil by reflecting solar energy.	The color of a particular mulch plays an important part in this process. Darker mulch absorbs more heat energy, for instance.
Evaporation protection	Mulch reduces evaporation by reducing surface temperatures as well as by creating a physical barrier	
Nutrient addition	Organic mulches contain carbon and other organic nutrients that can enhance both organic matter and nutrients in the soil	Nutrient and energy additions are variable and depend upon the material. For instance, straw is known to contain very little C and N while pine needles can be much higher. Wood chips may lock up N but contain high amounts of C.

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

PINE NEEDLES

Pine needles have been used in the Lake Tahoe Basin and elsewhere as a surface mulch since 1992. However, little research has been done on pine needle effectiveness. Pannkuk and Robichaud studied pine and fir needle cast following fires on both volcanic and granitic soils and found that a 50 percent cover of Douglas fir needles reduced interrill erosion by 80 percent and rill erosion 20 by percent. A 50 percent cover of ponderosa pine needles reduced interrill erosion by 60 percent and rill erosion by 40 percent. (Wright, Perry, and Blaser 1978). Pine and fir needles offer advantages over some short-lived mulches such as straw since they last anywhere from two to ten times as long, thus providing services over longer periods of time. Grismer and Hogan have been assessing pine needle effectiveness for a number of years. Reports currently in press or in submission describe the positive effects of pine needles on plant growth and erosion reduction (Caltrans Demonstration and Development Report, in preparation, {Grismer & Hogan In Press #5120} and have shown that some of the highest infiltration rates as well as the highest plant cover rates on restoration sites have occurred under a pine needle mulch. Modeled after native forest surface cover, the use of pine needles has shown very promising results.

Hydrologic Function

Physical Treatments

Tilling

Removal of compaction and/or reduction of soil density is a critical component of restoring function to soil. Froehlich and McNabb showed that compaction may last up to 30 years and can reduce stand growth in Pacific Northwest forests by up to 15%. However, they suggested that tillage of compacted soil can be effective to reverse this situation (Froehlich and McNabb 1984). Luce showed that on a highly compacted road that had been ripped, saturated hydraulic conductivity can be up to 35 mm/hr, or approximately half of the natural background. However, Luce also suggested that this rate represented a significant increase in infiltration and would effectively reduce runoff and thus erosion during rainfall events of over 1" per hour (Luce 1997). Grismer and Hogan measured infiltration rates of fully treated (wood chips tilled into a highly compacted soil) of over 4 inches per hour on a Tahoe area ski run (Hogan 2004b). Torbert and Berger (Torbert and Burger 2000b) reporting on research by Larson and Vimmerstedt (Larson and Vimmerstedt 1983)stated that compaction is likely the most important mine reclamation problem in need of solution. They stated that compaction is caused during several steps of reclamation construction such that soil bulk density is reduced to root limiting levels.

Soil Aggregates

Soil aggregate formation has been shown to link to soil organic matter content (Baldock and Nelson 2002; Blackmer 2000a; Wilkinson, Grunes, and Sumner 2000a; Kay and Angers 2002)as well as an increase in the soils ability to resist erosion as well as increased microbial populations whose production of extracellular polysaccharides enhances soil structure. Torri and Borselli (2000) have found that "increasing organic matter content makes aggregates more resistant to sealing and consequently decreases runoff and erosion." And further "… those relationships indicate that soils with good granular structure (high Fe oxide and organic matter content) are less erodible. (pg G-189)". These data suggest that organic matter plays a number of very specific roles in reducing erosion and is of critical importance.

Economic considerations

An extremely important consideration in designing and implementing a restoration, erosion control or revegetation project is the cost. One of the most overlooked elements of this process, and one which needs further study, is the 'cost over time' or cost per unit time aspect. We often discuss the cost of implementing an erosion control project as the cost of applying material to the project area. However, if we regard the replacement of FUNCTION to that site as a primary goal and add the element of time, an important question is "How well does this project function and for how long?" For instance, if straw mulch is used and lasts two seasons and costs $1000/ac compared to pine needle mulch which may cost $2500/acre but lasts five seasons, then the actual cost would be exactly the same per year effectiveness. More cost effectiveness assessment will be critical to determining the actual costs of projects, not just the application cost. Many projects in the Lake Tahoe Basin have been re-treated using the same, relatively inexpensive techniques (hydroseeding, no soil preparation) two and three times and still have not performed adequately (personal communication, Jason Drew- NRCD, Joe Pepi-CTC, Larry Benoit-TRPA.) At that point, the question becomes "How many times do you apply something that doesn't work before realize that resources are not being spent effectively?"

CONCLUSION

Disturbance and erosion need to be considered in a wholistic, systematic and functional context in order to help develop effective strategies to reduce or control that erosion (Dudley and Stolton 2003). We suggest that if the 'system' within which erosion takes place is ignored, erosion control measures are unlikely to succeed over the long term. It would be useful to be able to present information and techniques that would clearly show how to successfully stop erosion. However, that type of information is scarce. While a great deal of information has been published about the control of erosion, little of that information provides a complete picture of what is required at each site. Further, most erosion-related research tends to be single variable manipulation studies such as mulch, seed, fertilizer, plant type and so on (see "State of Erosion Control Knowledge" above). Beyond the single variable consideration, most studies are also point in time studies, which means they don't tend to measure results over a multi-year period. This type of information can be incomplete at best and misleading at worst. Most field practitioners must deal with multiple variables and do so over several seasons.

This situation presents us with both restrictions and opportunities. We are restricted by lack of complete knowledge. However, we are offered the opportunity to gain missing knowledge on our own projects through the use of an adaptive management approach (see adaptive management section). Thus, the information in this section can be used to further clarify where useful information exists and where more information may be needed. In this report, we have attempted to provide adequate information from which planning and implementation can take place. It is likely that without a common language and understanding, meaningful communication within a multi-stakeholder environment is difficult if not impossible.

LIMITATIONS AND OPPORTUNITIES

We have been limited by a lack of information, a lack of organized project tracking, testing and cross pollination of ideas. These limitations also represent our opportunities. We offer this literature report as a step in a positive direction toward gathering information.

Afterward

“All ethics so far evolved rest upon a single premise: that the individual is a member of a community of interdependent parts. His instincts prompt him to compete for his place in that community, but his ethics prompt him also to cooperate (perhaps in order that there may be a place to compete for).

The land ethic simply enlarges the boundaries of the community to include soils, water, plants and animals or collectively: the land.” (Leopold 1949)

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Appendix

We present a general discussion of erosion in the following overview article from the International Union of Geological Sciences since it is precise and straightforward and captures the general principles that are discussed in this literature reveiw. This article can be found at http://www.lgt.lt/geoin/topic.php?tid=checklist .

EROSION OVERVIEW; IUGS ARTICLE

Erosion, the detachment of particles of soil and superficial sediments and rocks, occurs by hydrological (fluvial) processes of sheet erosion, rilling and gully erosion, and through mass wasting and the action of wind. Erosion, both fluvial and eolian (wind) is generally greatest in arid and semi-arid regions, where soil is poorly developed and vegetation provides relatively little protection. Where land use causes soil disturbance, erosion may increase greatly above natural rates. In uplands, the rate of soil and sediment erosion approaches that of denudation (the lowering of the Earth's surface by erosion processes). In many areas, however, the storage of eroded sediment on hill slopes of lower inclination, in bottomlands, and in lakes and reservoirs, leads to rates of stream sediment transport much lower than the rate of denudation.

When runoff occurs, less water enters the ground, thus reducing site productivity. Soil erosion also reduces the levels of the basic plant nutrients needed for crops, trees and other plants, and decreases the diversity and abundance of soil organisms. Stream sediment degrades water supplies for municipal and industrial use, and provides an important transporting medium for a wide range of chemical pollutants that are readily sorbed on sediment surfaces. Increased turbidity of coastal waters due to sediment load may adversely affect organisms such as benthic algae, corals and fish.

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

HUMAN OR NATURAL CAUSE: Erosion is a fundamental and complex natural process that is strongly modified (generally increased) by human activities such as land clearance, agriculture (plowing, irrigation, grazing), forestry, construction, surface mining and urbanization. It is estimated that human activities have degraded some 15% (2000 million ha) of the earth's land surface between latitudes 72° N and 57° S. Slightly over half of this is a result of human-induced water erosion and about a third is due to wind erosion (both leading to loss of topsoil), with most of the balance being the result of chemical and physical deterioration (see http://www.lgt.lt/geoin/doc.php?did=cl_soilq).

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OTHER SOURCES OF INFORMATION: Environment, water/hydrology, soil and agricultural agencies, FAO, IGA, ISRIC, ISSS, UNEP.

RELATED ENVIRONMENTAL AND GEOLOGICAL ISSUES: Land degradation. Deposition of eroded soil particles with absorbed contaminants can endanger entire ecosystems along continental margins, in estuaries, wetlands and bottomlands, and on other areas of low slope angle. Soil erosion both affects and is affected by vegetation and crop cover.

OVERALL ASSESSMENT: Monitoring soil and sediment erosion is of the greatest importance in determining rates of land degradation.

SECTION FOUR: SUCCESS CRITERIA FOR SEDIMENT SOURCE CONTROL PROJECTS IN THE LAKE TAHOE BASIN

SECTION FOUR: SUCCESS CRITERIA FOR SEDIMENT SOURCE CONTROL PROJECTS IN THE LAKE TAHOE BASIN

PURPOSE STATEMENT

The ability to determine whether a sediment source control project is 'successful' or not will depend to a large extent on how 'success' is defined. Unfortunately, success is seldom defined clearly. Usually the definition of success is implied or assumed. Many hours have been spent in the field by experts discussing and arguing whether a particular project is successful, usually with little satisfactory conclusion. This section attempts to define success criteria as it relates directly to project goals.

In order for success criteria to be meaningful and useful, those criteria must be linked directly to project goals and objectives. Further, success criteria must be quantitative to the greatest extent possible. Once those criteria are stated in numerical terms, success becomes a more or less binary situation: you either meet the criteria or not. We develop a number of success criteria which are either direct measurements of erosion, such as with the rainfall and runoff values, or are indices of whether goals are being met or not, such as with the penetrometer and plant cover measurements.

This report attempts to break new ground for success criteria in that we suggest that plant cover per se may be an inadequate primary indicator of whether a site is erosion resistant. While most erosion control/revegetation projects have been based on the idea that plant cover equals control of erosion, recent research {Grismer & Hogan 2004 #5110}{Grismer & Hogan In Press #5120} has indicated that this is not always the case and in fact, a site can be actively eroding while maintaining a robust plant cover. The literature report section of this report develops the argument for soil function as a primary element in the control of erosion and thus, we include measurement of some of these functions as primary indicators of success along with total and plant cover values. However, we are suggesting that plant cover value become less important than other parameters such as mulch cover and penetrometer values.

PART ONE: SUCCESS CRITERIA VALUES

This section identifies specific values that have been established through data collection on projects throughout the Lake Tahoe-Truckee region. The current success criteria have been developed using the following assumptions:

- Maximum soil cover offers optimal protection against erosion as well as a number of other benefits
- Mulch cover usually has a greater effect on erosion that plant cover
- Infiltration rates are a primary limiting variable in sediment delivery
- Native species should increase over time (if this is a goal of the project)
- Cover values alone may not be adequate to determine the ability of a site to resist erosion. Visible evidence of erosion must also be considered.
- Visible evidence of erosion is probably the least useful success criteria parameter due to time and observation accuracy issues

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Table 4.1: Proposed values for success criteria for sediment source control projects

Year	**1**	**2**	**3**	**4**	**5**
% total cover	98	95	90	85	85
% vegetative cover[8]	10	25	30	30	30
Native Species	10% of target species present	40% of target species present	50% of target species present	70% of target species present	90% of target species present
Bare Areas	No areas larger than 3 square meters bare	No areas larger than 3 square meters bare	No areas larger than 3 meters without vegetation	No areas larger than 3 meters without vegetation	No areas larger than 3 meters without vegetation
% of target N_{tot}	90-100	85-90	80%+	80%+	80%+
% of target OM	90-100	85-90	80%+	80%+	80%+
or					
TKN	800 lb/ac	750 lb/ac	750	800	800
OM	2%	2%	2%	2%	2%
Infiltration In/hr (mm/hr)	2 (50)	2 (50)	2 (50)	2 (50)	2 (50)
Penetrometer values	Penetration to 12" with no more than 200psi	Penetration to 12" with no more than 250psi	Penetration to 12" with no more than 250psi	Penetration to 12" with no more than 250psi	Penetration to 12" with no more than 250psi

Background information for Table 4.1 (above) is provide in 'Part Two: Success Criteria Supporting Information" below. A complete description of monitoring protocols are presented in Section Six.

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[8] Vegetative cover shall be measured at a specific phonological stage. Typically, peak standing biomass of the dominant species is suggested. In this way, plant cover data will tend to be consistent.

Table 4.2: actual data values for Cave Rock. Values that meet success criteria are highlighted in blue. Those that don't meet criteria are highlighted in yellow.

Site & Year	Bare Total	Mulch Cover	Other Cover	**Plant Cover**	**Total Cover**	Sample	TKN	OM	**Site**	**Mean Pen. Depth**
CR 1 (02)	0.08	0.29	0.18	0.45	0.92	CR1-01	924	1.7	1	7.4
Cave Rock 1 (7) '02	0.06	0.17	0.19	0.58	0.94	CR1-02	755	1.5		
CR 2.1 (02)	0.04	0.32	0.06	0.58	0.96				2	17.1
									3	12.6
						CR4/5-01	327	0.8	4	19
						CR4-01	253	0.6		
						CR4/5-02	329	0.9		
Cave Rock 4 '01	0.02	0.63	0.00	0.35	0.98	CR4-02	827	1.7		
Cave Rock 5 '01	0.01	0.59	0.00	0.40	0.99	CR5-01	673	1.5	5	18.7
						CR5-02	997	2		
Cave Rock 6 '01	0.04	0.50	0.01	0.45	0.96				6	19.2
Cave Rock 7 '02	0.16	0.50	0.07	0.28	0.85				7	22.8
Cave Rock 8.1 '01	0.03	0.62	0.00	0.36	0.97	CR8.1-01	337	1.2	8.1	20.3
Cave Rock 8.1 '02[9]	0.12	0.52	0.11	0.25	0.88	CR8.1-02	656	0.8		
Cave Rock 8.2 '01	0.02	0.48	0.00	0.50	0.98	CR8.2-01	328	0.7	8.2	15.8
Cave Rock 8.2 (8) '02	0.02	0.41	0.03	0.48	0.98	CR8.2-02	507	1.3		
Cave Rock 8.2 '03	0.05	0.43	0.11	0.42	0.95					
Cave Rock 9 (6) '02	0.05	0.28	0.06	0.60	0.95	CR9-01	502	1.2	9	23.9
Cave Rock 9 (8) '02	0.04	0.23	0.07	0.66	0.96	CR9-02	1087	2.3		
Cave Rock 9 '03	0.07	0.33	0.15	0.45	0.93					
Cave Rock 10.1 '02	0.12	0.39	0.07	0.42	0.88				10.1	25.8
Cave Rock 10.2 '01	0.03	0.47	0.01	0.49	0.97				10.2	18.2
Cave Rock 10.2 '02	0.15	0.45	0.12	0.28	0.85					
						CR11.1-01	882	1.5		
						CR11.1-02	990	2.1		
Cave Rock 11.2 '03	0.06	0.21	0.14	0.60	0.95				11.2	12.1
success criteria (year 3)				0.30	0.90		650*	1.5*	12	

[blue] adequate, meets success criteria

[yellow] below success criteria

* suggested success criteria, further assessment currently underway

INTERPRETATION OF SUCCESS MATRIX; RECOMMENDATIONS

Success criteria were applied to actual Cave Rock data in order to assess whether each site met criteria.

[9] This value is low due to the early season monitoring

MANAGEMENT RESPONSES

When the adaptive management cycle is being used as a framework for project implementation, management responses are usually defined prior to project inception. Management responses are potential actions that can be used if success criteria are not met. For instance, if success criteria for mulch cover is set at 98% but monitoring data shows that mulch cover is only 80%, a management response would consist of adding mulch so that the 98% cover level is met. If plant cover isn't adequate, additional seeding can be done or additional seedling planting can be done. The main function of management responses is to have potential actions defined and in place in case success criteria are not met. In this manner, if the project doesn't meet success criteria, any one of a number of potential pre-determined actions (management responses) may be chosen, depending on the type and severity of 'failure'. The following section describes each category and some potential management responses. Some of these management responses were used in the original post treatment assessment and retreatment process. They may still be applied, though long term re-treatment was not part of this project.

Cover

Most sites met the total cover as well as the plant cover success criteria for year three. The sites that did not meet the total cover criteria were 7, 8.1 10.1 and 10.2. However, site 8.1 did meet the criteria in 2002. Plant cover criteria was not met in site 7 and 10.2.

PLANT

Management response: reseed; reevaluate in 2005 or 2006

MULCH

Management response: remulch

Organic Matter (OM)

Several sites did not meet the organic matter criteria. Organic matter samples should be taken in 2006 or 2006 in order to determine trends in organic matter as well as existing, point in time conditions.

Management response:

Wood chip mulch on surface; till more organic matter into soil (not recommended due to disturbance required.)

Total Kjeldahl Nitrogen (TKN)

TKN is a measure of mostly organic nitrogen and is generally analogous to total organic matter. TKN was adequate in only half of the sites. While the adequacy level was somewhat subjective, the low level of TKN and OM is most likely the result of only 6 inches of compost/fill material being placed on the surface of the project area. As stated earlier, this amount of material was the result of a conservative approach to the Cave Rock project necessitated by the untested nature of this technology on such steep slopes (1.25:1). One of the main lessons learned from the Cave Rock Project is that these steep slopes can be successfully stabilized if timing is correct and irrigation is used.

Management response

In order to increase total nitrogen at this site, one of two or three management responses may be used. Regular fertilization with an organic fertilizer can function to support and increase plant growth on the site, thus leading to an increase in plant litter and thus organic matter contribution to the soil. Additional compost may be added to the soil in fall as a top dressing. In that case, a compost with a relatively high amount of organic/woody material should be used. Additionally, additional pine needle and/or wood chip mulch can be used either alone or in combination with the above treatments to increase organic matter and total N over longer periods of time. This treatment mimics the natural cycle of organic matter input into soil and would also serve to select for a soil microbial community similar to that which exists in a native forest floor which is dominated by high carbon content materials.

Tilling Depth

Tilling depth measurements were taken on some sites as an initial survey. It is likely that full transects would reveal that the upper portions of some of the sites would not measure more than one to two inches.

Management response

Cave Rock is an extremely difficult site to treat after initial treatment had been completed. Retiling would cause significant disturbance. Some potential and promising treatments include surface application of tub grindings (a specific type of long-spear wood chip that is made in a tub grinder) and heavy application of pine needle mulch. Drilling has also been used

PART TWO: SUCCESS CRITERIA SUPPORTING INFORMATION

INTRODUCTION

The following sections discuss and describe elements of success criteria and information that supports those elements. The proposed success criteria will provide the foundation of monitoring protocols for upland projects in the Lake Tahoe Basin. Input for these success criteria has been provided by Caltrans, UC Davis, Integrated Environmental Restoration Services in collaboration with the Tahoe Regional Planning Agency (TRPA), Lahontan Regional Water Quality and the State of Nevada Division of State Lands.

STATUS AS A WORKING DOCUMENT

This document is intended to be a **working document** in that additional input should be used to further develop and establish these protocols. This document intends to set a foundation for that development. We anticipate that subsequent information will be produced during the next 2-4 seasons which will incorporate additional research findings, especially for nutrient cycling and infiltration study data. Additionally, these success criteria are developed within an adaptive management framework and as such will need to be reviewed and updated on a regular basis.

UPLAND REVEGETATION PROJECT *GOALS*

In order to establish success criteria and associated monitoring protocols for upland erosion control projects, goals must first be established. A 'goal' as used in this document may be described as the generalized or overall outcome of an activity or project. Once goals are established, objectives can then be developed. 'Objectives' may be described as measurable, specific project outcomes. For instance, a goal would be to improve or protect water quality by reducing erosion, while an objective would be to protect a soil surface by producing 90% cover on a disturbed site. [This terminology follows that of the Plan for California's Non-point Source Pollution Control Program (2000) and the 1987 reprint of the Water Quality Control Plan for the North Lahontan Basin.] This document and proposed success criteria assume that upland erosion control projects in the Lake Tahoe basin will have one or more of the following goals:

- **Maximize water quality**: The basic or primary goal of upland erosion control projects in the Lake Tahoe basin is improvement in or protection of water quality. Sediment is the chief pollutant in California streams, according to the Environmental Protection Agency (EPA 1999). Upland projects attempt to achieve that goal through containment of sediment on site, or SOURCE CONTROL. Source control consists of stabilizing soil, usually through a combination of revegetation, mulching and other soil treatments. The primary assumption here is that the greater the plant/soil cover (up to some level), combined with maximum infiltration, the greater is the potential to maintain the soil on the slope.

- **Re-creation of native plant community**: an increasing number of projects are incorporating a robust native plant community as a desired project outcome.
- **Replace/create wildlife habitat**: Secondary goals for some projects may include improvement in habitat values for the project site. This objective is closely related to the previous goal.
- **Aesthetic improvement**: Secondary goals for some projects may also include an improvement in aesthetic values for the project site. Aesthetic values are often subjective and need to be defined relative to aesthetic assumptions.
- **Other goals**: additional goals vary widely. These goals may include: limiting browse value of vegetation near roadsides so that wildlife are not preferentially enticed into that area; shade reduction near roadsides so that snow removal is less problematic; creation of low growing vegetation for ski area runs, and so on.

SEDIMENT SOURCE CONTROL COMPONENTS AND VALUES

Cover

Cover can be divided into three categories: plant cover, mulch cover (which includes 'other' cover) and bare areas. Plant and mulch will be discussed below. Other includes rocks, trees and any non-live plant cover that provides some protection against raindrop impact. The relationship of cover to protection against erosion follows assumptions contained in USLE-based soil erosion models: namely that higher levels of total cover result in lower overall erosion rates when all other variables are equal.

PLANT COVER-BACKGROUND

- Plant cover is associated with reduction in erosion due to raindrop impact interception. Plant and total soil cover are used in USLE-based soil erosion models where high values of plant cover imply low levels of erosion.
- Plant cover is a measure of the plant community present. The presence of a sustainable plant community also functions to bind soil together, create excess plant material that becomes mulch and creates small check structures at the soil plant interface that slow surface flow. Plant roots create channels for increased infiltration. Plant roots also interact with soil microbes to enhance soil aggregation.
- There are a number of interactive processes besides cover that exist between plants and soil (Stocking 1994:211-232). These include:
    - Physical binding of soil by plant stems and roots
    - Electrochemical and nutrient bonding between roots and soil
    - Detention of runoff by stalks and organic litter
    - Improved infiltration along root channels

- Greater incorporation of organic matter into the soil, resulting in better structural and water-holding qualities
- Increase faunal and biological activities, leading to better soil structure

These interactions are all implied by cover measurements.

PLANT COVER-VALUES

% Vegetative Cover

Sustainable plant communities are necessary to resist erosion, produce excess mulch to protect the soil surface and help sustain nutrient cycles in the soil. The vegetative cover values are intended to reflect this trend. In the suggested success criteria, a 10% initial value indicates that plants are present but may play a minor role in soil surface protection during the first season. However, in subsequent seasons, vegetative cover is intended to play an increasing role in overall protection of soil from erosion and by year 4 and 5 should have attained significant cover over the site. Target vegetative cover values currently proposed are based on project data collected over the 2000-2004 seasons.

Methodologies for measurement of total cover, including plant, mulch and other cover elements, have been developed and tested for Tahoe Basin revegetation projects. This methodology is based on the use of the point-cover intercept sampling method. The requirement for sampling precision is set to a minimum confidence level of 80% (though 90% is preferred and may be suggested in the future). Accuracy levels are reflected in a confidence interval of 20% (10% ± the mean). To provide consistency between sampling years, vegetative cover will be measured as close as possible to peak standing biomass of the dominant grass species.

Native Species

The presence of native plant species are included as success criteria because native species are mandated by several land management agencies and suggested by others. It is assumed that native species are the most appropriate plants available to provide both long-term, sustainable source control, and replacement of the indigenous plant communities. The plant species endemic to the area are adapted to the local soil and climatic conditions, do not invade or out-compete natives and do not contaminate local gene pools or degrade native habitats.

The proposed success criteria involve identification of the 10 most common native species, incorporating early-late successional species that are present on site or from a reference area. Increasing presence of these species would be required, with the majority present by year 5.

MULCH AND OTHER PROTECTIVE COVER-BACKGROUND

- A variety of mulch materials currently exist. Short-lived materials such as straw and wood fiber mulch are not considered here since they are not favored for use in soil restoration projects. The main types of mulch considered here are pine needles and wood chip/tub grindings since they are long lasting and provide some level of carbon to the soil.
- Mulch acts as a surface protection to 1) intercept raindrop impact and 2) create numerous small check dams to slow surface flow, thereby reducing velocity and increasing infiltration.
- Mulch also acts as a nutrient source for microbes, especially fungi, and ultimately for plants as well. Mulch insulates the soil surface and reduces water loss by reducing evaporation.
- Mulch continues to provide 'services' even after the plant community has become well established. In fact, a sustainable (non-alpine) plant community in the Sierra Nevada generally contains an associated mulch layer. Mulch will continue to protect the soil surface against high velocity surface flows as well as provide raindrop impact protection between plants. Mulch can therefore be considered a long-term investment in revegetation and erosion control success.

MULCH-VALUES

Mulch should provide the bulk of soil surface protection for approximately 2-5 years until a robust plant community can develop. Therefore mulch amounts must be adequate to provide that protection and to be present on site even as plant cover increases. Initial mulch values of 98% reflect this need as well as the reality that there may be some small openings in mulch cover after application. However, a 100 percent cover of mulch is optimal. Subsequent decreasing mulch values of 95 through 85 percent reflect the breakdown rate of mulches but suggest that slowly decomposing mulch such as pine needles will be preferable to rapidly decomposing mulch such as straw or wood fiber mulch.

Bare Areas-values

Bare areas or areas that do not contain vegetation can be interpreted as areas that may not spontaneously regenerate plant or mulch cover. Therefore, in order to maximize cover effectiveness, those areas will be considered problematic when the size of the area is greater than that stated in the success criteria. This area measurement is included since, when sampling a large area with random sampling techniques, relatively large bare or unvegetated problem areas may not be sampled. Those areas are likely to be problematic, nonetheless. These criteria ensure these small areas will be identified and remediated.

Visible Erosion

VISIBLE EROSION-BACKGROUND

Areas that are visibly eroding are obviously producing sediment available for transport to streams. This erosion is not measured in any of the other measured parameters. When those areas are encountered, remedial actions must be taken where erosion is considered moderate to severe. Subsequent erosion from the same area is likely to constitute an ongoing or systematic problem that needs to be ameliorated.

VISIBLE EROSION-VALUES

Visible signs of erosion are difficult to quantify. Subjective analysis of erosion will be used in conjunction with feedback from agency personnel regarding need for remedial action. Visible erosion levels will consist of ‘slight’, ‘moderate’ and ‘severe’. Where remedial action is required, project planners will provide a systematic plan to ameliorate erosion that is acceptable to agency personnel and that will provide for repairing the erosion and dealing with the cause of the erosion.

Nutrients

SOIL NUTRIENT POOLS-BACKGROUND

- Soil nutrients are the foundation of plant-soil-microbial communities. Where soil nutrients are adequate in amount and type (or ‘quality’), plant communities are generally robust and sustainable. The measurement of soil nutrient cycles can be an effective diagnostic tool that can indicate adequacy of nutrients to drive a sustainable (long term) soil-plant community capable of protecting against sediment yield off-site.

SOIL NUTRIENT POOLS-VALUES

Research on disturbed sites in the Lake Tahoe basin showed a correlation between certain nutrient pools, especially nitrogen, and plant cover on previously disturbed sites (Claassen and Hogan 1998). This research is supported by many other studies throughout the world on previously disturbed semi-arid upland sites that indicate that N is critically limiting on many disturbed sites (Bradshaw 1992:53-74; Reeder and Sabey 1987:155-184; Roberts. R.D. et al. 1981, 69:153-161; Bradshaw 1980; Bradshaw 1983, 20:1-17; Berg 1978:653-664). We suggest that amounts of total N (TKN) are at least 800 lbs/ac and that organic matter is at least 2%. Soil nutrient values must be assessed by a trained wildland soil specialist. Recommendations for testing labs or fertilizer manufacturers are generally unreliable since they are usually aimed at agricultural situations.

Rainfall Infiltration

RAINFALL INFILTRATION-BACKGROUND

The amount of water or rainfall infiltrated into the soil is inversely proportional to the amount of runoff produced. Runoff is a primary limiting variable for sediment yield. Thus, if infiltration is maximized, runoff and sediment yield will be minimized. Infiltration is also affected by antecedent soil moisture (the amount of soil water present prior to rainfall.) We assume that infiltration is measured in typical summer-dry conditions and that we are concerned with summer rainstorm (thundershower) type events. Winter and spring infiltration rates in the Sierra can be difficult to predict due to a broad range of variability in soil moisture, runoff rate, snow pack water content, etc. However, a higher summer infiltration rate will assume a relatively higher winter rate as well, all other things being equal.

Infiltration rate has been measured by a rainfall simulator. Each type of site will be associated with a slightly different infiltration and runoff rate, depending on soil type, soil condition, landscape position, etc. It is impractical to measure each site individually. However, data is currently being gathered which will allow monitoring personnel to approximate the infiltration potential of specific soils and soil conditions through the use of a cone penetrometer. For the purpose of this success criteria section, we include infiltration values. However, penetrometer values are being suggested as a surrogate for actual infiltration rates while further infiltration-penetrometer correlation research is being conducted (see ‘Penetrometer Values’, below).

WATER INFILTRATION-VALUES

Water infiltration values have not been established for Tahoe Basin soils. Permeability values used in the Tahoe Basin soil survey are based on soil particle size analysis (Rogers, 1974) rather than actual measurements of soils. Further, disturbed sites may not resemble native soils in many characteristics so that soil survey values may not be applicable. Currently, research if being conducted to evaluate soil infiltration rates by simulated rainfall on a range of sites throughout the Lake Tahoe Basin in order to establish baseline infiltration data. This research is providing useful infiltration data that can be linked to simple field measurement techniques. This information can then be used to evaluate and assess projects on a site-by-site basis. We are suggesting that for success criteria, if infiltration criteria are to be used, that criteria will be stated in relationship to a ‘design storm’. The so-called 20 year 1 hour storm varies in actual numerical value from approximately 0.7 in/hr to 1.0 in/hr in different areas within the Tahoe Basin. At any rate, research has shown clearly that infiltration rates on soils similar to Cave Rock soils can be at least 60 mm/hr (2.36 in/hr) and in some cases much higher. Therefore, we suggest setting infiltration rates at 2 inches per hour. Actual infiltration rates measured at Cave Rock varied from a low of 1.8 in/hr on bare soil to 2.3 in/hr for a recently treated site. No simulated rainfall occurred on the actual project site. However, given the penetrometer values from monitoring on some slopes, the treatment site infiltration is expected to be higher than the values above. On other sites that received similar treatment to Cave Rock, rates as high as 5 in/hr were recorded.

PENETROMETER MEASUREMENTS

A cone penetrometer is a device that is used to measure soil density or compaction. A penetrometer can also measure depth to a restricting layer such as bedrock or other infiltration-reducing layer. Cone penetrometer measurements can be used as a surrogate for infiltration, thus allowing monitoring personnel to determine the relative amount of potential infiltration on a particular site. Further, soil density is directly linked to plant root penetration and thus to overall plant growth. Penetrometer measurements are relatively easy and quick to obtain, making this type of measurement cost effective. Two years of penetrometer data has been collected throughout the Tahoe Truckee region and from that data, we have developed an interim ‘benchmark’ value for soils.

PENETROMETER MONITORING TECHNIQUE

Penetrometer measurements are taken in the same manner as cover point data. If cover point data is to be collected, a penetrometer measurement is taken at each point and the same analysis method is used to determine statistical confidence. If cover by cover point is not measured, the same technique is used except that penetrometer measurements are used instead of cover measurement. .The actual measurement recorded is the depth that the penetrometer is able to reach at a maximum of 200 or 250 psi, depending upon the year following treatment. Actual measurements for Cave Rock are as follows:

Table 4.2: initial penetrometer values for cave rock slopes. These data were collected from lower slope areas and are not associated with a statistical confidence level

Site	**Mean Pen. Depth** (inches)
1	12.6
2	17.1
3	12.6
4	19
5	18.7
6	19.2
7	22.8
8.1	20.3
8.2	15.8
8.3	15.6
9	23.9
10.1	25.8
10.2	18.2
11.1	11.4
11.2	12.1
Mean (all sites)	**18.0**

PENETROMETER VALUES

The interim penetrometer value for treated soils is set at 12” depth minimum at a psi value of no greater than 200 for the first season and 250 psi for subsequent seasons. This value may be adjusted with subsequent research data. However, given the current data set, these values have been linked to sites with very low runoff and high infiltration values.

TIME

Time is implicit in all of the listed success criteria. In fact, sustainability, though difficult to measure directly, may be defined as the attainment of goals over an extended period of time. Therefore, all of these parameters must be measured at specific points in time. The amount of sampling necessary to define an index of sustainability is not known so at this point, we suggest yearly sampling until more data is available. Once trends are defined, sampling will be adjusted to reflect adequate interpretation of those trends.

REDUCTION IN IMPORTANCE OF VEGETATIVE COVER-THOUGHTS FOR THE FUTURE

Vegetative cover has been a primary concern and area of focus for revegetation and erosion control projects for many years. Recent research and a refocusing on soil as a primary factor in the control of sediment movement have suggested that vegetative cover/plants are not the primary variable in the control of erosion. Recent studies are indicating that vegetation is usually the surface manifestation of soil condition. For instance, Cheatgrass (*Bromus tectorum*) is linked to shallow, disturbed soils, while existence of other types of perennial grasses such as Blue Wildrye (*Elymus glaucus*) and Mountain Brome (*Bromus carinatus*) may be linked to deeper, more organic rich soils (IERS, in preparation, Matt Curtis, MS Thesis in preparation). This information suggests that in the future, we may focus more on soil elements when assessing success in erosion control projects, such as soil density and nutrient content. The data presented here supports that direction by showing that where

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SECTION FIVE:

METHODOLOGIES FOR ATTAINING SUCCESS

SECTION FIVE: METHODOLOGIES FOR ATTAINING SUCCESS

INTRODUCTION

The literature review section discusses many of the methods and materials suggested for attaining success. Success can be described as the ability to recreate maximum function in a previously disturbed site such that erosion is minimized. That function is described as hydrologic function, nutrient cycling, and energy capture. To assure that those elements are re-created and sustained over time, the following elements are suggested as critical components.

SITE ASSESSMENT-ESTABLISHMENT OF CURRENT CONDITIONS

In order to understand what needs to be replaced, one must understand what is missing. In order to reestablish those critical functions, baseline information about soil nutrient/organic matter content, soil density, plant community and soil cover should be understood. This baseline assessment should be the foundation of future treatment activity. The following table lists the types of information that can be gathered during a site assessment:

Table 5.1: various methodologies for monitoring sediment source control projects with assessment of each type.

Type	Analysis
Site physical assessment	• Useful for getting a physical understanding of the site. Also extremely useful for finding the site is subsequent seasons. This information includes such things as slope, aspect, soil type, location and so on.
Soil nutrients	• Critical to understand how much and what types of amendments may be needed
Soil density	• Important key to be able to understand the soils ability to infiltrate and store water. This assessment will suggest what type and how much soil physical preparation will need to take place.
Solar input	• The amount of sun that reaches a site each day may be more informative than strictly aspect or slope measurements. Solar input can me measured by a number of devices. A Solar Pathfinder www.**solarpathfinder**.com is an instrument that is used to site houses for either active or passive solar systems and can be quite useful for determining solar input. The higher the solar input, generally, the higher the evapo-transpiration from a site and thus the less available water in the soil.
Soil Moisture	• Soil moisture data, when compared to other similar sites, will help the planner to understand whether this soil is able to hold adequate water or whether additional irrigation, organic matter or mulching will need to be applied to reach the required moisture levels in the soil.
Other	• There are a great many assessment protocols that may be used. The main criteria should be the NEED for the information and the usefulness of that information to the planning, implementation and monitoring or tracking process

Soil Sampling

Soil should be sampled for organic matter, total nitrogen and other macro and micro nutrients. Those values should be compared to a nearby native reference site and any information soil databases that exist to get an idea of what and how much should be added. For the Cave Rock project, soil samples were taken and compared to reference sites. From that information, an amount of organic matter was specified based on differences between the two and the amount of organic matter that could be stored in the soil.

TREATMENT ELEMENTS

Soil preparation

Soil preparation consists of removing compaction from the soil and potentially incorporating organic matter.

DESCRIPTION:

Soil physical preparation consists of breaking up or loosening the soil to increase water infiltration, root penetration, aeration and nutrient movement. Physical preparation is generally done on highly compacted or otherwise dense soils.

Drastically disturbed sites, such as road cuts, ski runs and construction sites, are often underlain by dense and/or compacted material. Compaction and high-density material may be the result of one or more forces. For instance, a road cut may consist of dense subsoil or parent material, as is the case in much of the Sierra Nevada and other mountainous regions. Construction activities also usually compact soil. Compaction and high bulk density result in several negative impacts on soil, plant growth and ultimately sediment yield from that site. Soil physical treatment is used to de-compact soil and allow increased infiltration, root penetration, gas exchange and aeration for both plants and microbes.

Opinions vary as to the depth of soil loosening. Twelve inches is currently being used as a standard. This depth represents a trade-off between ecological/hydrologic benefits and costs. Simple calculations suggest that for each additional inch of tilling, given a compacted soil of 20% pore space, the soil will be able to hold an additional 0.31 gallons per square foot for every additional inch of depth tilled. So for instance, the difference between 6 and 12 inches over an acre would be 81,675 gallons of water potentially infiltrating into the soil and/or stored in the soil as water for plant growth. Thus, one can see that the two main obvious benefits of soil preparation, beyond the effect on plant growth, are increase in infiltration and the associated decrease in runoff as well as the increase in the amount of water that can be stored in the soil.

Soil physical treatment can consist of a number of treatment types. Physical treatment may include tilling, ripping, turning soil over or the use of infiltration tines to open and loosen dense soils without turning them over. The latter technique would be used on a steep and/or unstable slope where massive disruption of the soil ‘strength’ may result in a mass-type of soil movement.

Soil physical treatment is often combined with application of organic amendments such as compost or aged wood chips in order to incorporate those materials to a specific depth as tilling or ripping is done. Table 1 lists a number of treatment types.

Appropriate uses, applications

Soil physical treatment is used wherever soil density is high enough to limit plant growth and infiltration. It is difficult to give exact values for soil density that would suggest physical treatment. A useful approach to determining whether the soil is dense is to measure density on a native or highly functional site. This information is used as a reference. No standards have been set relative to what is 'acceptable'. However, if density is 20 or more percent higher than the native site, it may be advisable to apply some sort of soil physical treatment. As more information is gathered from treatement areas regarding this critical issue, additional guidelines will be developed.

Soil physical treatment can be used on flat or steep slopes, areas where topsoil has been removed, areas where machines have mechanically compacted the soil or on cuts where subsoil is exposed.

In the Cave Rock project, loosened soil was placed on top of roughened bedrock and so the 6 inches of 'soil-like material' called out in the specifications was in fact of low density.

Soil Treatment Alternatives

Table 5.2: soil physical treatments

Alternative	Analysis
Machine tilling	• Machine tilling may include soil loosening by a back hoe or hoe-equipped excavator. This type of tilling can completely mix the soil and any amendments that are placed prior to tilling. This allows for a much more consistent breaking up of dense soil. The potential drawbacks include destabilizing very steep slopes and in some cases, access is difficult for back hoes and excavators. In cases of very steep slopes, tilling can be done with a reach forklift of other mechanical means. However, if steep (>2:1) slopes are tilled, it is essential to establish plants during the season that the soil is tilled in order to stabilize the slope with plant roots. • Tilling application can be extremely cost effective if access is good.
Rototilling	• Rototilling involves turning over the soil using a rotary tine attachment on either a hand operated machine or a tractor. Typically, in mountainous soils, rototilling is of very limited usefulness due to the rocky nature of the soils. Rototillers can penetrate up to 4-6 inches, depending on the nature of the soil.
Ripping	• Ripping is the use of ripper shanks that penetrate into the soil to decompact and loosen. Ripping is usually faster than tilling but is not always as complete for mixing. Since ripping is done by tractor mounted attachments, slope angle can be a limiting factor for where ripping can take place. Winches can be used to extend the areas where ripping can take place.
Hand tilling	• Hand tilling is used where machines are not available or cannot reach. Hand tilling is limited by how deep hand tools can go and the enthusiasm of the hand labor crew. Typically, six inches is the limitation of hand tilling depth.
Auguring/drilling	• Auguring and drilling are utilized on very steep slopes where other methods of soil loosening would tend to destabilize the slope. Drilling is done such that the native stability of the soil is

Alternative	Analysis
	maintained. That is, holes are drilled on 6, 12 or other centers to ensure that a general level of stability is maintained. Drilling allows soil amendments, water and plant roots to penetrate down into channels, thus allowing some level of plant growth and infiltration/water storage. In many cases, drilled areas need to be irrigated for one or two seasons. Irrigation MUST be done infrequently and deeply so that water can penetrate down into the channels, thus encouraging roots to follow the water. Shallow irrigation will result in shallow roots, thus defeating the purpose of drilling.

SOIL AMENDMENTS

Description:

Soil amendments describe any number of materials that are used to enhance soil physical or biological properties, such as water retention, permeability, water infiltration, drainage, aeration and structure. Soil amendments may consist of organic fertilizers (covered in the 'fertilizer' technical note), compost, tilled-in wood chips, mycorrhizal inoculum, or any number of other materials that are used to improve some element of the soil. Many soil amendments also contain nutrients and thus may be considered 'fertilizers' and will provide dual roles in soil treatment.

Appropriate uses, applications

Soil amendments are widely used and recommended for any number of situations where soil has been disturbed. Often, soil amendments are used without adequate understanding of exactly what is missing in the soil or without proper understanding of the potential and limitations of the amendment. In order to specify and apply the appropriate amendments, soil and plant conditions should be assessed and the need for a particular amendment determined.

Perhaps the most widely useful soil amendment is compost. Typically, in road cut, home site, ski run and other construction sites, most of the organic layer is buried or removed. It is this layer that drives the soil-plant system. Once it is diminished or removed, most of the physical and biological function is severely impacted. In order to restore that function over the long term, organic matter will usually need to be added. In many cases, organic fertilizers or other amendments such as mycorrhizae are added with the belief that those additions will effectively 'restore' the system. However, if one assesses the amount of nutrients and organic matter that have been removed and compare that to the amount that is needed, it becomes clear that the addition of fertilizer or mycorrhizae alone is unlikely to replace the amount of nutrients or microbial activity needed for robust, sustainable erosion control. As an example, if 2000 pounds of an organic fertilizer with 6% nitrogen (N) was added to a site, that would provide the site with 120 pounds of actual N. The amount and form of N is likely to be inadequate to effectively recapitalize that site or support robust plant growth over an extended period of time since it has been established that in the Tahoe Basin, at least 1200 pounds of organically bound N is needed for robust

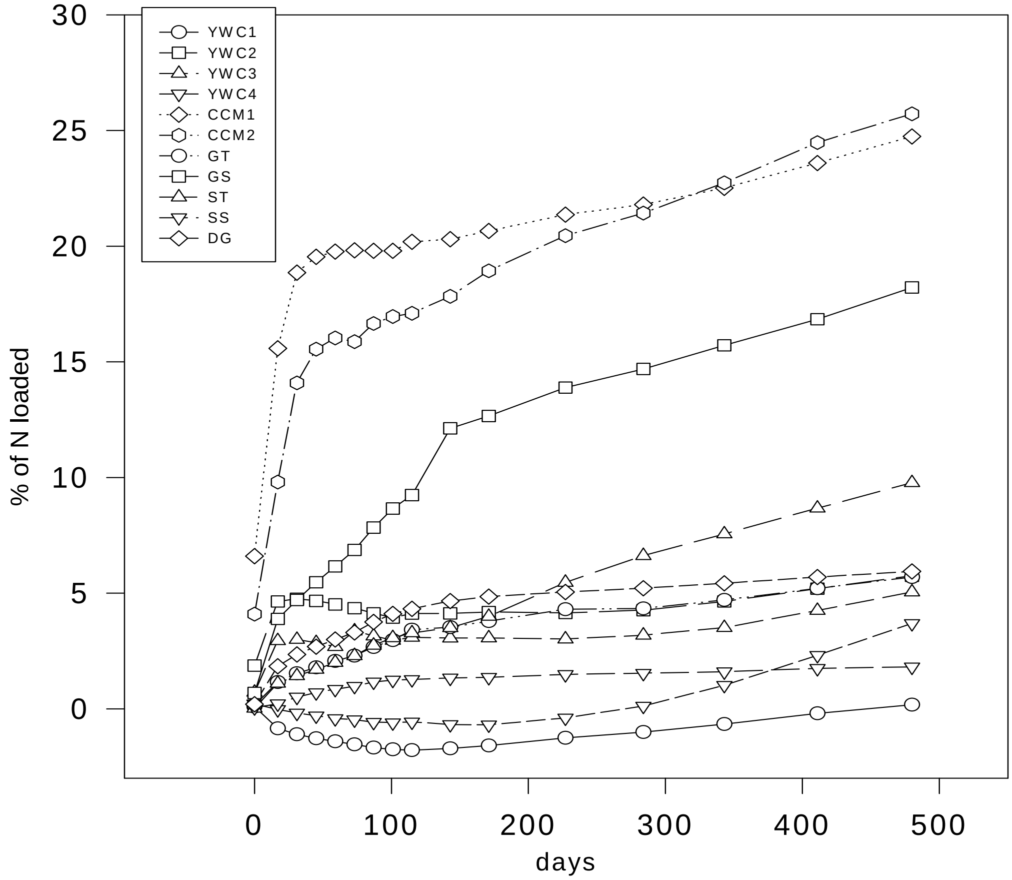


Figure 5.1: Nitrogen yield (percent of total N loaded) over a 480 day aerobic incubation of soils and amended soils. From Claassen and Hogan 1998

plant growth (Claassen and Hogan 2002). The type of N in organic fertilizers is generally of a much faster release rate and would likely be used up or leached from the system in 2-3 seasons. On the other hand, composts, which tend to have a much lower N release rate, can in practice, have varying N release rates. Figure 5.1 shows a graph derived from N release data from four types of compost. Two composts release a robust amount of N in a short period of time and then slowly release the remainder over time. However, two other types of compost actually lock up N, making it unavailable to plants for some period of time. While all of these 'composts' contain N, two would actually improve plant growth while two would diminish plant growth unless additional, more available N were added. Thus it is critical to understand what is in the soil in order to know what and how much to add to the soil.

Soil Amendment Alternatives

Table 5.3: soil amendments, types and description

Alternative	Analysis
Compost	The term "compost" is used to describe a number of materials derived from the breakdown of organic matter. Unfortunately, there is little commonly accepted definition of compost material. To that end, the US Composting Council has produced the following definition: "**What is Compost?** Compost is the product resulting from the controlled biological decomposition of organic material that has been sanitized through the generation of heat and Processes to Further Reduce Pathogens (PFRP), as defined by the U.S. EPA (Code of Federal Regulations Title 40, Part 503, Appendix B, Section B), and stabilized to the point that it is beneficial to plant growth. Compost bears little physical resemblance to the raw material from which it originated. Compost is an organic matter source that has the unique ability to improve the chemical, physical, and biological characteristics of soils or growing media. It contains plant nutrients but is typically not characterized as a fertilizer. "- *Adapted from The U.S. Composting Council's (USCC) Field Guide to Compost Use.* • Organic additions such as aged manure, aged wood chips, and a broad range of other materials, can be used as organic amendments. However, it is difficult to know what effect they will have on the soil without adequate testing. Some materials may not have the desired effect, others may have a greater effect than desired (for instance, excess N or P). The use of the above definition of compost will at least allow us to use the same term for a similar product. • One word of caution regarding using compost: some municipal composts are made from sewage sludge and even though this material is approved in some agricultural and forestry settings, this sludge derived material can contain a great deal of available N and potentially some heavy metals and pathogens. Before using ANY compost, it is important to know what it was made from and whether application of that material is approved by the local water quality agency.
Wood chips	• Wood chips, either fresh or composted, may be an effective alternative to using compost, which tends to be expensive to produce and haul. This project did not address the potential to use wood chips but we mention them since other projects have shown some interesting results using them. When wood chips are used, plant cover may not be a significant element of success for some years following treatment.
Organic fertilizer	• The term organic fertilizer covers a broad spectrum of materials from chicken manure to lignite/ammonium combinations. There is little standard for what defines an 'organic' fertilizer. It may be useful to ask whether a particular material is approved for organic farming, which sets a high standard. Some organic fertilizers may actually contain a great deal of available nitrogen and phosphorus, thus creating a tendency toward leaching or runoff of nutrients. Other fertilizers may contain residual toxins, thus creating the potential to bring unwanted materials into the soil. For instance, one 'organic' fertilizer has been banned by the Wyoming Department of Transportation because of the

Alternative	Analysis
	potential to import residual pathogens from the source chicken manure. • When choosing an organic fertilizer, it will be useful to understand the relative release rate of the nitrogen and the amount of especially N and P needed, as shown through soil tests.
Mycorrizal inoculant	• Mycorrizal inoculant is intended to re-introduce a type of fungi into the soil that is an important element for plant growth in many types of plants. Mycorrizal inoculants are available from a number of producers or can be collected from native areas. The effectiveness of these amendments is the subject of a great deal of study and debate (see literature report).
Soil conditioners	• Soil conditioners are generally used to chance or enhance a physical component of the soil. For a complete discussion of soil conditioners, see: http://attra.ncat.org/attra-pub/altsoilamend.html#soil
Seaweed Products	• Seaweed products are added to a soil or compost pile to increase N and other minerals. Seaweed products may contain salts that can be harmful to plant growth.
Humates	• Humates or "humic acids" are intended to mimic the "active" part of soil humus. The sheer volume of organic matter in even moderately rich soils suggests that agronomically affordable applications of humates may not produce significant improvements. The top six inches of soil weigh approximately 1,000 tons per acre; each percent of organic matter, therefore, weighs ten tons. Even assuming that the organic matter in humate products actually is similar to that in soil, it requires two tons of humates per acre to increase soil organic matter by 0.1%. •

PLANT MATERIALS SELECTION

General considerations: Plant materials include any live or potentially live materials such as seedlings, transplants or seeds that are used to enhance an erosion control or landscaping project. Plant material should be considered relative to its specific function within an erosion control project. For instance, plants roots provide an important function in holding soil together and providing soil strength. Plants also provide mulch when they are mature enough to produce excess leaf material. Plant leaves provide cover over the soil, thus protecting soil from raindrop impact.

It is important to understand the functions associated with each individual plant type and match that function to the service needed in a specific erosion control project. For instance, many grasses provide a quickly established plant community that can tie the soil together, produce surface mulch and help bootstrap the soil nutrient cycle. Some grasses may be invasive or persistent while others may die out in a few seasons. Seedlings of shrubs and trees may be used for additional erosion control but may not provide much protection for several years due to their slow growing habits.

The actual erosion control 'service' provided by each plant type and form should be carefully considered. For instance, the presence of grasses (or other plants) on a site does not necessarily assure that site of being erosion free. The ability to resist erosion is derived from a number of elements including infiltration, mulch cover, adequate soil organic matter and so on. Plants are one component of that system and cannot be expected to be the sole determinant of erosion. So in choosing the appropriate plant material, consideration should be given to how that plant, plant type or form fits into the overall system that is being treated or restored. Plants cannot be expected to perform all erosion control functions. Plants should be considered in the context of the entire system within which they function.

Native vs. non-native: Some land managers are required or would prefer to use all native species. Others may choose to do so or opt for adapted species. There are no clear-cut parameters for choosing native vs. non-native in a strictly erosion control context. However, each type has its strengths and weaknesses. Historically, non-native grasses were used due to the belief that natives were slow-growing. However, recent experience has shown that some native grass species, such as *Bromus carinatus, Elymus* (glaucus and elymoides) and others may grow as fast as many of the adapted species. It is also commonly believed that native plants can thrive on nutrient poor soils. This has been shown to be erroneous. In the table below, native and non-native species are assessed.

Native vs native: Another consideration when choosing a native species is whether it is genetically indigenous (local origin) or simply the same species. For instance, *Elymus elymoides* (Bottlebrush Squirreltail) grows from the California coast to the upper elevations of the Sierra Nevada and across the Great Basin. However, the genetic makeup, and thus growth habits and preferences of the same species growing in different locations vary broadly within the same species. Therefore, if native species are used, it is suggested that local genotypes be selected. There is some concern that local gene pools may become ‘polluted’ or weakened by non-local genotypes. Beyond the genetic considerations, usually, locally collected plant material will perform better than material from a different climate and altitude.

Weed free seed: Seed should be specified as weed free since even native seed, when field grown, can introduce weeds. Weeds can become established and crowd out more useful species. Some weeds, such as Tall Whitetop (*Lepidium latifolium*) can be extremely invasive and is known to be included in some seed mixes or with straw mulch.

Pure Live Seed (PLS) The concept of pure live seed is extremely important in the ordering and application of seed to a project. PLS is the amount of seed that can actually be expected to grow within a batch of bulk seed. All seed should be tested within the past year. Tests will indicate how much of the material in the seed bag is actually seed (some material may be ‘fluff’ or chaff or other material). Some of the seed itself may not be viable. Seed testing determines the amounts of non-seed and non-viable seed and is usually reported as ‘impurities’ and ‘viability’. So if 20% of a 50 pound bag of seed is made up of impurities and non-viable seed, then only 40 pounds of that bag contains seed that can be expected to grow. Therefore, if one needed to apply 40 pounds per acre, 50 pounds of bulk seed would be required. It is important to always order and specify seed as PLS. For instance, if a seed supplier had an old bag of seed in which only 10 percent was viable and you applied 100 pounds per acre, you would only be putting 10 pounds of actual live seed on that acre. Thus, if plant response was poor, you would not know if it was a plant issue or some other reason.

Appropriate uses, applications

Plant type, growth habits and aesthetic value should be matched to the project goals. For instance, if erosion control was the main goal, one may not choose seedlings as the main line of defense since seedlings usually do not develop significant root structure or canopy cover for a number of years.

Alternatives

Table 5.4: general assessment of various plant types, forms and habits

Alternative	Analysis
Grasses	• Quick growing, usually fiberous root structure. Grasses require moderate to high amounts of water. Some grasses are better as scavenging water than others (Elymus elymoides, for instance).
Forbs	• Some are quick growing, add to aesthetic of a site; difficult to get native seed.
Shrubs	• There are a broad range of shrubs available. Some research is required to determine habits, requirements, etc. Shrub seedlings usually require some supplemental irrigation in the first season. Possibly the most effective means of choosing the proper shrubs is to contact the local nursery, especially if they deal with native plants.
Trees	• Very slow growing, may be of limited use in ski areas.
Planting procedures	• General procedures include soil preparation, adequate planting hole size, supplemental irrigation, mulching.
Seed vs seedlings	• Seed is usually most appropriate for grass establishment. Shrubs and trees may be established more quickly by planting seedlings. However, seedlings (live plants) are much more expensive to install. More work needs to be done on the ability of many plants to grow from seed. Native plants demonstrate a range of response to direct seeding. The exact cause and effect relationship is not usually clear. For instance, how soil type, nutrient level, mulch depth, solar radiation % and others can effect germination of many native seed. Further, germination triggers are not always known or if they are, such as in the case of fire, trigger mechanisms may not be available. • A great deal of work remains to be done on how a range of native shrub and tree species seeds can be used successfully in erosion control projects.

MULCH

Description:

Mulch is a covering of any number of materials placed directly over the soil surface. Erosion control mulch typically consists of pine needles, wood chips, straw or wood fiber mulch.

Surface mulch is one of the most cost-effective and essential elements of sediment source control and slope protection. Mulch provides protection from raindrop splash detachment, potentially reduces surface runoff rate, traps sediment, reduces surface temperatures and evaporation. Mulch helps reduce surface soil sealing and can eliminate freeze thaw-caused erosion in early and late season low snow situations. Mulch can also protect soil surfaces from impacts by foot and vehicle traffic especially when soil is wet.

Appropriate uses, applications

Mulch should be an essential component of almost all erosion control/sediment source control projects. Some mulches may not adhere to the soil surface on extremely steep slopes without special techniques.

The table below assesses strengths and weaknesses of various mulch materials.

Table 5.5 mulch alternatives

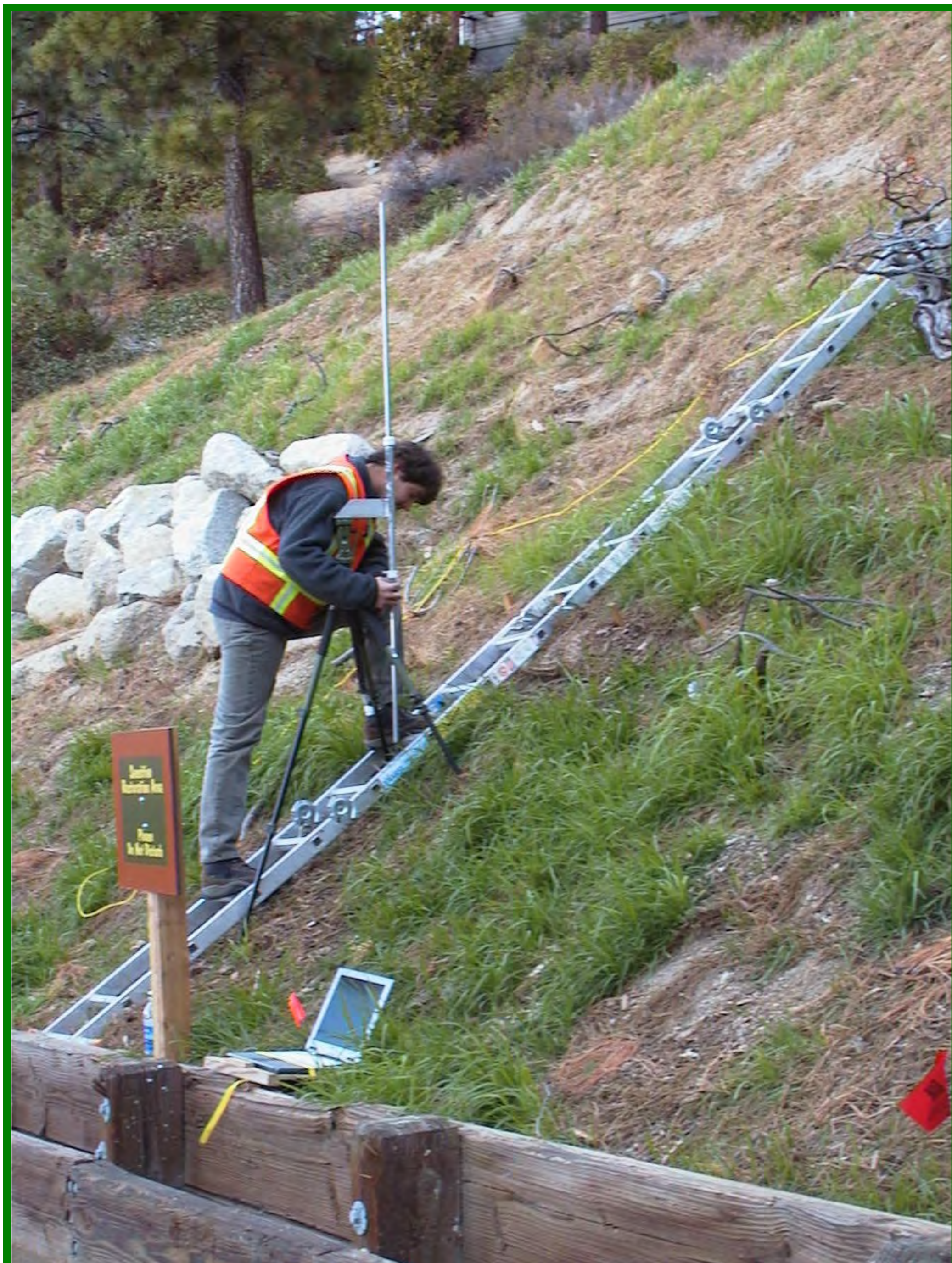
Alternative	Analysis
Straw mulch	• Relatively short life (1-2 seasons) • Potential for weed importation, even with 'weed-free' straw • Little nutrient value • Less expensive to purchase • Relatively easy to blow on
Wood chip mulch	• Shorter fiber length=less water path-length, less potential for sediment reduction • Some wood chips can move off site with water runoff • Local studies show good sediment reduction potential in many cases • New chips may contain phytotoxins • Long life, possibly longer than pine needles
Tub grindings	Tub grindings are wood chips derived from a tub grinder. Tub grindings should be derived from tree stumps or other 'virgin' timber and not from construction waste. • Heavier density • Less prone to washing from the surface than wood chips • Longer lasting if made from stump material
Wood fiber mulch	• Low potential for sediment reduction once surface flow occurs • Prone to 'peeling' off soil surface, especially in freeze prone areas • Little nutrient value • Easy to apply • Needs to be reapplied after each rain storm • Hasn't been shown to be effective in Sierra for erosion control
Woven fabric mulch	• Surface protection • Studies indicate low potential for protection against surface flow erosion
Pine needles	• Long lasting (2-5 years) • Natural appearance • Relatively high, long term nutrient value • Available in most mountain regions in the West • Low tendency to import weeds, especially if collected locally • Can be a significant part of a waste reduction and fire reduction program

Known or measured outcomes of mulch use

- Reduction of surface runoff velocity and sediment yield (Grismer and Hogan 2004)
- Reduction of soil surface temperature
- Reduction of evaporation from soil
- Reduction of potential for frost heave
- Protects soil surface from raindrop impact and splash detachment (natural and sprinkler-caused)
- Provides very slow release nutrient addition to soil (experiment underway)

SECTION SIX:

MONITORING



SECTION SIX: MONITORING

INTRODUCTION

This section discusses monitoring processes and protocols. We begin with a definition of monitoring, present a philosophical discussion of the need for monitoring and include a step by step description of cover point and penetrometer monitoring.

DEFINITION OF MONITORING-COVER AND PLANT MONITORING

Monitoring can be defined in a number of ways. We assume that monitoring will be used either implicitly or explicitly in an adaptive management context, which assumes that clear project goals and outcomes have been stated during the planning process and that a project offers the potential for gaining information that can be used for increasing future project performance. Adaptive management is described in more detail in Section Two. Monitoring can be described in a number of ways. According to Tate, in the UC Davis Agronomy and Range Science Monitoring Series No.1, "*the term monitoring suggests a series of observations over time*." Elzinga et al (1998) further clarifies monitoring as: "…the collection and analysis of repeated observations or measurements to evaluate changes in condition and progress toward meeting a management objective, [goal or success criteria[10]]." This document will emphasize the second definition since it directly addresses issue of concern to erosion control projects.

Tate characterizes seven types of monitoring including: *trend, baseline, implementation, effectiveness, project, validation and compliance*. For clarification, the UC Davis monitoring series document is included in Appendix F. The type of monitoring that we are most interested in is *effectiveness monitoring*, though the protocols that we describe can be used for baseline, implementation, project and compliance monitoring as well. In defining monitoring protocols, we follow the idea that once effectiveness is improved to a level of sufficiency, and where that effectiveness is repeatable, monitoring information can be used as a basis for compliance. That is, once effectiveness (success) is defined, compliance values can be set to that standard and adjusted as necessary.

These cover monitoring protocols are intended for use on upland revegetation and restoration sediment source control projects and are most applicable for low-growing (<18") plant communities. This will include most early and mid-seral stage revegetation projects less than 6 seasons since installation. These protocols can be used on slopes up to 1.5 to 1 with proper techniques and have been used on steeper slopes.

MONITORING INTENSITY

Monitoring involves a range of monitoring intensity. This intensity generally refers to how much effort is involved in a particular monitoring activity. Generally, the more intensive the monitoring, the more accurate and precise the monitoring will be. For instance, simple visual inspection of a site will not usually be defensible or repeatable. Further, as we discuss elsewhere, visual interpretation, even by so called experts, is not reliable. On the other hand, monitoring that is done to a specific confidence level is much more reliable, even though it requires a great amount of effort or intensity.

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[10] Authors addition in [square brackets].

Linking monitoring to erosion

Plant and mulch cover help protect and stabilize soil, thereby reducing erosion *at its source*. In order to apply the appropriate types of monitoring, it is critical to understand some basic processes of erosion as well as some methods of controlling erosion at its source. Then monitoring can be linked to those processes so that monitoring data reflects site condition as those conditions relate to erosion potential and/or actual signs of erosion. This linkage between monitoring and the essential elements of erosion is a critical step in developing an effective monitoring program and one that has been overlooked in the past. (See literature review for a more complete discussion of erosion.)

The placement and number of monitoring transects are critical decision factors that affect both the accuracy and precision of the data. Fortunately, formulas are available to help field personnel determine exactly how many transects are needed.

THE NEED FOR ACCURACY AND STATISTICAL ANALYSIS IN MONITORING

A critical consideration for collecting and interpreting monitoring data is how ‘good’ that data is. In other words, how ***accurate*** or ‘true’ is the information that is produced during the monitoring process. Can we rely on the information to approximate reality? Can two individuals measure the same area and get similar values? Or is the information simply a subjective judgment? We will develop the concept of statistics in monitoring early in this paper. The need for statistical analysis of data is often poorly understood and sometimes overlooked completely. This oversight may render data useless for decision-making. Therefore, a discussion of basic statistical concepts, as they relate to cover monitoring, is developed.

When we collect monitoring data, we cannot measure (or 'census') every plant in the area. We 'sample' an area. That is, we collect information on a portion of the population of interest. We hope that the value(s) we get are close to the 'real' or true value of that population. However, the value we get will depend greatly on how variable the population is, where we sample and how many samples we take. As an example, in figure 6.1, we see a slope with vegetation in varying locations. If a transect is placed in position A, a total cover of approximately 15% would be measured. If that transect, with the same number of points, were placed in position B, quite a different value, approximately 45%, would be measured. The problem of variability across the slope can be seen through this example. We assume that the more samples we collect, the closer to the true value we get. The question becomes, how many samples are needed to get close to the true value? And how are transects best positioned? We can determine this question, within limits, observing variability across a site, placing transects so that they capture that variability and then undertaking 'pilot' monitoring. A small number of transects are measured and the variability of those transects is used to determine the total number of transects needed. This setup is considered the most effective for capturing the variability on a road cut. The value for each vertical transect is used to estimate variability across the slope and then the correct number of transects needed determine cover to a specific confidence level is determined (see sample size equations, below).

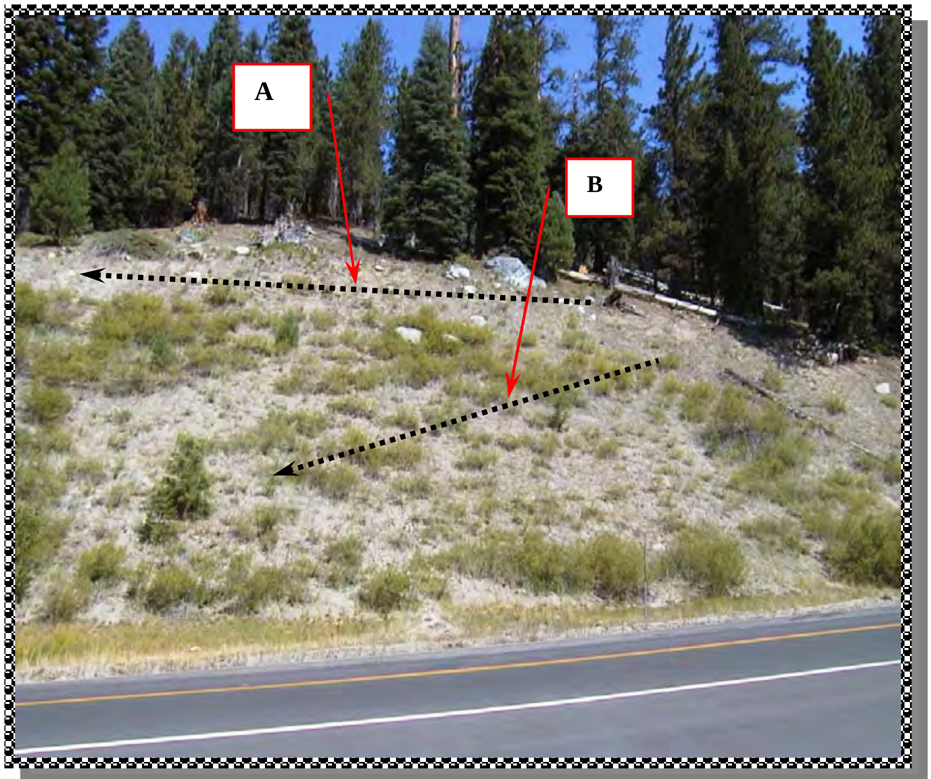

Figure 6.1 : potential transect placements

It is useful to keep in mind that, since we cannot measure all of the plant community, we produce an ***estimate*** of the true cover. In order for that estimate to useful, we must know how close to the true value that estimate is expected to be. Precision and accuracy levels are the values that state the limits of 'correctness' that we are willing to accept. David Turner develops this concept in his technical report 'Estimates Without Measures of Precision are Unacceptable'. In that paper, Turner reports that without measures of precision and accuracy, reported cover values may be biased, over or under-estimated and simply guesswork. That sort of output is seldom useful for making management decisions and can result in wrong decisions, *leading to costly actions where they may not be needed or to no action where action* ***is*** *needed*. For instance, if a project set as its goal a total cover level of 90% and a plant or vegetative cover level of 40%, and the data showed that total cover was 86% and that plant cover was 30%, what action would be triggered to address this situation? We would need to know how accurate that information was. Therefore, where data is used for any important decision, such as whether a project has met a desired cover level, statistical analysis that includes precision and accuracy levels and required sample size to meet those levels, must be calculated.

TYPES OF MONITORING PROTOCOLS

CHOICE AND JUSTIFICATION

Monitoring protocols can differ greatly depending upon the type and use of the

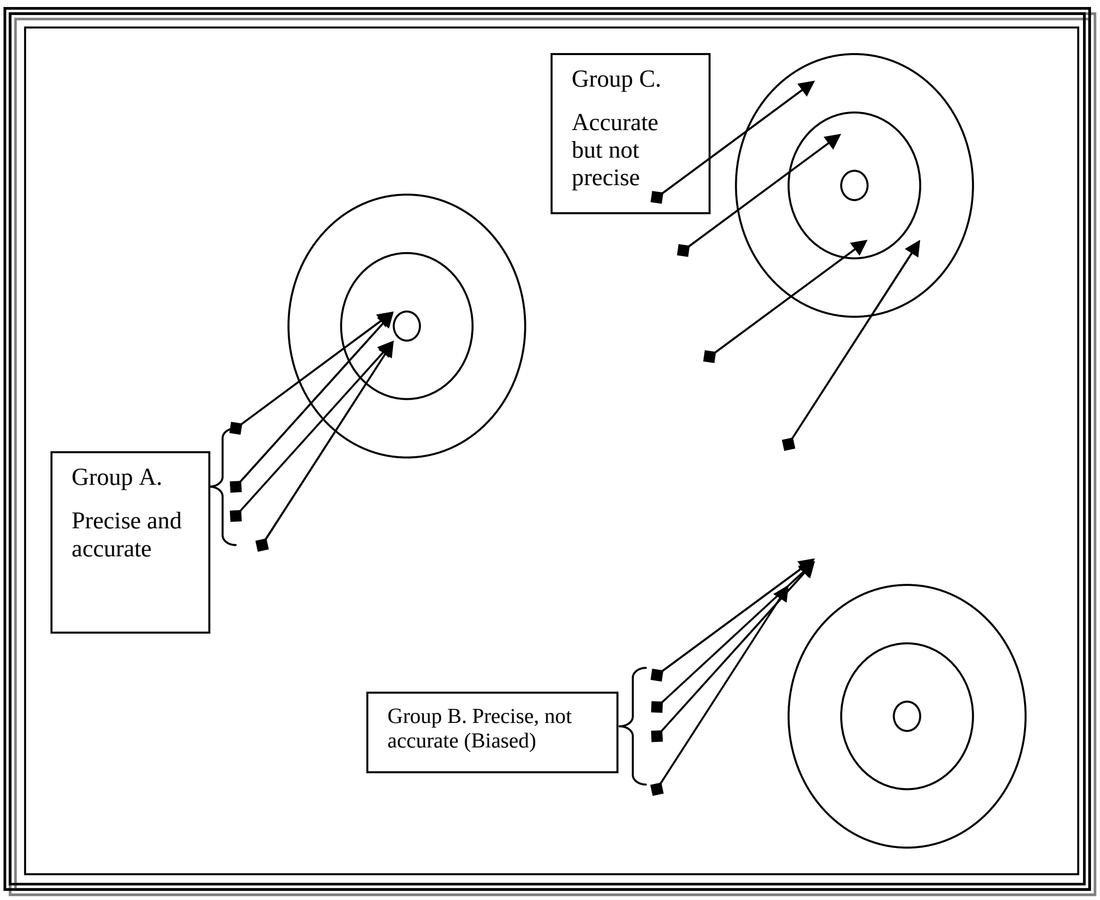

Figure 6.2: Accuracy and precision diagram

information required. Monitoring can range from visual inspection to photo point monitoring through statistically validated (accurate and precise) types of monitoring.

The less intense the level, typically, the less reliable (and useful) the information. This document describes a numerical approach for estimating plant and mulch cover on upland revegetation treatment projects. There are a number of monitoring protocols that may be used to determine specific aspects of a plant community. Typically, for cover measurement, the most common numerical method employed for erosion-related measurements is the 'cover point', 'point intercept', 'line point' or 'point quadrat' method. All of these names are used interchangeably. In this document, I will refer to the method as 'cover point' unless quoting another source. While other methodologies are sometimes used to determine cover, especially in shrub or forest communities, cover point may be the most effective and efficient, especially for early and mid-seral species typically used for slope stabilization, such as lower growing grasses and forbs. (BLM 1996; 1989; 1998)

In the Lake Tahoe Basin and elsewhere, empirical methods such as **visual or 'ocular' estimates** of cover have sometimes been made. However, visual or 'ocular' estimates have been shown to be highly variable, inaccurate and indefensible. For instance, Schultz et al (Schultz, Gibbens, and DeBano 1961, 108:259-270) describe a study where professional range scientists were asked to estimate cover on an artificial quadrat. Estimates range from 6 to 62% when true cover was actually 20%. Elzinga et al describe several studies that indicate the amount of observer bias that is possible in ocular measurement from a difference in 25% to a difference in over ten times (an order of magnitude). Fischer (Fischer 1986:189-217)suggests that: "The greatest disadvantage to the empirical approach is the inability to attach precise, defensible confidence levels to the resulting estimations [of cover]." This type of monitoring, then, is extremely prone to misinterpretation and misuse. Data available suggests that ocular estimates of cover are unacceptable as a useful and defensible monitoring protocol. The exception to the potential inaccuracy of ocular estimates may be found in situations where presence-absence determinations need to be made such as in the presence of visible signs of erosion or the occurrence of a species of plant.

Another common type of monitoring that has been used for cover is the **quadrat method**, especially the Daubenmire quadrat protocol. However, several authors have found that quadrats should not be used for measuring cover due to inaccurate estimates and other problems (BLM 1996;Floyd and Anderson 1987, 75:221-228) (Kennedy and Addison 1987, 75:151-157;Kennedy and Addison 1987, 75:151-157). Similar to ocular estimates, many quadrat methods rely on visual estimates and are therefore difficult and sometimes impossible to assign a valid confidence level.

Line transects are often used for cover. However, line intercept methods are more appropriate for dense, semi-continuous shrub canopies rather than low growing species such as grasses and forbs. Whitman and Siggeirsson (Whitman and Siggeirsson 1954, 35:431-436) reported in the 1950s that line transects gave significantly lower estimation of cover than did the point method in mixed grassland. This is a significant issue since the currently described protocol will be used for estimating early to mid-seral plant communities that will be generally dominated by grasses and forbs. Elzinga et al., BLM and Bonham all suggest line intercept is not efficient for cover measurements of low growing graminoids and forbs due to the non-continuous nature of grass and forb canopies (BLM 1996; 1989; 1998).

"Points are considered to be the most objective way to estimate cover." (Bonham 1989, pg 20

A review of methods of surveying grasslands by Crocker and Tivner has suggested that line-intercept and point quadrat [cover point] methods appear to be the primary, *objective* methods for measuring cover (Crocker and Tivner 1948, 3:1-26). They further suggest that the cover point or "point quadrat method" is preferred because:

-it provides an objective estimate of cover

-it is more expedient to use than other cover methods of equal reliability and objectivity

-randomization and replication is possible

-most species cover estimates are more precise and accurate using this method

Additionally, the point intercept or point quadrat method may be used with minimal slope disturbance when ladders or other bridging methods are employed to suspend the sampling personnel (1989). Bonham further suggests that: "***Points are considered to be the most objective way to estimate cover.***" (Bonham 1989, pg 20). Several researchers found point intercept to be more efficient than line intercept by as much as 66 percent (Floyd and Anderson 1987, 75:221-228); (Brun and Box 1963, 16:21-25;Heady, Gibbens, and Powell 1959, 12:180-188) although points are less accurate at low (<3%) and high (>95%) cover levels. Given the information above, we have chosen to employ the **cover point** type of monitoring protocol for reasons stated above.

Strengths

The type of monitoring most conducive to analysis of total ground cover on forbs, grasses and low-growing shrubs is cover point monitoring. Plant canopies more that 1 m high can be problematic to analyze and may require different equipment. However, this monitoring protocol is suggested for young (<6 years) revegetation projects and/or sites with low-statured plant communities. Cover point monitoring is relatively quick to set up and complete. A large, difficult (steep, loose soil) site can be completely monitored in one day or less. Easier, sites can be completed in less time, sometimes in 2-3 hours. When properly set up, protocols are easily repeatable. Monitoring can be accomplished by trained technicians with minimal botanical and erosion background. Unknown plants can be numbered in the field, collected in plastic bags and taken to a botanist to identify, thereby keeping field costs down. Cover point monitoring can be accomplished with a minimum of equipment. Cover point devices can be purchased for under $100 plus a tripod. Ladders are required on steeper and/or unstable areas. Additional field equipment, such as ropes and harnesses, ruggedized computers, field notebooks, or other accessories can be used if desired.

Limitations

Cover point monitoring produces an *average* of cover over the entire area of interest. Small areas of inadequate cover or areas that are actively eroding may not be picked up or adequately represented in by cover point analysis. This limitation is addressed in the overall monitoring protocol presented, which also uses visual observation of problem areas as triggers for management (see 'Proposed Monitoring" section, below).

Therefore, where information is to be used for important decision-making, such as evaluating whether a project has met a specific outcome, additional analysis and observation will be employed.

Costs vs. Benefits

Cost is sometimes suggested as a limitation for this type of monitoring. However, where defensible and accurate (within stated limits) monitoring is required, no other method that we investigated produces more reliable results at a lower cost than cover point monitoring. Monitoring will ultimately be an extremely minute portion of the overall cost of a project but will provide a great deal of information regarding how well the project has met goals and how future projects may be improved. Some erosion control projects in the Tahoe Basin have been done twice since they didn't 'take' the first time. In fact, there is documentation of at least one project being done THREE TIMES, without satisfaction from the project sponsor (Jason Drew, personal communication). Accurate monitoring would allow more precise estimate of project outcome and would have allowed adjustments in management practices. We suggest that the cost of monitoring and the resultant information is many times less than projects that failed to meet their expected outcome. We need to know that resources are applied to projects effectively. A good monitoring program will allow that information to be developed. And without adequate and accurate information, project outcomes will be difficult to interpret at any rate.

DESCRIPTION OF MONITORING PROTOCOLS

PROPOSED MONITORING PROTOCOL(S) FOR REVEGETATION PROJECTS IN THE LAKE TAHOE REGION

The proposed monitoring protocols incorporate a number of elements that, together, can be used to document and analyze a sediment source control project site, such as a road cut, abandoned road or ski run. The total proposed protocols include:

CONCEPTUAL DESCRIPTION OF PROTOCOLS

Site evaluation-site conditions

Site information is gathered on data collection sheets. An example data sheet is included in Appendix E. Information gathered will identify current conditions including location, (lat-lon), slope, aspect, elevation, vegetation type, vegetation association (if applicable), soil type, description of disturbance, and other physical conditions that may indicate current conditions and the sites ability to respond to treatment. Information used for planning include visible signs of erosion, depth to restricting layer and so on. ***Information sheets should be standardized and information should be entered into a searchable, relational database for comparison with other sites and for sharing between users.***

Photo point monitoring

Photo points, or photographs taken from specific, documented points, are used to collect visual information on the site. Gross differences can be observed with photo points and differences over multiple seasons can be seen. Photo points have advantages, such as ease of collection and low cost and disadvantages, such as difficulty in interpretation when photos are taken at different times of the day, season or physiognomic state of vegetation. Also, photo points are difficult to use for management decisions since they provide little real data and so, are easily misinterpreted. However, photo points, if taken correctly, can demonstrate gross erosion, general existence of a plant community, plant community type and other visual information. Where monitoring funding is low to non-existent, photo points are preferable to no monitoring at all. And where complete monitoring is done, photo points are an important part of that monitoring. Photo point examples are included in the appendix.

Cover point monitoring

Cover point monitoring is accomplished as described in Appendix D. This monitoring provides data with which to analyze current conditions or project success. Cover point monitoring provides information of aerial cover from the perspective of a raindrop. In other words, cover is measured from above looking straight down as a raindrop on calm conditions would fall. Monitoring should be reported to a specific accuracy and precision level. Monitoring data is entered into a relational database for comparison with other sites.

Erosion evaluation

Erosion is evaluated visually and is either present or not. Often, interpretation of surface characteristics to determine whether erosion is actually taking place requires an individual with experience in interpreting evidence of erosion, since surface erosion is not always obvious. Rills and gullies and mass movements are relatively easy to observe. However, shallow surface flows (pre-rill conditions) and micro-rills as well as evidence of wind and other erosion, is difficult to ascertain to the untrained eye. Fortunately, this sort of training is achievable in a short period.

This information is used to determine whether a problem exists or not. Where a problem exists, management response should be triggered. For instance, on a completed project, if rills or a shallow mass movement is observed, recommendations for repair or amelioration should be developed and those recommendations implemented.

Soil evaluation

Soil nutrients and soil physical conditions are essential variables that help determine whether plants can become established and will persist over time. Organically bound soil nutrients provide the basis for nutrient cycling, microbial populations and sustainability of plant communities. It is extremely important to know the amount of soil nutrients, especially total nitrogen, phosphorus and organic matter.

A related soil parameter Soil nutrient cycling potential and root restricting layers should be determined in order to assure that conditions are optimal for sustained plant growth (Cummings 2003, 4:S79-S82; Claassen and Hogan, 2002). Soil evaluation will typically consist of soil samples from the project area and from a reference area.

VEGETATION, SOIL COVER AND PENETROMETER MONITORING PROCEDURES AND PROTOCOLS

INTRODUCTION

The following section describes specific steps to completing cover point monitoring for upland sites. This protocol will provide percent total cover values to the precision and accuracy levels stated in the goal section of the project. At the end of this section, we include penetrometer monitoring protocols which essentially follow cover point monitoring.

PROCESS OF FIELD MONITORING FOR COVER ON REVEGETATION AREAS

Site data collection

1. Delineate the area of interest. The area of interest will generally be that area where the project was done and that received the same treatment. Determination

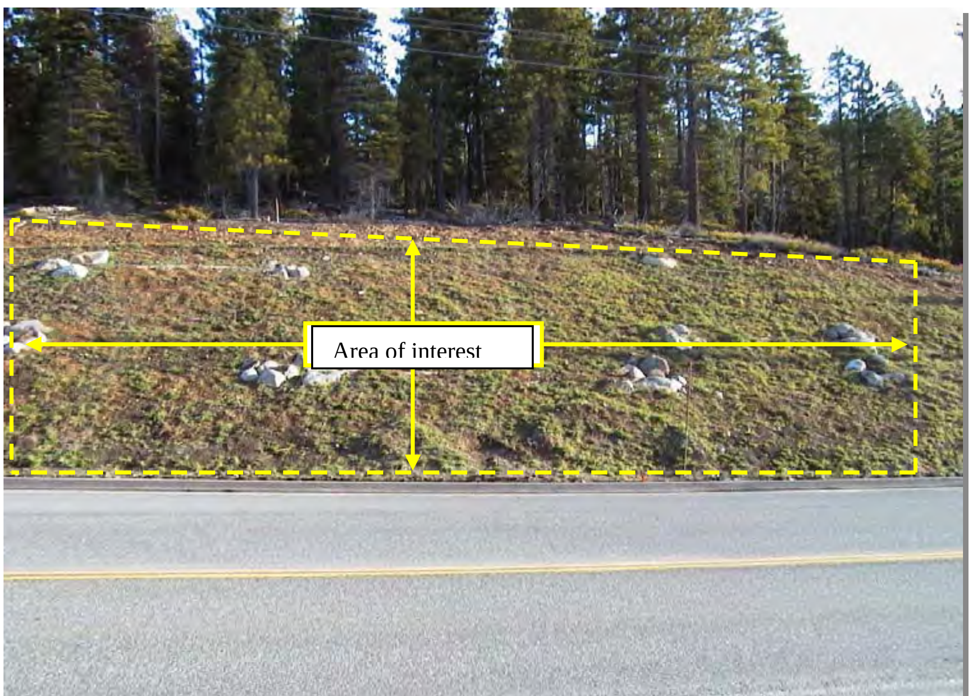

Figure 6.3: an example of delineating the area of interest

of the area of interest usually does not include surrounding untreated or native areas.

This is done in order to clarify the area to be monitored. It should be noted that monitoring will be used to characterize that area only. Inferences can only be made to that specific area. Upon arriving at the monitoring area, the area of interest, or the area about which one wishes to make inferences, is delineated. Monitoring takes place within that area and monitoring data is relative to that area only. Adjoining areas cannot be described by monitoring data. This area needs to be described carefully.

2. Measure the extent of the area. For road cuts and fills, the bottom of the slope will usually be considered the baseline.
3. Develop site map with landmarks and photo point locations. This map is used in subsequent monitoring efforts (see site map example, below).
4. Collect site data as described in (see Appendix C). This is the physical description of the site, its location on the larger landscape, etc.
5. The site is recorded on 3 to 5 photo points. These photo points are recorded on the map as shown and either measured to the nearest landmarks or located by GPS coordinates. If the site has been previously monitored, identify the photo point locations and re-photograph those points.
6. (Optional) Develop a botanical list of the ten or twenty most common plants in that area. This step is optional since plant ID can take place during monitoring. However, we have found that an experienced botanist can ID most of the plants within a short period of time prior to monitoring, making the monitoring procedure itself more efficient.

Transect location process[11]

7. Set a baseline for transects along the bottom of the slope. Transects will run from the bottom to the top of the area to be monitored[12]. These transects will be considered the SAMPLING UNITS.
8. Divide the baseline by ten (ten total possible sampling units or vertical transects).
9. Generate random numbers to locate X and Y coordinates.

First, generate a random number between zero and the baseline divided by ten. For instance, if the baseline is 200 meters long, 200/10= 20. So generate a random number from a random number table or calculator between zero and twenty.

Second, determine the spacing of sampling points along each transect. (Sampling points should be far enough apart so that the same plant is not counted twice. However, this is not critical since in this type of sampling, the transect is considered the sampling unit. While it is critical that each sampling unit be independent, points along the transects are not required to be.) Then, generate a random number between zero and the distance between points. For instance, if each point is to be taken every 2 meters (200 cm), then a random number between zero and two hundred can be used. It is suggested that point spacing be between 0.5 and 2.0 meters, depending on the size of the slope.

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[11] This type of transect location is known as two-stage, systematic random sampling and is covered in Elzinga et al,(1998) pgs 122-125.

[12] This type of monitoring assumes that the vegetation differences, if they exist, will be averaged over the entire slope. In this manner, inferences can be made about the entire slope.

Typically, a total of between 20 and 30 points are preferred. Smaller slopes will require closer spacing in order to achieve the desired number of points.

Third, locate this starting point on the map so that the map so that a permanent record of random starting points can be archived.

10. Mark initial transect X Y coordinates (starting points) on the ground with a wooden stake or other method so that it can be found again.
11. Do pilot monitoring. Pilot monitoring would typically consist of sampling a portion of the transects. Typically, gather data on five of the ten marked transects. Then that data is fed into the appropriate sample size equation (in this case, sample size equation #1 from Elzinga, et al, pg 346, Appendix A). For a complete description of the physical sampling process, see appendix B: Tools and Equipment for Sampling Soil Cover
12. Decide sample size adequacy using appropriate equations from appendix and do appropriate additional sampling, if required. If additional samples are required, determine the additional numbers of transects needed, generate that many additional random numbers between zero five and use those numbers to decide which of the remaining marked transects will be sampled . For instance, if sample size equation 1 shows that seven samples (transects) are required, since we have already done five, three additional transects will be required. So, if the first three random numbers between zero and five are 4, 1 and 5, then the fourth, first and fifth unsampled transects will be sampled. These seven transects will then produce the adequate number of samples to meet adequacy.
13. Sample additional transects
14. Prepare and analyze data

This monitoring protocol can be done quickly and efficiently once the monitoring personnel are familiar with the process.

Data generated in this process can be used to ascertain whether success criteria have been met.

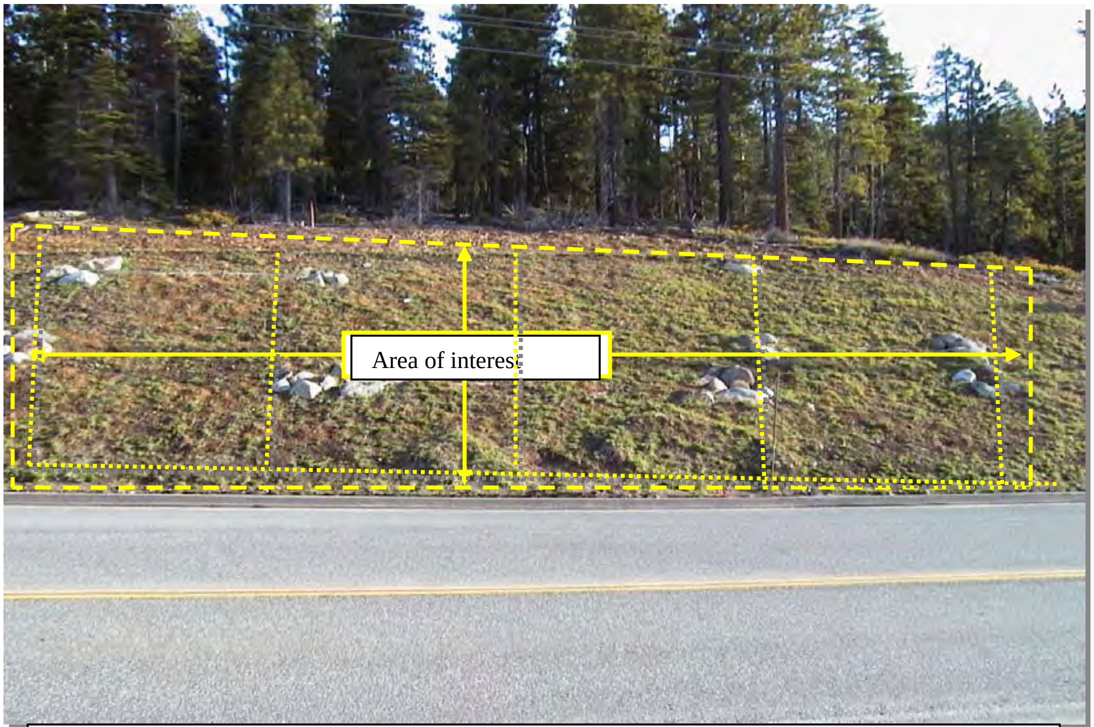


Figure 6.4: photo or area of interest with transects laid out

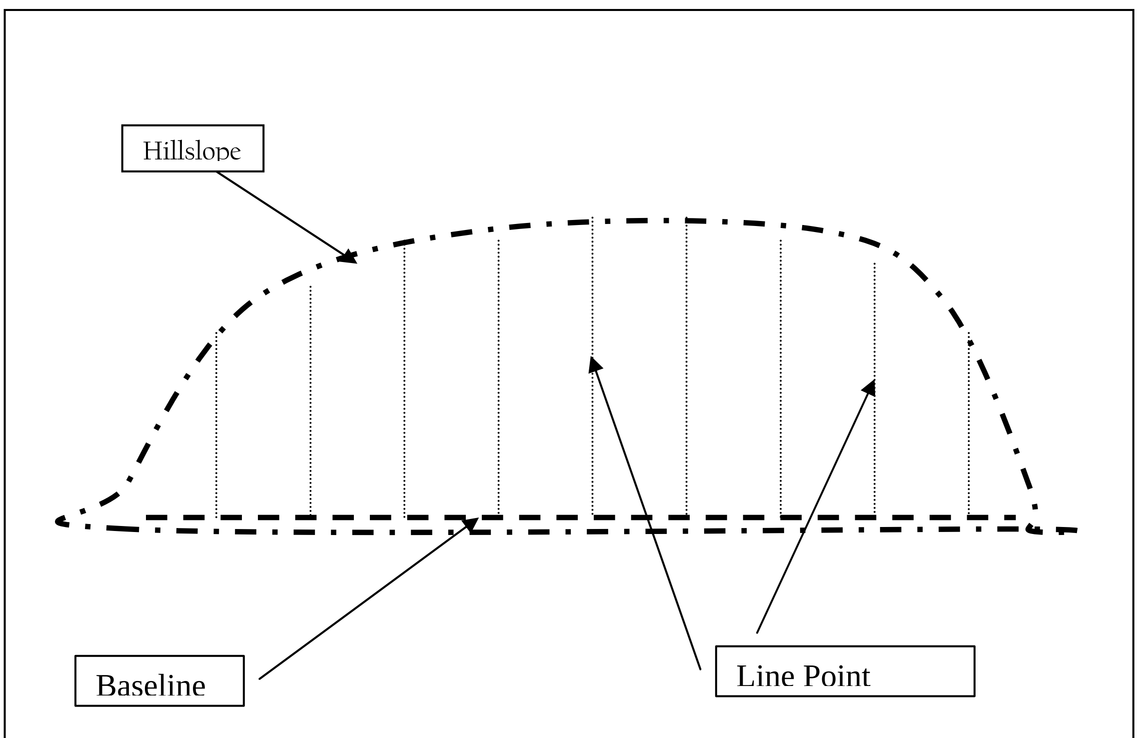


Figure 6.5: description of initial transect layout

SAMPLE SIZE EQUATION

The following sample size equation is used to determine the necessary sample size for estimating a single population mean or total with a specified level of precision (from Elzinga, et al, 1998):

$$n = \frac{(Z_a)^2 (s)^2}{(B)^2}$$

n= The uncorrected sample size estimate

Z_α=the standard normal coefficient from the table below

s= the standard deviation

B= the desired precision level expressed as half of the minimum acceptable confidence interval width. This needs to be specified in absolute terms, rather than a percentage. For example, if you wanted your confidence interval width to be within 30% of your sample mean (i.e. χ ± 30%, your sample mean = 10 hits average per line/sampling unit then B= (0.30 x 10= 3)

Table of normal standard deviates for Z_α for various confidence levels		
Confidence level	**Alpha $_\alpha$ level**	Z_α
80%	0.20	1.28
90%	0.10	1.64
95%	0.50	1.96
99%	0.01	2.58

n* = corrected sample size. The table for this is presented in Elzinga, et al, (1998) on pg 346.

Typically, all of the calculations necessary are performed in a spreadsheet so that if data is entered correctly, instant sample size estimates can be accomplished on site.

OUTPUT

This monitoring protocol provides cover data that is accurate to pre-determined accuracy and precision levels, generally ±10% accuracy and 90% precision level based on ***total cover***. These values are not set by legal mandate but are designed to allow the best resolution with the most efficient use of time. Higher resolution generally requires much greater time commitment. Reducing resolution below 80% makes outcome statements much less accurate.

Output products will vary depending on the purpose of monitoring and the need for specific output data. The current standard for output includes the following:

- Introduction, which lists the purpose of monitoring and other general and specific information of relevance

- Overall site map, generally a digitally produced 7.5’ topo quad with the site located on that quad.
- Project summary statistics by site which lists % total cover, % mulch cover, % plant cover and % bare ground with the standard deviation, coefficient of variation, total points and transects needed to attain the desired confidence.
- Site photo showing a general depiction of the site
- Site map with photo points marked, and including any reference points or physical references on or near the slope such as post mile markers, telephone poles, etc.
- Photo point page showing specific photo points listed by photo point identifiers and date taken

- Site description sheet listing all of the pertinent site data
- Data analysis pages which show more complete data with cover by specific type and plant cover by species
- Appendix, including plant code list and other information not appropriate for the main report.

Figures 6.6 a, b and c: point measurement tool and tripod with ball mount leveling device.

- Erosion evaluation
- Visible signs of erosion are recorded and if monitoring is for project evaluation, success monitoring, signs of erosion will likely trigger management response. In other words, some action will need to be taken to both repair the erosion damage and eliminate the cause of erosion. If this is a pre-project site evaluation, signs of erosion can be used to determine problem areas and potential causes of the problems.

PENETROMETER MONITORING PROTOCOL

OVERVIEW

An extremely useful type of monitoring for sediment source control projects involves the use of a cone penetrometer. Cone penetrometers measure soil density by measuring resistance to force and can thus be used as an index of infiltration. The concept behind this index is that the less dense a soil is, the higher the relative infiltration rate if all other variables are constant. A compacted soil will infiltrate less water and limit root growth more that in a loose, friable soil. A decompacted or low density soil will allow a greater amount of water to infiltrate and will allow roots to more easily penetrate below the surface, thus allowing plant roots access to more water, nutrients and other resources. Penetrometers are relatively easy to use and a great deal of data can be collected quickly. For this reason, this particular instrument is very promising for treatment site assessment, both before and after treatment.

PROTOCOLS

Survey level assessment

Penetrometers can be very used for survey level soil assessment both before and after treatment. Survey level assessment consists of initial probing with the penetrometer in order to assess the depth to refusal or to a root restricting layer. Baseline measurements using the penetrometer can quickly show how compacted the soil may be and/or whether the site in question needs physical treatment.

Statistically valid penetrometer assessment

Penetrometer assessment is done in much the same manner that cover point monitoring is done if statistical confidence is required. In fact, we use the same transects and points as cover point monitoring. Typically, during cover point assessment, the same spreadsheet and calculations can be used to assess mean soil depth and resistance.

Methodology

While there are a number of methods available to measure soil density to specific depths, we have found that the most straightforward method involves measuring depth to refusal (the point at which the penetrometer cannot be pushed any further into the soil) and noting the maximum pressure. This method can be accomplished using an analog cone penetrometer. Typically, a psi reading of less than 300 indicates a non-compacted soil. While further data is being collected, current data analysis indicates that both granite and volcanic soils in the Tahoe region begin to become dense at approximately 300-350 psi and at this point, infiltration seems to be reduced and roots become somewhat restricted. Further research is currently underway to help determine the levels of compaction/ infiltration/root restriction associated with various soil densities.

The two types of penetrometers used with these measurements are Spectrum Field Scout SC-900 and Spectrum Analog Soil Compaction Meters (www.spectrumeters.com).

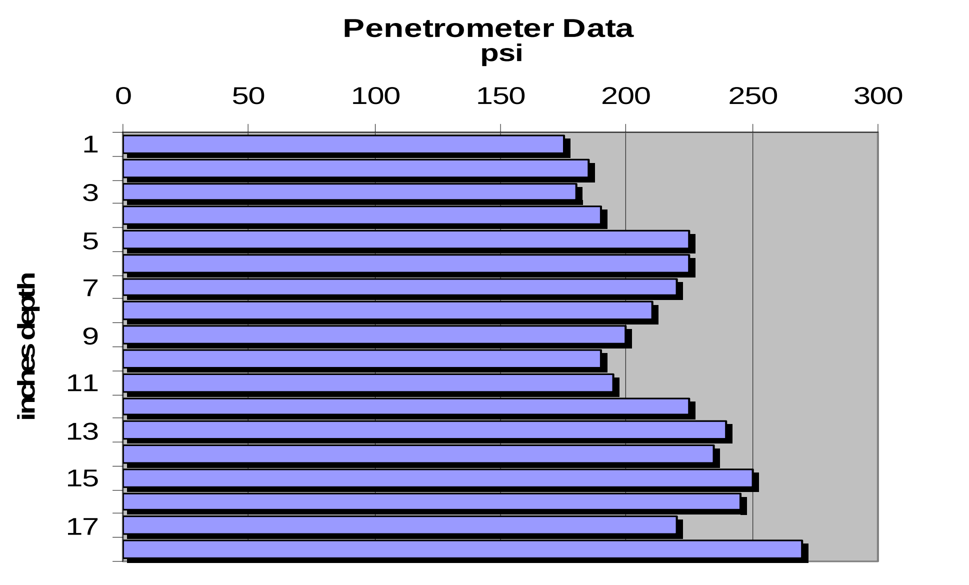


Figure 6.6 data from the Field Scout 900 which measures soil density every inch. This type of data is useful for research level assessment but may be beyond what which is required for site and/or success assessment.

SOIL SAMPLING PROTOCOLS

There are a number of soil sampling protocols that can be used to assess soil nutrients on a particular site. The following protocol has been developed to help assess soils on large projects and represents a solution that combines assessment with cost effectiveness. More samples are usually better but can become costly. This sampling protocol averages soil nutrient values across a particular site with the assumption that a particular site will be treated with the same amount of amendments, fertilizers, etc., rather than small sections of a site being treated separately.

Protocol

The following procedure and tracking process has been developed and used by Integrated Environmental in both standard and experimental soil sampling projects.

1. Field Sampling- area of interest
    a. Locate the area of interest, typically a treatment area, an area where soil cover monitoring is done, etc.
    b. Define sampling intensity.
        i. Low intensity:
            1. composite 5 sub-samples from throughout the site
            2. Sample those 5 areas at a depth of 0-30 cm
            3. Dig a core or hole to 30 cm and collect soil all throughout that 0-30 depth. In other words, you are trying to collect an average of the soil. Take about 100 ml (1/2 cup) of soil from each sub-sampling site and place into a plastic, heavy duty quart Ziploc bag.
            4. Mark bag with sample site name, ID, date of sample and samplers name (see below).
        ii. Higher intensity
            1. Take multiple or replicate samples from the area of interest. At least three (3) replicate samples will be taken so that variability can be estimated[13].
            2. For statistical validity, a sampling grid should be laid out in a stratified random or other random design.
            3. Dig a core of hole as in ‘i.3” above. Determine the sampling depths. Typically, for a research level sampling regime, 0-2, 2-10, 10-20, 20-30 and 30-50 cm levels might

[13] It should be noted that soil is extremely variable. This method most often shows a level of variability that suggests a great number of samples are required for a high confidence level. However, if samples are composited, some variability can be averaged out.

be sampled. For a simpler sampling regimen, 0-2 and 20-30 may be used. Standardizing depths allows comparison with data collected in the Tahoe Basin.

4. Composite soil from each sampling hole evenly from the depth of interest and place in a bag as described above in 'i.3-4'.

c. Recording coarse fragments

   i. When sampling, it will be necessary to estimate the amount of coarse fragments such as cobbles, rock, etc that is not included in the sample bag. For instance, in some volcanic soils, a great deal of the 'soil' is actually rocks that are not included in the sample bag. Estimating is done on a volumetric basis. In other words, if you imagine a square meter or foot of soil, how much of that volume is taken up by coarse material? This is estimated on a % of total volume.

d. Sample sheets

   i. A sample sheet is filled out for the soil sampling area or areas and includes the appropriate information

   ii. Notes would include any information that might effect soil-plant interactions, such as a root restricting layer, gopher holes, ant activity, a large amount of roots, and so forth.

2. Field sampling-reference site

   a. Typically, samples are taken from the area of interest, such as a bare area to be treated or an area that has recently been treated.

   b. Samples are usually taken from a reference site such as a nearby native site or a revegetated site that has shown a good response to treatment and can be used as a comparison site. Reference sites allow us to understand how far we are from nutrient levels of a site that is known to support adequate vegetation.

   c. Samples are taken in the same manner for the reference site as they are for the treatment site and at the same level of intensity and at the same depths.

3. Drying

   a. Soil should be either immediately sent for analysis or dried if sieving is to take place before shipment to the lab.

   b. Drying can be done by leaving the mouth of the bag open and setting in a warm area. Ideal drying temp is 30 degrees C (86°F). This temperature is possible by setting soil near but not in a sunny window. Drying boxes can be constructed as well.

   c. Soil can also be dried by spreading soil in a plastic box such as a small Tupperware container with an open top. Soil can be 'stirred' occasionally.

4. Processing
    a. When soil is to be sieved, dry soil is passed through a 2mm sieve. The material that doesn't pass through is placed in a container and weighed. The material passing through the sieve is also weighed and a percentage coarse material is calculated.
    b. The % coarse material is recorded and used later for back calculating the analysis data to an actual field value (this calculation is discussed elsewhere).
5. Sending for analysis
    a. Soils are sent to the lab (A&L) for analysis (SC3 plus organic nitrogen and other tests as needed.)
    b. A soil sample tracking sheet is marked regarding how many samples were sent, who sent them and the date sent. When the sample data is returned, the sheets are marked accordingly.
6. Instructions for sample identification
    a. Sample sheets and bags will typically marked in the following manner. Additional notes may be included on the bag if those notes will help the lab person understand the sample better. Otherwise, notes should be included on the sample sheet.

LP 2.3 0-2 cm =

Sample ID Standard				
Letters to identify the site	Sample area	Sub-area	Sub-sub-area where applicable	Depth (in cm)
LP	2.	3		0-2cm

In this case, the sample bag would read: LP 2.3 0-2

This would be a low intensity sample site. If more than one set of composited samples were taken, the 'sub-sub' descriptor would be used. For instance, if, on Luther Pass, we were sampling slopes 2,3 and 4 and each area was divided into sub-areas, and each sub area had 3 samples taken all of the descriptors would be used. This would be considered an intensive sampling regime and all of the appropriate information would be recorded in the Soil Sample Data sheets. Which would mean that the sample was taken from Luther Pass, site 2, sub-sample area 3 on April 23rd, 2003 by Hulk Hogan. With this information, which is also tracked on a sample sheet, we can determine where the samples were taken from by the bag ID and if someone has questions, they can ask the sample person.

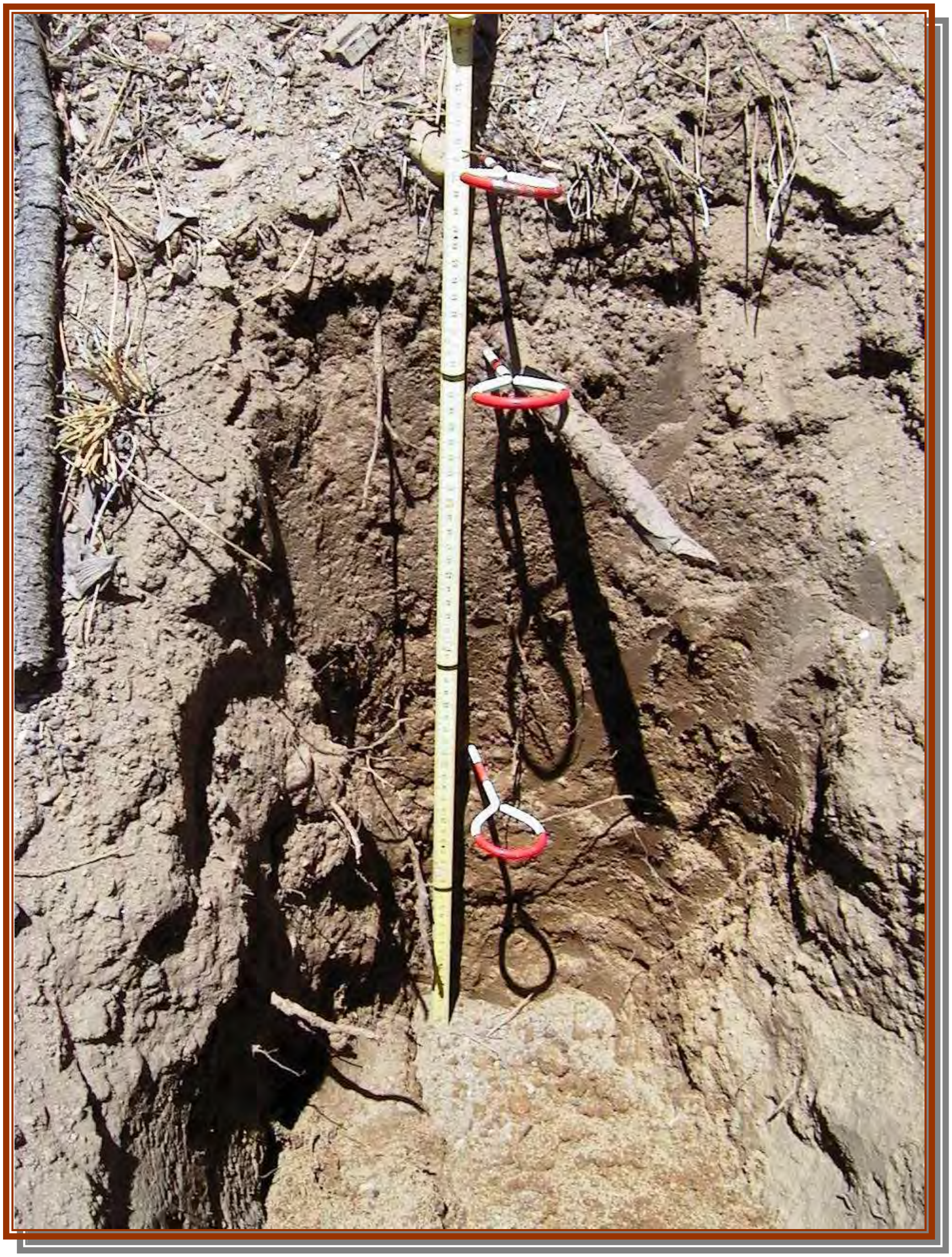
Choose the area of interest, typically a whole slope or treatment area. Locate at least three randomly placed sampling locations that are evenly spaced within the treatment area. Using a pick mattock or other digging tool, dig three pits to at least 12 inches (30 cm). The holes should be rectangular at least 12 inches long as well at deep. Using a one quart Ziploc bag, collect at least 10 small, teaspoon size sub-samples evenly through the sampling pit. Samples should be taken evenly both horizontally as well as vertically so that no single layer will be overly represented within the sample. Exclude rocks, roots and other high organic matter materials which will skew the sample values. When one pit has been sampled, follow the same process for the other two pits, mixing all of the soil material in a single bag. Place the bag in a warm, 70-80 degree f area with the mouth of the bag open to maximize evaporation. For wet soils, the soil bag may need to be shaken and mixed occasionally until dry. (Note that sending wet samples to the lab may increase the amount of nitrate and ammonium measured during analysis.)

Take one sample for each site prior to treatment. Also, choose at least one native and/or well vegetated area and repeat sampling on that or those areas so that a target or ‘reference’ area value can be obtained.

Using the data derived from these samples as well as whatever soil databases are available (IERS, Inc. currently maintains a soil database of over 600 samples taken from around the Tahoe Truckee region.) Amounts of compost and fertilizer are then calculated from those values. In order to calculate specific values, compost and fertilizer values must be known or approximated. Note that when calculating the amount of nutrients and organic matter to add to a specific site, two variables must be considered: 1) the amount of organic matter and total N that will need to be added to the soil to bring that soil up to the appropriate value and the amount of N that will be take up by plants in the first season of growth. As an example, if a soil was tested and total N was 300 pounds per acre but the native reference site value and data base suggested that the appropriate value was 1200 pounds of N per acre, that additional amount of N, in the form of organic matter, would need to be added PLUS an amount that would be represented by the first year plant and microbial biomass produced. That amount may be as much as an additional 4-600 pounds of N per acre.

NOTE: when analyzing soil, the nutrient of concern is total N, which is usually analogous to organic matter. Mineral or fertilizer N is not used to replenish soil organic matter.

SECTION SEVEN: CAVE ROCK MONITORING DATA SUMMARY AND INTERPRETATION



INTRODUCTION

Three years of data have been collected for the Cave Rock Project. This section summarizes the highlights of that data and attempts to interpret that data.

Data Summary

PERIOD OF SAMPLING

Cave Rock Data suggests clearly that the time of sampling is important. For instance, the seasonal changes graph shows that site 8.2 had drastically different amounts of plant cover measured depending on the time of the season. Measurements taken in June were less than 10% while those taken in November were 50%. This data

COVER AND SOIL NUTRIENTS

Plant cover data were compared to soil nutrients, especially total N and organic matter. As figures 7.1 and 7.3 suggest, plant cover and total N are generally related. Areas of low total nitrogen generally support less plant growth. This same trend was also supported by Claassen and Hogan (2002) on older sites. It should be noted that these data are relatively short term. Data should be collected from this site at 5 and 8 years post treatment to determine longer term trends.

SOLAR INPUT AND PLANT COVER

Another measured variable was solar input, or the amount of solar exposure each site received each day to see if there might be a relationship between sunlight and plant growth. As can be seen by figure 7.2, lower rates of solar input are associated with higher levels of plant cover. This data suggests that higher solar radiation results in more evaporation and transpiration, thus depleting soil moisture. This may account for less growth and thus less plant cover. Two conclusions may be drawn from these results:

1) higher solar exposure is likely to be related to a more drastic or dry site. Thus, these sites may need more water if irrigation is applied. They may also be related with lower plant cover and plant survival
2) if a site has a higher amount of solar radiation, that site may need additional materials such as wood chip compost, that adds water holding capacity, to produce the same amount of plant growth.

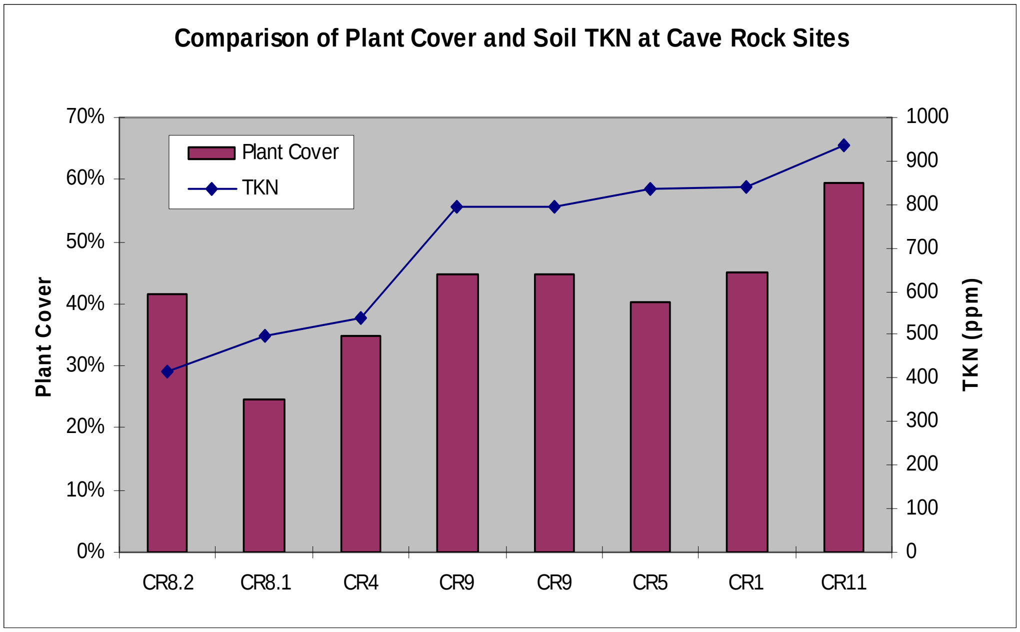


Figure 7.1. Plant cover and soil TKN (total Kjeldahl nitrogen) at Cave Rock sites. The data suggests that there is a positive relationship between soil TKN and plant cover. Cave Rock site 11 had the highest N but may still be below an adequate threshold level. This project would have possibly benefited from more compost added. The single outlier in this dataset, CR 8.1, is a result of early season (June) monitoring on that north facing slope.

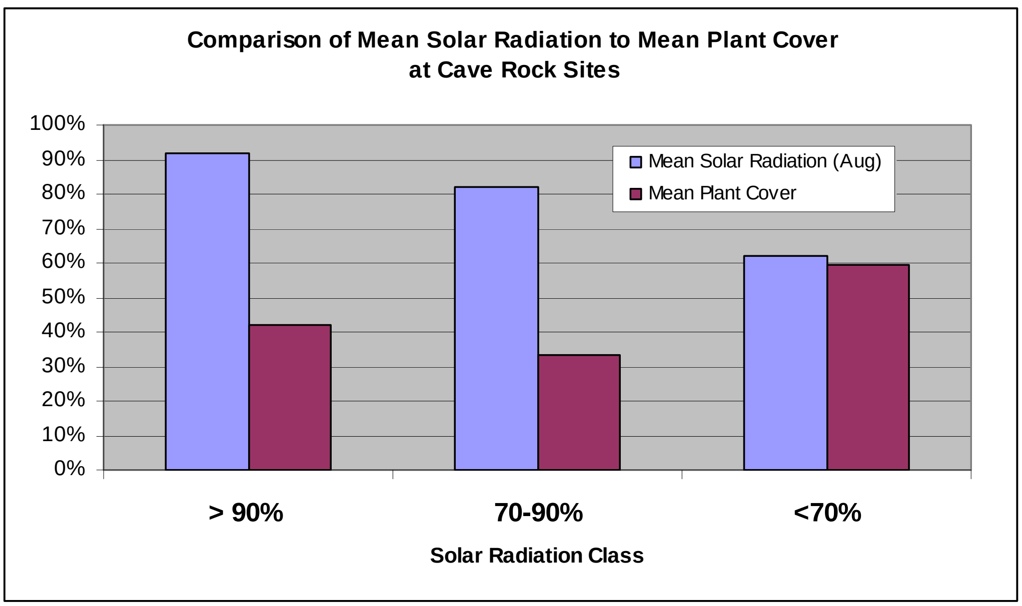


Figure 7.2. Mean solar radiation and mean plant cover at Cave Rock sites. Lower plant cover was measured at sites with high solar radiation (>70%) as compared to sites with more moderate solar radiation (<70%). One potential explanation for these results is that plant growth is limited at dry, heavily exposed sites due to high evapotranspiration (ET) rates, which can rapidly reduce the amount of water available for plant growth.

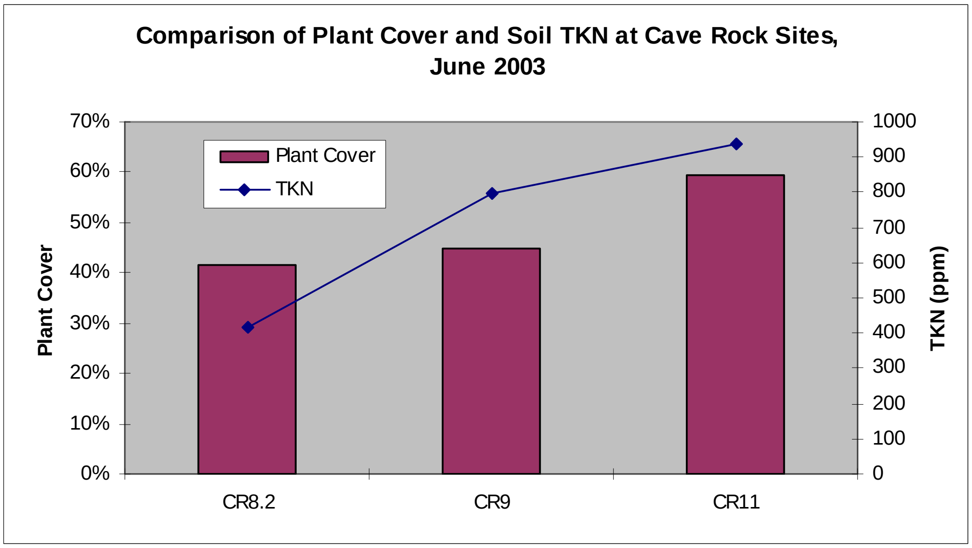


Figure 7.3. Plant cover and soil TKN at Cave Rock sites, June 2003. Since all data represented in the chart above was collected in June 2003, it is reasonable to make comparisons and assess the relationship between the two variables. This data from Cave Rock indicates that plant cover generally increases with soil TKN, which supports similar results from plant-soil monitoring at other sites.

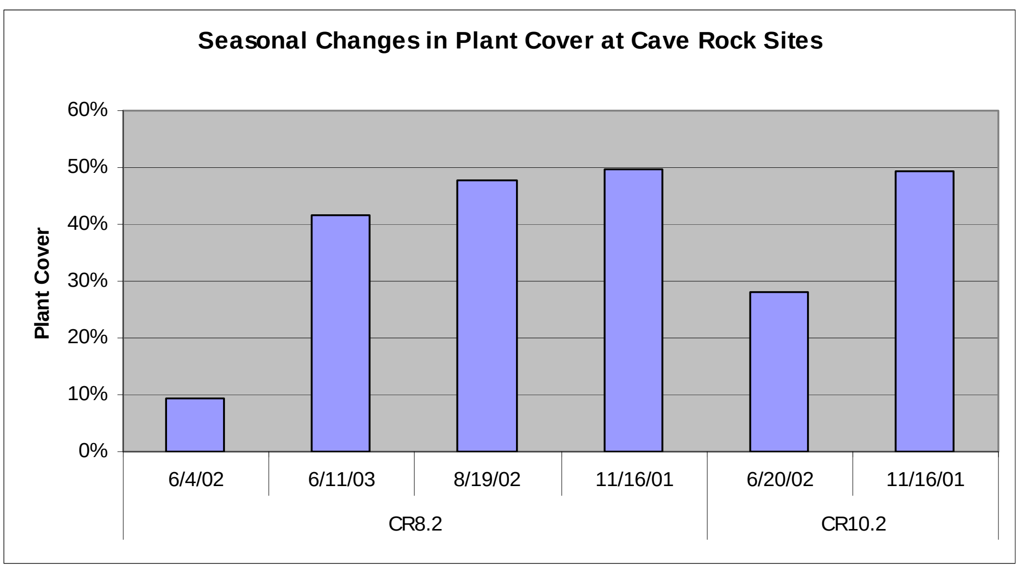


Figure 7.4. Seasonal changes in plant cover at Cave Rock sites. Data suggests that plant cover generally increases throughout the growing season and may remain high into late fall (even during senescence). For this reason, it is critical that the seasonal timing of monitoring is consistent from year to year if long-term trends in plant cover are to be accurately assessed.

Table 7.1 TKN, OM and various soil nutrient values for Cave Rock sites. All site numbers without letters after the site name are associated with post treatment nutrient values.

Sample	TKN	OM	NO3	P (wb)	P (Na ext)	K
CRNA2	375	2.9	10	101	26	90
CRNA1	361	2.2	10	58	25	61
CRCON	267	1.7	11	35	16	41
CR9-02	1087	2.3	7	72	68	211
CR9-01	502	1.2	6	52	47	168
CR8.2-02	507	1.3	9	52	41	112
CR8.2-01	328	0.7	6	10	22	67
CR8.1-02	656	0.8	6	47	36	49
CR8.1-01	337	1.2	6	91	27	107
CR5-02	997	2	11	106	81	359
CR5-01	673	1.5	5	133	65	342
CR42N	290	1.9	10	54	44	160
CR41T	315	2.8	10	47	21	124
CR4-02	827	1.7	20	50	53	337
CR4-01	253	0.6	6	124	23	96
CR4/5-02	329	0.9	5	88	20	92
CR4/5-01	327	0.8	7	28	37	90
CR32N	290	2.0	10	49	21	154
CR31T	387	2.0	11	45	39	123
CR22N	379	2.0	10	45	21	249
CR21T	329	2.0	10	53	21	173
CR12N	392	2.1	10	62	21	298
CR11T	398	2.3	14	63	14	157
CR11.1-02	990	2.1	9	60	51	405
CR11.1-01	882	1.5	5	120	63	442
CR1-02	755	1.5	7	189	34	134
CR1-01	924	1.7	7	75	68	343
CN3	131	0.8	10	17	5	103
CN2	138	0.7	10	19	3	78
CN1	161	0.8	9	22	7	43

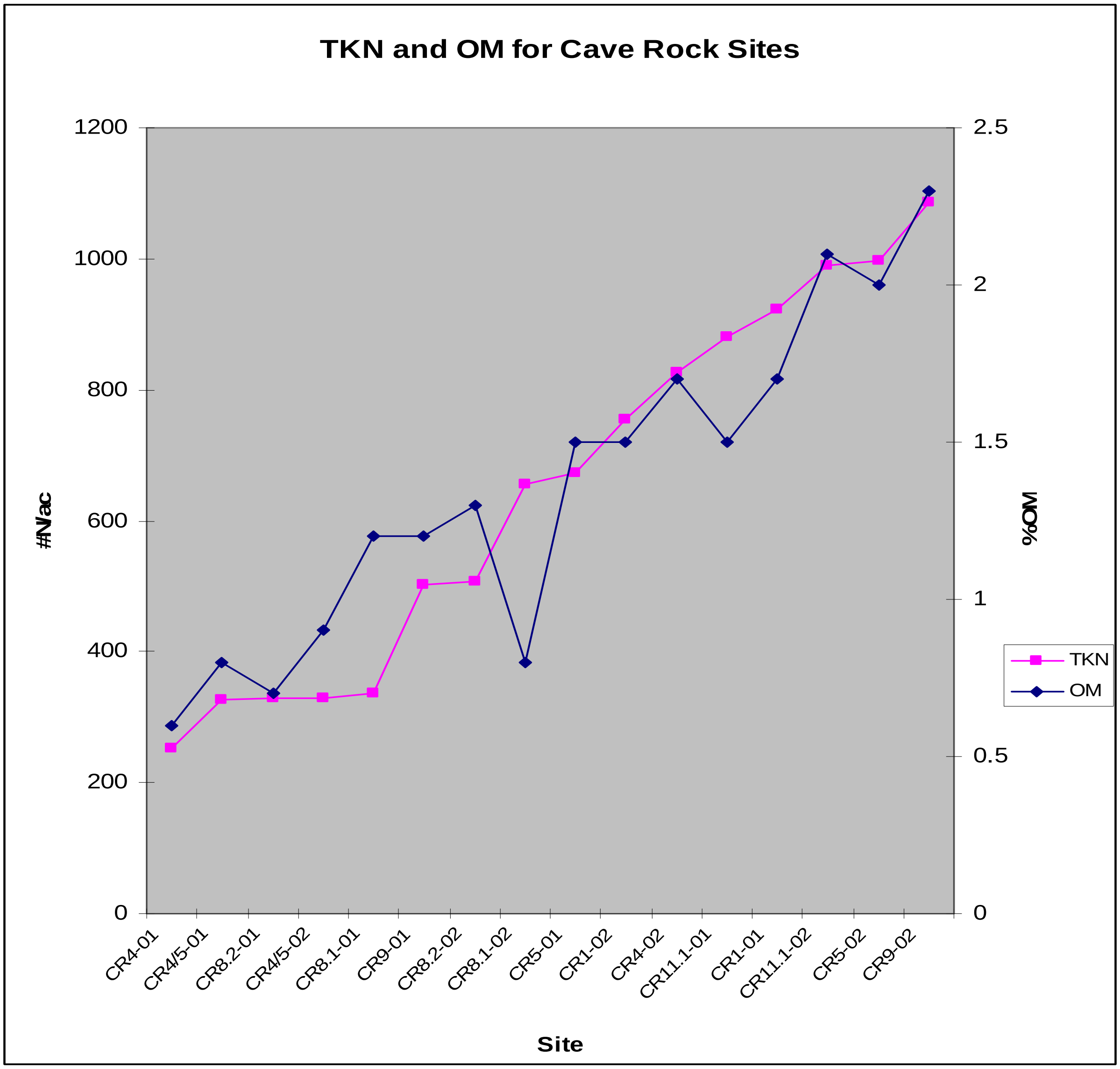
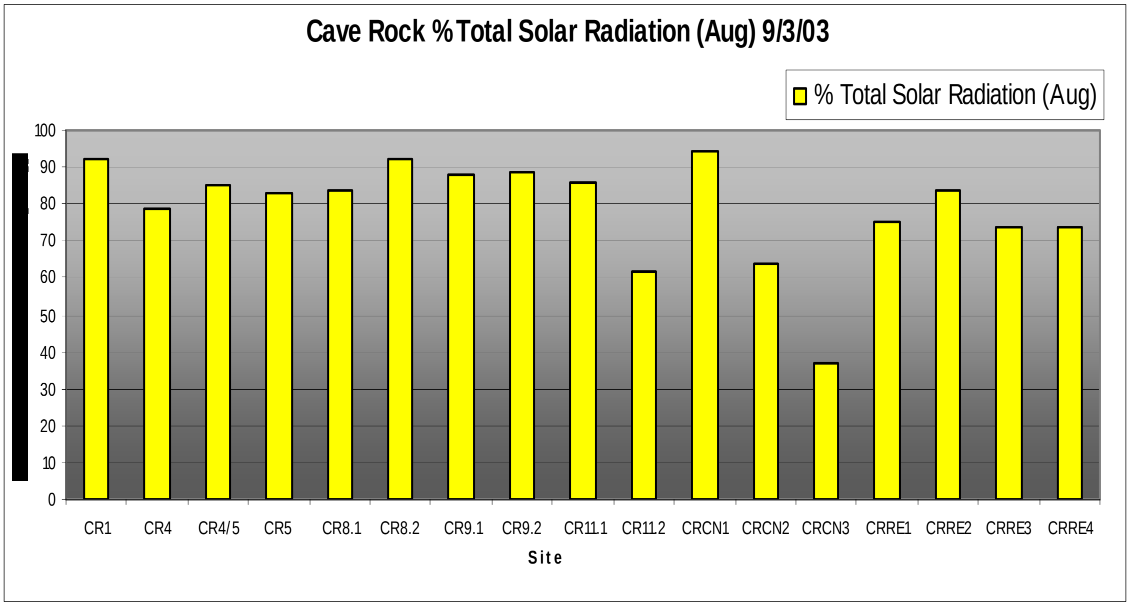


Figure 7.5: the graph above show TKN (total Kjeldahl nitrogen) and organic matter for various sites at Cave Rock. Note what with minor exception, TKN and organic matter follow a similar pattern. This information can be used to assess amount of either TKN or OM needed on sites like Cave Rock. TKN of 1000#/ac and above and 2.2% OM are associated with adequate plant growth.



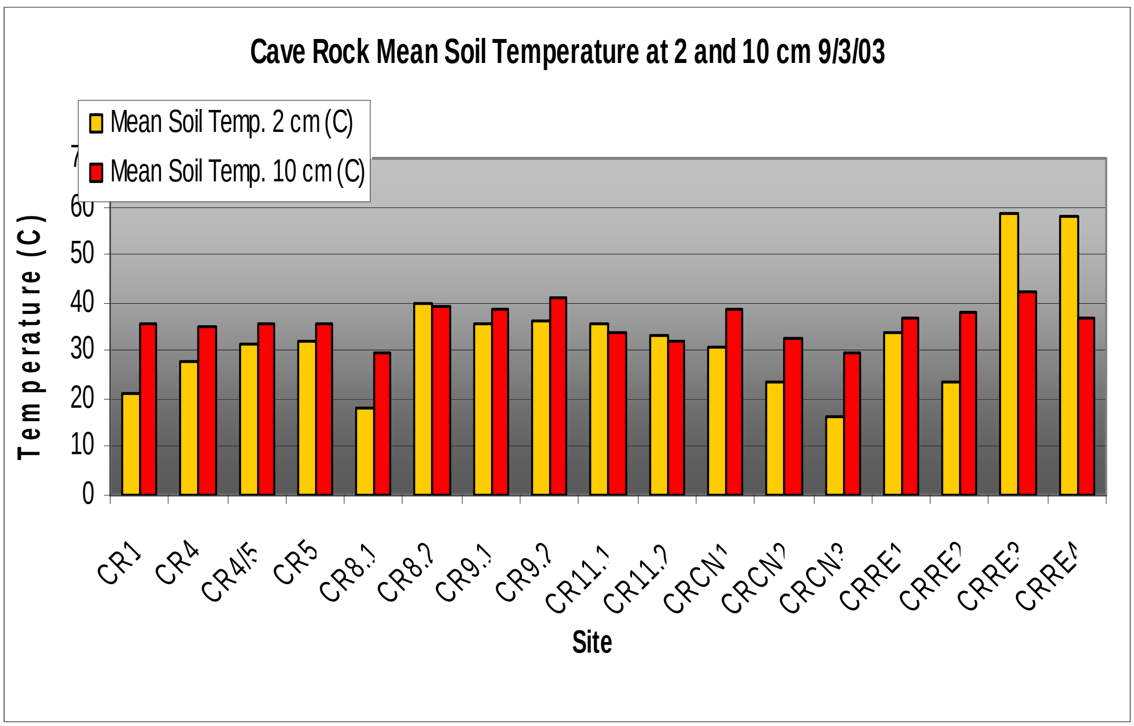


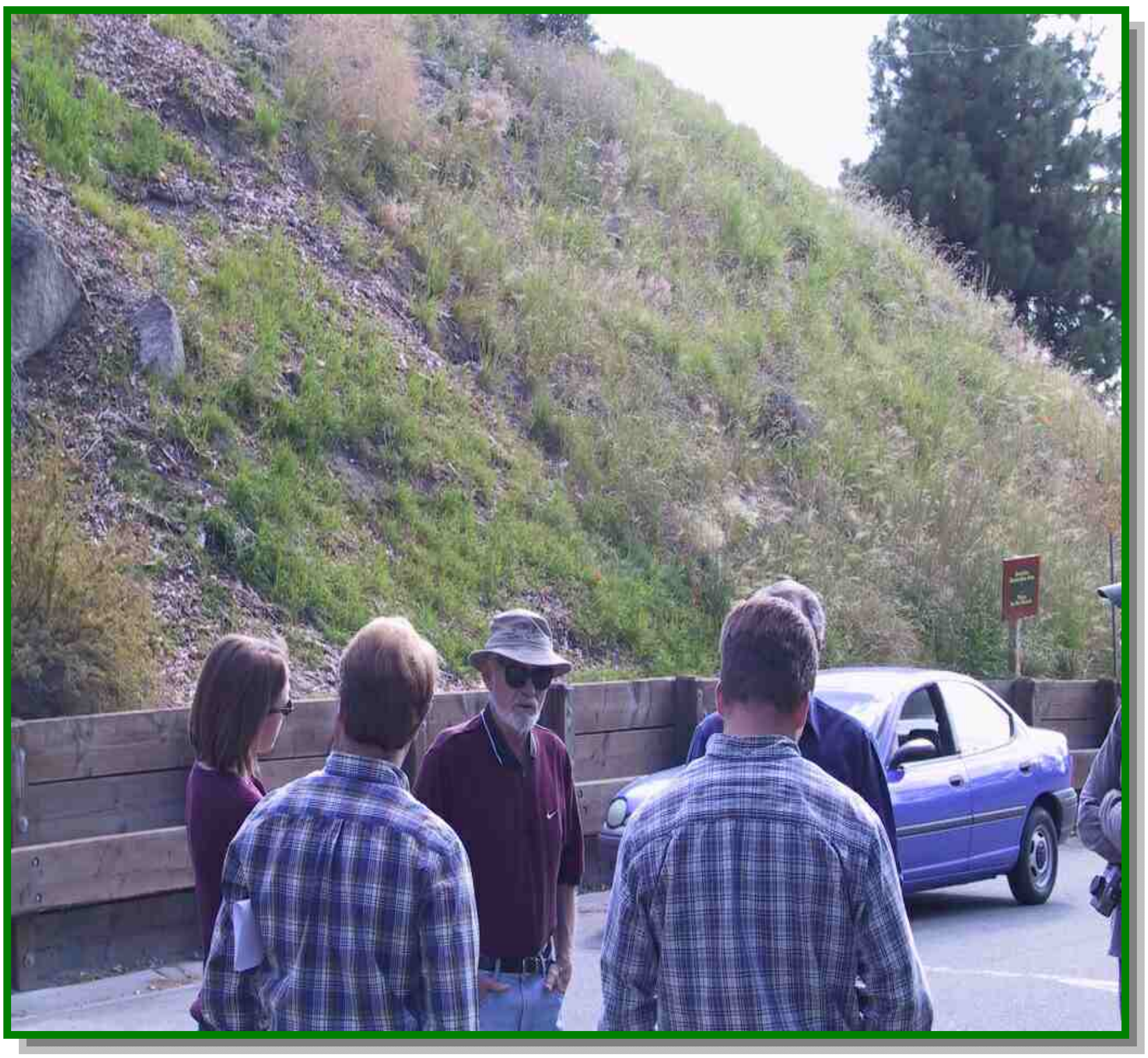
Figure 7.6 a and b: solar radiation and soil temperature data. These graphs illustrate additional information that has been gathered in order to help understand which variables have a measurable influence on plant cover. No obvious correlation was seen.

CONCLUSION

Soil monitoring and sampling data collection at Cave Rock Estates have provided a great deal of information on plant and soil conditions and the potential for erosion from this site. This information is useful to plan and implement erosion control and sediment source control projects and to determine success on this and other projects. If pre-project monitoring and sampling is not done, a project will be based on speculation and guesswork. Post project monitoring provides us with information on how well the project is functioning and whether it has met the stated success criteria. Further, monitoring data can provide information on what improvements can be made. For instance, soil nitrogen and organic matter amounts are relatively low when compared to the Tahoe soil data base. This data suggests that more compost could have been used to invest the soil more completely. While not all of the sites at Cave Rock met the original plant cover success criteria, initial penetrometer data showed a high rate of potential infiltration, thus indicating a very low runoff and erosion potential. The data that has been collected can expand our complete understanding of a site that reaches beyond plant cover alone. Plant community issues can be viewed in conjunction with other ecosystem information. For instance, long term succession will need to be determined on projects such as this one over longer periods of time and can be compared to soil nutrient data to get a better understanding of the successional mechanism. Soil sampling is suggested for every project that is undertaken if proper understanding of existing conditions is to be gained

SECTION EIGHT:

CURRENT STATUS, LESSONS LEARNED, RECOMMENDATIONS



SECTION EIGHT: CURRENT STATUS, LESSONS LEARNED, RECOMMENDATIONS

OVERVIEW

This chapter discusses the current condition of the Cave Rock erosion control project, what lessons have been learned and information gaps filled and includes recommendations for further work. This information is offered as a component in the adaptive management process. These lessons may be (should be) incorporated into future projects of similar design.

Current Status

Cave Rock EC project slopes are stable as indicated by the lack of sediment moving from those slopes as well as the fact that vegetation is persisting. Vegetation type is progressing on some slopes from the original planted grass to a native shrub and tree community. Since the project was completed in two phases, growth patterns are not exactly the same. Further, the second phase consists of mostly north facing slopes, which are much less exposed to solar input and thus are not as dry, due to lower evapo-transpiration rates. No slope failures have been experienced. There are a number of bare areas, all associated with either rodent disturbance, human or animal disturbance or with outcropped bare areas that weren't sufficiently graded.

LESSONS LEARNED

Internal (project based) lessons

The Cave Rock Erosion Control Project has been an extremely productive format for learning, testing and improving. Among the general lessons, we include physical lessons and process lessons.

Physical information

- Slopes of up to 1.25:1 CAN be successfully stabilized using specific soil-vegetative treatments and irrigation combined with proper timing
- Unconsolidated soil on steep slopes will not necessarily slip downslope in summer thundershowers. This statement is supported by observations made during a thunderstorm of approximately 0.75" in 45 minutes, delivered approximately two weeks after treatment of steep slopes but prior to initial irrigation.
- Irrigation may be critical for initial stabilization of very steep slopes that may experience mass failure without irrigation. (In a similar project completed by Caltrans on Highway 267 in 2004, irrigation was not applied. Some slip outs did occur but only where concentrated water was diverted onto the site from an adjoining roadway.)
- Extended irrigation, into the fall, can create shallow rooted plants that have a low regeneration rate. Irrigation should cease in mid to late August, should be infrequent and should not be used to keep plants green for aesthetic reasons beyond the normal growing season

- Six inches of soil depth is inadequate to sustain a robust plant community without some supplemental irrigation. (Since this project was the first of its kind, we hesitated to place more that six inches of loose soil on a compacted substrate at the slope angles involved. We have since learned, and shown elsewhere, that a minimum of twelve inches of soil is required to adequately provide plants with water and nutrients. In the case of a fully exposed granite soil such as most of those at Cave Rock, an even greater depth is suggested.)
- Compost additions of two inches were not adequate to supply a fully robust soil nutrient cycle to these systems, given the preexisting amounts of N and organic matter in the pre-treatment soil. Again, as an early project using compost, we were hesitant to use too much material. Other subsequent projects have shown us that deeper tilling and more organic amendments are not only justified but required to achieve project goals. In this case, the amounts used will likely translate to a slower successional process.
- Compost with a high amount of coarse woody material helps hold water in the soil. Woody material also breaks down more slowly, thus providing a longer term nutrient benefit. This information has been gleaned for other projects done subsequent to Cave Rock.
- Plants can and do provide shear strength in very steep soils. (Studies are currently underway in the Tahoe Truckee area to quantify shear strength provided by plant roots.)
- Adequate soil preparation is critically important to plant root development and infiltration.
- Plant cover will change over time. When grasses are planted, they can change and give way to shrubs, trees and other native species. The Cave Rock project may be used to determine long term trends. Those trends may not be clear for several to many years.
- Information sharing: sharing information on projects like Cave Rock, where new methodologies are being used, is essential for advancing practices, methods and materials for sediment source control projects. We have shared the Cave Rock project with an estimated 2-300 persons over a five year period. While the Cave Rock Erosion Control project has met with criticism from some individuals, that criticism can only be harmful for advancement of erosion control projects, especially when that criticism is unfounded.

Process information

- Follow-up treatment is critical in any adaptive-management based project, such as this one.
- Follow-up treatment can be accomplished with a well-written, flexible contract and a cooperative contractor.
- Revegetation/erosion control contractors should be officially ‘qualified’ for challenging jobs such as this one since many changes may be made. This reality

points out the weakness of a low bid contracting systems where a contractors profit may lie in change orders rather than the base contract funding. A contractor who bids adequately and is flexible is critical for a positive outcome on a project such as this.

- Information sharing is an important step in the continued effort to improve projects. We have hosted at least 25 groups at Cave Rock in an effort to discuss and improve this and future projects.
- Monitoring will be an absolutely critical part of any project where project performance evaluation, project improvement (the existing or future projects) and follow-up work are to be done
- Research data and field studies clearly suggest that soil physical and biochemical (nutrient) monitoring is at least as important as plant cover monitoring in determining erosion protection and sustainable ecosystem restoration. However, mulch cover monitoring will be extremely important to help determine whether adequate soil protection is in place.
- Most importantly, project partners, including the sponsor, funding agencies, planners and contractors, must be willing to take and accept some calculated risks in projects in order for those projects to find improvements. Contractors that are not comfortable taking these risks should not be asked to bid.
- Monitoring should be linked directly to project goals. That is, infiltration, no erosion, etc., should be the basis of success criteria and not solely plant cover, since we now understand that plant cover alone is not always adequate to control erosion.
- Direct oversight of project installation must occur. Daily or almost daily inspections of construction and erosion control installation is critical. Specifications must be followed or adjusted as appropriate by the person who prepared those specifications or by someone who has a complete understanding of the intention and process described in the specifications.
- Contractors (general and erosion control) need to be flexible and cooperative. Contractors whose main goal is to maximize profit at the expense of project performance should be screened from the contractor pool if possible.
- Communication between contactor and project planners and engineers is critical to maximizing performance. Many ‘mistakes’ that occur on projects may be the result of incomplete or improper understanding which could be circumvented with regular communication.

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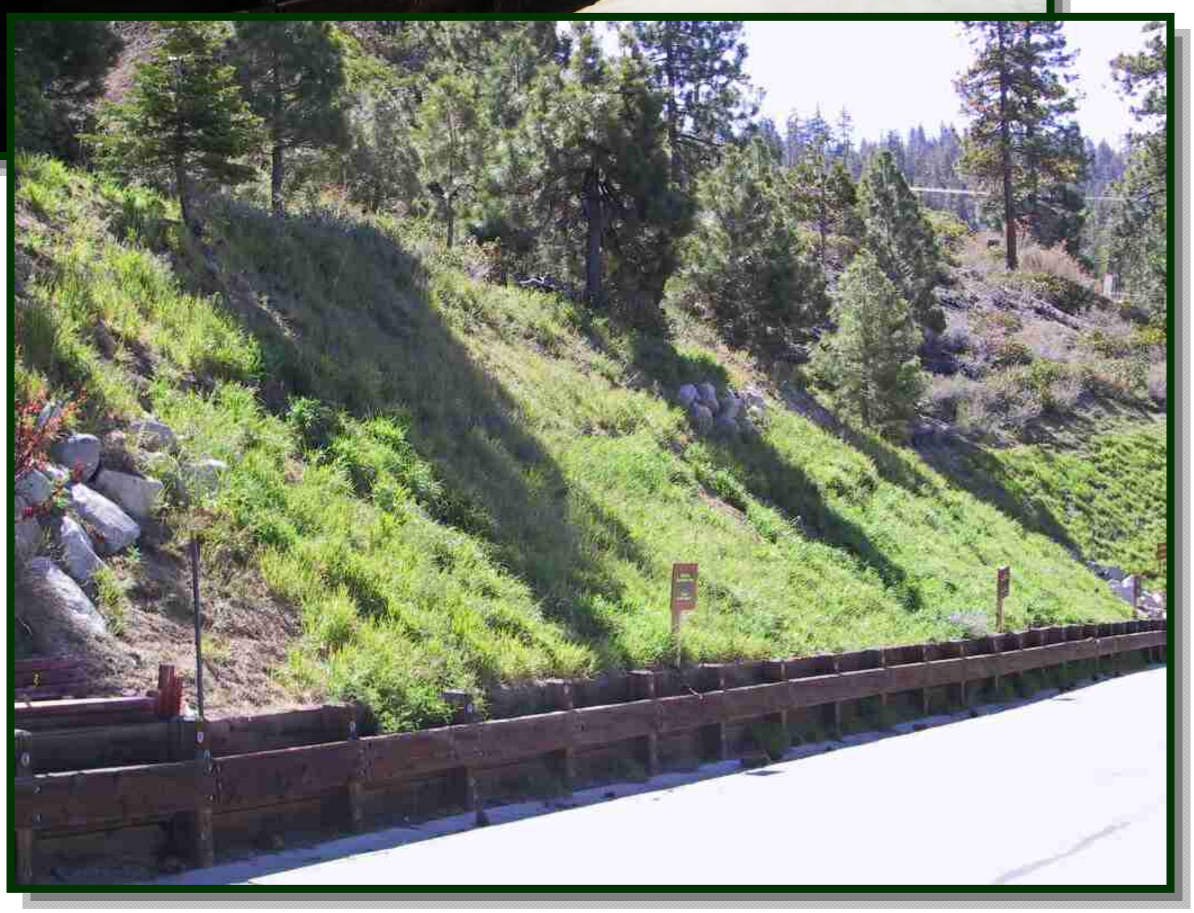
SECTION NINE: AFTERWORD



SECTION NINE: AFTERWORD

Monitoring within an adaptive management framework offers many benefits to sediment source control projects. These benefits include the ability to determine the success of a project, the ability to learn how to make projects more effective, the ability to more readily share information and equally important, the potential to develop a consistant and effective agency standard of evaluation. The objective of this report has been to assist with these and other goals in an ongoing attempt to further the effectiveness of upland sediment source control projects in and beyond the Lake Tahoe Truckee region. This report and the work represented here are a step in that direction and should be considered in that light. We offer starting points for success criteria and monitoring protocols which are suggested as opportunities to apply these methods in a site specific manner.

Monitoring provides an important link to project success and understanding. This monitoring should be based on field trials, experience, a foundation of established knowledge and understanding and communication between stakeholders whenever possible. We hope that this report has offered some useful information to those ends.

APPENDICES

APPENDIX A: CAVE ROCK SOIL -VEGETATION SPECIFICATIONS

333 REVEGETATION

OVERVIEW

The Cave Rock Erosion Control project will use vegetation, mulch and soil amendment to control erosion at its' source by keeping soil in place on the steep slopes of the project. This will be accomplished by replacing the components necessary to create and sustain a robust soil-plant system, increase water infiltration and protect the soil surface with a long lasting mulch. These elements of this vegetation-based erosion control project will help assure a long-lasting improvement in water quality and aesthetics in this project area.

MATERIAL AVAILABILITY

Some of the materials required to complete the revegetation portion of the project are in limited supply. Within 60 days of award of the contract the Contractor shall submit to the Engineer written statements from the suppliers of seed, mulch, compost, fertilizer and live plants. The written statement shall state that the Contractor has made arrangements to obtain these materials for Part 1 of the project and that the materials will be available when required to allow the project to be completed on time. The suppliers name and telephone number shall be included on the statement.

SOIL AND SOIL AMENDMENTS

Soil is the foundation of an erosion resistant plant community. In order for plants to form a robust community that is capable of protecting the soil surface from erosion and produce excess biomass that will provide a protective surface mulch, the soil must contain amounts and types of nutrients that will sustain that plant community. Additionally, a dynamic soil is capable of creating soil aggregates that function in many ways to reduce erosion. Much of this project has as its' goal the re-creation of adequate soil nutrient cycles.

Soil nutrient cycles will be re-created through the use of locally derived compost and slow-release organic fertilizer. The amounts used will be based on soil samples taken from each site. Those samples will be compared to well-vegetated soils in the same area. Amounts of soil amendments (compost and fertilizer) will be based on this data.

MULCH

The mulch used on this project will be native pine straw. This material will provide a long term (5+ years) protective soil cover. Pine mulch reduces or eliminates many erosive forces by intercepting raindrop impact and reducing overland flow velocities. Mulch also serves to increase water infiltration and soil residence time by reducing evaporation from the soil. This increase in water infiltration and soil water residence time effectively increases water available for plant growth.

SEED AND PLANT MATERIAL

Plant material will be derived from local sources whenever possible. Local plant material is better adapted to fluctuations in local climate than many non-indigenous species. Additionally, local species do not generally exhibit invasive habits as often occurs in some non-native revegetation species. A major difference between this planting approach and typical approaches used in the past is that, in terms of seeding, we are attempting to reinoculate the soil seed bank and create a robust plant community rather than simply establish a replacement planting. Many revegetation projects in the Lake Tahoe Basin and elsewhere have used the replacement approach, in many cases unsuccessfully. The forces working against establishment of seeded species are great. Such elements as rodents, birds, insects, weather and grazing mammals can have a significant first year impact on seed and seedling establishment. Native systems have up to thousands of seeds per square foot and this fact allows those native systems to respond to disturbances in a much more dynamic fashion. Disturbed systems such as the one we are attempting to restore have had most of this seed bank removed. Therefore, this project will use a greater amount of seed than is typically applied with the aim of recreating a seed bank in the soil. This seed bank then, will be able to respond to ‘adverse’ forces much better that a strict ‘replacement’ amount of seed.

TIMING

Spring vs. Fall planting

Part 1 of this project is designed for construction in the Spring of 2001. Cave Rock Erosion Control Project 2A has demonstrated the ability of a spring planting to develop a successful plant community. The crucial element of this spring planting is rewetting of the soil profile. If the entire soil profile is rewetted following materials application, the soil mulch and organic amendments will allow the soil to retain a great deal of the applied water and consequently allow plants and seed to establish and grow even in the dry season. If the soil profile is properly and completely rewetted, planting may take place as late as July and August, as has been successfully demonstrated on the 1999 Dollar Hill penstemon planting.

SEQUENCE OF APPLICATION

The following list outlines the revegetation activities in sequence. This procedure will take place for each slope area following mechanical treatment:

1. Construction of mechanical treatment which includes: unclassified excavation, stacked rock retaining walls, soldier pile retaining wall with stacked rock facing, boulder remove and reuse, adjust sewer cleanout to grade, and placement of unclassified fill.
2. Delineation of revegetation treatment area by revegetation specialist
3. Application of compost
4. Tilling or incorporation of compost into top 3 inches of soil. (This step will include loosening of compacted or consolidated resident soil material if the construction contractor has not done so.)
5. Installation of pine wattles
6. Application of topsoil
7. Installation of live plant seedlings
8. Application of seed
9. Application of fertilizer

10. Raking seed and fertilizer into the top 1” of soil
11. Application of pine mulch
12. Tackification of pine mulch
13. Re-wetting of soil profile

MATERIAL APPLICATION

CONSTRUCTION

EXTENT OF REVEGETATION TREATMENT

Revegetation treatment shall extend to at least three and no more than five feet above the actual cut-face surface of each project area in order to slow and intercept overland flow onto the project area. The construction contractor will scarify this portion of the project area in order to increase runoff infiltration and root penetration into those areas. This scarification can take place with teeth mounted on the excavator bucket, a scarifying device mounted on the bucket of a Grade-all or any other method that is agreed upon by the contractor, the revegetation specialist and engineer. The revegetation specialist will mark the extent of all treatment areas with pin flags or other suitable marking devices. These markers will be left in place until final project inspection.

PREPARATION

SOIL PREPARATION

Soil: All treated areas must consist of soil or soil-like material that is capable of infiltrating water to at least 6 inches. Compacted soil or saprolitic parent material must be loosened or broken up in order to allow this infiltration capacity. In areas where this is not possible, the construction contractor must place at least 3 inches of unclassified fill material over a loosened or broken subsurface.

Surface Roughness: Surface must be left in an irregular, uneven fashion when grading and revegetation treatment are completed. Surface irregularities must be no more that six inches in total relief but soil surface must not be smooth. Irregularities produce micro-environments for seed and plants.

Woody Materials: The construction contractor will place and key into the slopes woody materials such as roots and branches in critical areas in order to minimize human and large mammal traffic.
Off site soil preparation: Soil material from at least three and no more than five feet above the project area must be loosened and planted. The same requirements will apply as are stated in the ‘Soil Preparation’ section, above.

REMOVAL AND STOCKPILING OF SALVAGED TOPSOIL

In areas where slope lay-back or other construction will take place that will disturb or remove native or existing vegetated soil, that soil shall be salvaged and stockpiled above or near the project slope. For the purposes of this project, ‘Salvaged Topsoil’ will be defined as*: the top 1.5 inches of material that includes organic matter, plant material and mineral soil from a native or well vegetated site.* This Salvaged Topsoil shall not remain piled for more than 30 days without approval from the revegetation specialist. Stockpiles shall be no more than five feet in either height or width. Length may be up to twenty feet. Salvaged Topsoil should be stored in a cool shaded area where possible.

COMPACTION

Soil, subsurface and applied materials shall not be compacted. Compaction reduces water infiltration and creates differences in bulk density between surface and underlying materials which may lead to mass slope failure.

PLACEMENT OF SALVAGED TOPSOIL

Any available Salvaged Topsoil shall be placed at the top of the reconstructed slope and raked downward. Salvaged Topsoil shall be spread to cover the top half of the slope only.

COMPOST

Application Methods

Compost can be placed on the slope using any number of methods. Compost shall be applied to the appropriate depth as specified on the plans. Compost shall be spread evenly across the slope. The process of spreading shall consist of raking the compost upward or diagonally upward in order that gravity doesn't move compost downward and concentrate it on the bottom half of the slope through the process of placement. **Compost placement shall be inspected by the revegetation specialist on each slope prior to incorporation into the soil** so that proper depth can be field checked and verified. The revegetation inspector shall be notified at least 24 hours prior to application of compost.

Incorporation into soil

Compost shall be worked into the soil using a rake, pick mattock or equivalent, or excavator or tractor bucket with teeth. Other methods may be employed by the contractor with the prior approval of the revegetation inspector. Compost shall be mixed evenly into the soil to a depth of at least 3-4 inches.

PINE WATTLES

Construction of pine wattles

Pine wattles will be constructed according to the specifications listed below in the 'Materials Requirements and Samples' Section.

Placement and Installation of pine wattles

Pine wattles will be placed as shown on the plans.

Pine wattles will be installed 2-5° off slope contour.

Pine wattles will be installed so that 2/3 of their thickness is buried below the soil surface.

Pine wattles will be staked with wooden 2” x 2” x 12 to 18 inch stakes, depending upon the thickness of the wattle, unless otherwise approved by the revegetation specialist. Wattles will be staked 6” from each end and every 3 feet along their length. Stakes will protrude from the tops of the wattles no more than 2 inches. Stakes may be cut following installation by power saw if necessary.

Wattle installation will be demonstrated by the revegetation specialist prior to installation by the Contractor.

Excavated material will be placed on the uphill side of the pine wattle and lightly tamped to backfill the length of wattle.

LIVE PLANT MATERIALS

- Live plant material will consist of plants grown from seed or cuttings collected within the Lake Tahoe Basin or within 50 miles of the Lake Tahoe Basin and within ±1000 vertical feet of the project elevation. Seedlings will be delivered in 2¼" x 2¼" x 5" deep pots unless otherwise specified or approved by the revegetation specialist.
- Seedlings will be delivered to the Tahoe Basin a minimum of 2 weeks prior to planting in order to acclimate plants. Storage and interim care shall be the responsibility of the contractor and shall be approved by the revegetation inspector prior to plant delivery. During storage and interim care, plants shall be kept moist and shaded. At no time will plants be allowed to dry out.
- Seedlings will be inspected by revegetation specialist upon delivery in order to ascertain condition and viability. If plants are in poor health or show a low level of vigor, those plants will not be allowed to be planted nor will payment be made for planting.
- Seedlings will be delivered to the project site no more that 24 hours prior to planting unless otherwise approved by the revegetation specialist. Upon delivery to the project site, plants will be kept moist and in a shaded environment.

Placement

- Plant placement will be specified by the revegetation inspector prior to planting. Plants will be planted in a 'planting island' configuration consisting of areas of approximately 200ft^2 within which 25 to 100 plants will be placed, depending upon species. Areas, plant numbers and species will be specified by the revegetation inspector at least 24 hours prior to planting. The revegetation contractor must inform the revegetation inspector at least 3 working days prior to planting so areas can be delineated and plants assigned to areas.

Planting

- Seedlings will be planted in the following manner:
- A hole will be dug a minimum of four times the width of the planting pot and 10 inches deep.
- Two heaping tablespoons of fungal mycelium based fertilizer will be mixed with twice that much excavated soil and added to the bottom of the planting hole. The fertilizer-soil mixture will then be covered with 1 ½ to 2 inches of excavated soil.
- The planting hole will then be filled with water to it's rim, allowed to drain and refilled a second time. When all of the water has drained from the planting hole, the seedling will be planted.
- The seedling will be placed in the excavated hole and backfilled with the excavated material to the crown of the root.
- Excess material will be placed so as to form a semi-circular watering berm on the bottom half of the excavated hole to trap water. This berm will be 6-8" radius from the crown and 2 inches high.
- After the seedling has been planted, the planting hole has been backfilled and the watering berm has been constructed, 2-3 inches of pine needle mulch shall be placed around the plant to a diameter of at least 6 inches.

- Each plant will then be rewatered, saturating each planting hole without allowing water to run down the slope below the plant.

SEEDING AND FERTILIZING

Fertilization/soil amendments

Fertilizer can be hand applied, applied by pneumatic applicator or hydoseeder. Fertilizer shall be applied as evenly as possible. Fertilizer shall then be lightly raked into the soil surface no deeper than 0.5 inches using the flat (back) side of a flat steel rake. Seed and fertilizer can be applied together or in a 2 step process and then raked in at the same time. Raking shall be from the bottom to the top of the slope in an upward direction.
The revegetation specialist shall be notified at least 24 hours prior to initial application of fertilizer and fertilization application shall not commence until revegetation specialist is on site to inspect and approve application and methods.

Seeding

The seeding portion of this project is designed to partially replenish the soil seed bank as well as create a robust plant community. All seed will be collected from within the Lake Tahoe Basin or within 50 miles of the Basin and within ±1000 vertical feet of the project elevation unless otherwise noted. Seed from areas adjoining the project should be given priority. If these criteria cannot be met, substitutions may be approved by the revegetation specialist.

If any of the seed material listed is not available, the Contractor MUST contact the revegetation specialist to arrange substitutions **prior to ordering** seed.

Seed tags must be presented to the revegetation specialist 24 hours prior to application of seed to the project site. If seed tags do not match the seed mix listed in these construction specifications and if written variance has not been received by the Contractor, seed will not be allowed to be applied until proper seed is inspected and approved by revegetation specialist.

All seed amounts are given in PLS (Pure Live Seed) equivalent. Bulk pounds will be greater than PLS pounds and is the responsibility of the Contractor to assure that seed is delivered and applied in PLS equivalent.

Seed can be hand applied, applied by pneumatic applicator or hydoseeder. Seed shall be applied as evenly as possible with the heaviest amount of seed applied to the top of the slope. If applied by hydroseeder, seed must be mixed in the hydroseeder tank for no more than 45 minutes. Wood fiber will be mixed in the tank as a tracer at the rate of 200 pounds per acre. If applied by pneumatic applicator, seed will be fed directly into the airstream on either side of the fan but in no case shall seed be fed into the inlet side of the hammermill if the machine is so equipped.

Following application of seed to soil surface, seed shall be lightly raked into the soil surface no deeper than 0.5 inches using the flat (back) side of a flat steel rake. This process increases soil-seed contact and improves germination.

The revegetation specialist shall be contacted at least 24 hours prior to seeding by the revegetation contractor and seeding shall initially commence when the revegetation specialist is on site. Seeding shall proceed with the approval of the revegetation specialist and feedback will be given by the revegetation specialist to the revegetation contractor to assure proper seed application.

MULCHING

Application thickness

Pine mulch shall be applied to a uniform thickness of 1.5 inches to the entire project area as delineated in the plans and described above in 'Extent of Revegetation Treatment' section of this document.

Approved methods

Pine mulch shall be applied by pneumatic application equipment (blower) in order to attain the greatest mulch-surface contact. Material specifications are listed below.

TACKIFIER

Tackifier shall be applied evenly over the pine mulch so that the mulch may withstand wind and other disturbance until the plant material can become established. A wood fiber mulch will be used as a tracer to assure even distribution of tackifier. Tackifier and wood fiber mulch will be applied by hydroseeder equipped with a paddle agitator and recirculating pump. Material will be mixed for a minimum of 15 minutes prior to application. Tackifier shall be applied to pine needle mulch within 48 hours of mulch application unless otherwise approved in writing by the revegetation inspector.

IRRIGATION

Soil profile re-wetting

Following complete revegetation treatment, each project area will have its' soil profile rewetted in the following manner:

Timing: Re-wetting will occur within 48 hours of installing live plants and revegetation treatment unless otherwise approved by the revegetation specialist. Soil will be rewetted to field capacity but not to saturation. In the event of surface runoff, irrigation will cease immediately. Re-wetting will take place by the use of low-flow stream rotor irrigation heads set up temporarily at the slope bottom, top or combination of placements so that the entire slope is wetted. Approximately head to head coverage shall be employed so that the precipitation rate is as uniform as possible. Irrigation plan shall be inspected and approved by the revegetation specialist prior to the start of irrigation. Other types of irrigation may be approved by the revegetation specialist if they fulfill the same function and with the same low infiltration rate as described above. In no case shall direct application from a watering truck be allowed. Contractor will notify the revegetation Inspector at least 48 hours prior to irrigation so that the inspector can be present before and during initial irrigation. **Revegetation inspector must approve the irrigation system design, installation and operation.**

MATERIALS REQUIREMENTS AND SAMPLES

Compost

Compost shall consist of material derived from chipped, shredded or ground vegetation, wood products, dairy manure or a combination thereof. Wood products shall be derived from the Lake Tahoe Basin wherever possible. Compost shall be processed so that an internal process of at least 57 degrees C (135 degrees F) is maintained for 15 continuous days. The compost shall be turned a minimum of 10 times during the composting process. And shall go through a minimum of 15 days curing period after the 15 day thermophyllic process has been completed. Deleterious materials such as plastic, glass, metal or rocks shall not exceed 0.1 percent by weight or volume.

The Moisture content of the compost shall not exceed 25 percent. Moisture content shall be defined by California Test 226.

The compost shall contain between 1.2 and 2.0 percent total nitrogen, 2.0 to 3.0 percent phosphorus (as a combination of P and P_2O_5), 2.0 to 7.0 percent potassium (as a combination of K and K_2O), 0.3 to 4.0 percent sulfur, 0.8 to 1.5 percent magnesium, 1.5 to 2.0 percent calcium and 0.3 to 0.5 percent sodium.

Compost source and material shall be approved in writing by the revegetation inspector and compost samples shall be provided to the revegetation inspector at least one week prior to delivery to the project site. Samples will not be required until after delivery if compost producer can supply sample data from the actual compost to be used and those sample data are delivered to the revegetation inspector at least 15 days prior to delivery.

Fertilizer

Slow-release organic fertilizer shall consist of material containing no more than 10% total nitrogen of which no more than 1.5% is in mineral form. Required material is derived from fungal mycelium byproduct with 5.5-7% total nitrogen (0.5% mineral form as NH_4 + NO_3), 1-3% available phosphoric acid (P_2O_5) and 3% soluble potash (K_2O). Materials other than that derived from fungal mycelium and other NPK values must be approved by the revegetation specialist before substitution.

Pine Wattles

Pine wattles will consist only of clean, fresh (< 1year old) pine needles and duff wrapped in coir fabric. Coir fabric will be as follows:

Coir DeKoWe 400 or comparable fabric consisting of:

- 100% spun coir fabric
- Meets ANEUNGO test, wheel spun, wheel cleaned evenly spun and uniformly twisted: scorages range from 12 to 20
- 400 grams per square meter weight (ASTMD-3776C)
- 65% open area
- Meets or exceeds ASTM D4595-86 standard, wide width tensile strength as follows:
- dry lbs./in.(MD/CD) 51/31
- wet lbs./in.(MD/CD) 38/24
- elongation at failure %
- dry lbs./in.(MD/CD) 35/30
- wet lbs./in.(MD/CD) 47/44
- water flow velocity: 8ft/sec

No plastic or other type of synthetic material will be used in the pine wattles. Pine wattle length shall be 10 feet unless otherwise specified and approved by the revegetation specialist.

Diameter of the wattles will be between 8-10 inches. Wattles will be tied by jute, coir or hemp biodegradable twine. Each wattle will be double-wrapped and tied a minimum of every 50 cm.

Live Seed

Species	seed # per acre
Elymus glaucus (Stanislaus 5000)[14]	36.0
Bromus carinatus (Mokelumne Brome)[1]	35.0
Elymus elymoides (Tahoe Collection)	30.0
*Lupinus spp (Lupinus grayi*i, *L. breweri*, *L. lepidus*, *L argentus, L arbustus*)	4.0
Achillea millefolium [1]	1.0
Artemesia tridentata [1]	0.5
Purshia tridentata (Tahoe Collection)	9.0
Arctostaphylos patula (Tahoe Collection)	5.0
Ceanothus velutinus (Tahoe Collection)	5.0
Eschscholzia californica [1]	2.5
Total	**128.0 # per acre**

All seed tags for seed used on this project will be presented to the revegetation specialist when requested.

Live Plants

Seedlings will be chosen by the revegetation specialist from a list of available plant material. Since accurate availability of plant material is not known until a short time before the project start date, no specific plant list will be provided until just prior to signing the contract. Plants will be contract grown by an approved nursery and the list of available plants will be provided to the revegetation contractor prior to delivery. The revegetation specialist will assist the revegetation contractor in arranging delivery from the grower.

Seedlings will be delivered in 2¼" x 2¼" x 5" deep pots unless otherwise specified or approved by the revegetation specialist.
Seedlings will be delivered to the Tahoe Basin a minimum of 2 weeks prior to planting in order to acclimate plants. Storage and interim care shall be coordinated with revegetation specialist prior to delivery.

[14] Commercial seed material.

Seedlings will be inspected by revegetation specialist upon delivery in order to ascertain condition and viability.

Plants will be planted as described above in ‘Materials’ section

Delivery invoices will be given to the revegetation specialist when requested.

Pine mulch

Type: Mulch will consist of pine needles and associated duff material. Pine needles will contain no more than 15% impurities such as pine cones, twigs, or other woody organic material. Garbage shall represent no more than 0.5% of the total volume. Mulch shall contain no more than 1% by volume mineral soil and no more than 10% decomposed organic matter.
The needle length of the material shall be as follows: 25% to be less than 1 inch in length; 50% to be between 1 inch and 3 inches; 25% to be greater than 3 inches. Mulch shall be tackified following application using the following portions per acre:

Tackifier

Type: M-binder or equivalent
Rate: 100 #/acre
Fiber: 200#/acre

QUANTITIES

REVEGETATION TREATMENT

METHOD OF MEASUREMENT

Revegetation Treatment will be measured by the square foot as designated in the Engineer’s Estimate. Quantities of revegetation treatment to be paid for by the square foot will be determined from the dimensions shown on the plans or the dimensions directed by the Engineer and Revegetation Specialist. Treatment placed in excess of these dimensions will not be paid for.

BASIS OF PAYMENT

The contract price paid per square foot for Bid Item No. 11 “Part 1 Revegetation Treatment”, Bid Item No. 12 “Part 2 Revegetation Treatment”, and Bid Item No. 13 “Part 3 Revegetation Treatment”, shall include full compensation for furnishing all labor, materials, tools, equipment, and incidentals, and for doing all the work involved in constructing revegetation treatment, complete in place, including soil amendments, mulch, seed and plant material, compost, soil preparation, woody materials, off site soil preparation, surface roughness, stockpiling of salvaged topsoil, compaction, placement of salvaged topsoil, fertilizing, seeding, mulching, and tackifier, as shown on the plans, and as specified in these construction specifications, and as directed by the Engineer.

LIVE PLANTS

METHOD OF MEASUREMENT

Live Plants will be measured by the individual plant as designated in the Engineer’s Estimate. Quantities of live plants to be paid for by the individual plant will be determined from the dimensions shown on the plans or the dimensions directed by the Engineer and live plants placed in excess of these dimensions will not be paid for.

BASIS OF PAYMENT

The contract price paid per each for Bid Item No. 14 "Part 1 Live Plants", Bid Item No. 15 "Part 2 Live Plants", and Bid Item No. 16 "Part 3 Live Plants" shall include full compensation for furnishing all labor, materials, tools, equipment, and incidentals, and for doing all the work involved in installing live plants, complete in place, including delivery, storage, planting, fertilization, and irrigation, as shown on the plans, and as specified in these specifications and the special provisions, and as directed by the Engineer.

PINE WATTLES

METHOD OF MEASUREMENT

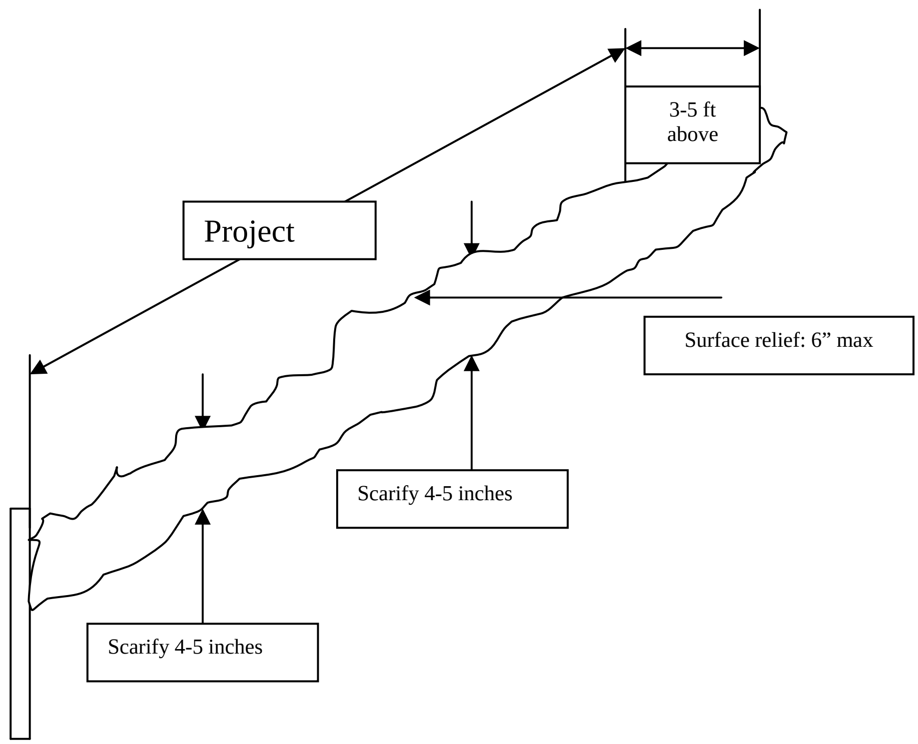
Pine Wattles will be measured by the linear foot as designated in the Engineer's Estimate. Quantities of pine wattles to be paid for by the linear foot will be determined from the dimensions shown on the plans or the dimensions directed by the Engineer and pine wattles placed in excess of these dimensions will not be paid for.

Quantities of pine wattles to be paid for by the individual plant will be measured in conformance with the provisions.

BASIS OF PAYMENT

The contract price paid per linear foot for Bid Item No. 17 "Part 1 Pine Wattles", Bid Item No. 18 "Part 2 Pine Wattles", and Bid Item No. 19 "Part 3 Pine Wattles" shall include full compensation for furnishing all labor, materials, tools, equipment, and incidentals, and for doing all the work involved in installing pine wattles, complete in place, including construction, excavation, placement, staking, and backfill, as shown on the plans, and as specified in these specifications and the special provisions, and as directed by the Engineer.

Schematic Diagrams



Schematic Diagram of typical project slope showing depth of scarification and extent of treatment area.

APPENDIX B: SITE MAP OF CAVE ROCK

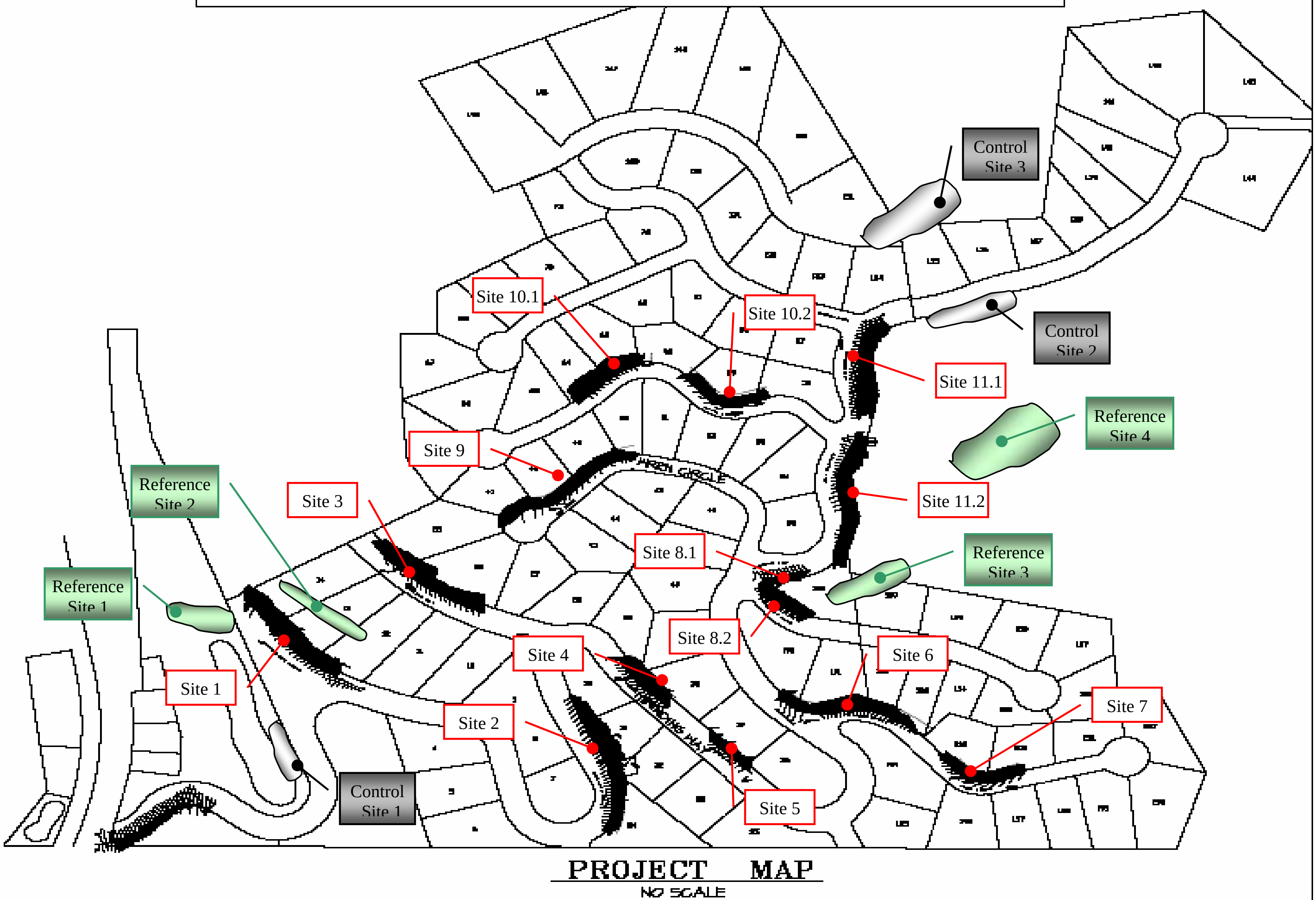


Fig. A.B. 1: Cave Rock Project Site Map. Note that reference site refers to a ‘native’ or undisturbed site and control refers to a disturbed, untreated site.

APPENDIX C: CAVE ROCK SOIL DATA

Table C. 1: Soil nutrient data for Cave Rock Estates treatment sites

Sample	TKN	OM	NO3	P (wb)	P (Na ext)	K	Mg	Ca	Na	S	Zn	Mn	Fe	Cu	B
CRNA2	375	2.9	10	101	26	90	19	447	23	18	0.4	1	46	0.1	0.2
CRNA1	361	2.2	10	58	25	61	7	185	14	3	0.1	1	35	0.1	0.1
CRCON	267	1.7	11	35	16	41	6	281	16	3	0.2	1	16	0.1	0.1
CR9-02	1087	2.3	7	72	68	211	226	1738	51	22	1.5	3	15	0.7	1.4
CR9-01	502	1.2	6	52	47	168	191	1500	72	10	0.8	3	14	0.7	0.9
CR8.2-02	507	1.3	9	52	41	112	180	1453	42	2	0.7	2	10	0.6	0.7
CR8.2-01	328	0.7	6	10	22	67	157	1310	40	6	0.4	2	11	0.8	0.4
CR8.1-02	656	0.8	6	47	36	49	52	598	19	10	0.8	2	13	0.8	0.5
CR8.1-01	337	1.2	6	91	27	107	184	1503	34	18	0.5	2	15	1	0.8
CR5-02	997	2	11	106	81	359	305	2038	99	23	1.6	6	13	0.6	1.7
CR5-01	673	1.5	5	133	65	342	365	1901	45	12	0.9	4	12	0.4	1.2
CR42N	290	1.9	10	54	44	160	13	285	11	5	0.2	1	24	0.1	0.2
CR41T	315	2.8	10	47	21	124	12	326	14	7	0.3	1	19	0.2	0.1
CR4-02	827	1.7	20	50	53	337	172	1350	35	3	0.9	2	11	0.3	0.7
CR4-01	253	0.6	6	124	23	96	146	1008	52	2	0.4	2	12	0.4	0.3
CR4/5-02	329	0.9	5	88	20	92	236	1790	28	5	0.3	4	11	0.3	0.4
CR4/5-01	327	0.8	7	28	37	90	282	1790	40	2	0.4	2	10	0.3	0.5
CR32N	290	2.0	10	49	21	154	10	290	10	3	0.2	1	19	0.1	0.2
CR31T	387	2.0	11	45	39	123	10	267	12	11	0.1	1	18	0.1	0.2
CR22N	379	2.0	10	45	21	249	18	301	16	4	0.2	2	18	0.1	0.2
CR21T	329	2.0	10	53	21	173	18	384	15	4	0.4	2	16	0.1	0.3
CR12N	392	2.1	10	62	21	298	15	406	26	3	0.2	2	19	0.1	0.3
CR11T	398	2.3	14	63	14	157	15	351	15	3	0.2	1	21	0.1	0.3
CR11.1-02	990	2.1	9	60	51	405	195	1380	158	12	4.8	7	35	0.8	1
CR11.1-01	882	1.5	5	120	63	442	159	1255	30	10	1	4	32	0.6	0.7
CR1-02	755	1.5	7	189	34	134	177	1449	42	3	1.3	3	20	0.3	0.8
CR1-01	924	1.7	7	75	68	343	267	1825	85	6	1.8	3	22	0.5	1.8
CN3	131	0.8	10	17	5	103	97	1010	8	8	0.1	2	22	0.1	0.1
CN2	138	0.7	10	19	3	78	100	998	10	7	0.1	3	18	0.2	0.1
CN1	161	0.8	9	22	7	43	47	574	12	11	0.1	2	15	0.1	0.1

APPENDIX D: COVER DATA FORMS

The following three pages show the spreadsheets used for data collection and analysis for cover point monitoring. Penetrometer monitoring uses the same format.

Microsoft Excel - Adj_Cave Rock 2.1 06-12-02

Notes: Area was watered before monitoring. Very soft material at top of slope.

Observers: JTB (Monitor) JSM (Recorder)

\# of transects: 10

	code	total cover per type		std deviation	cv (in %)	Sample Size (80%cl; 20%ci)	Sample Size (90%cl; 10%ci)	Sample Size (95%cl; 10%ci)
8	needle	0.267	+/-	0.113	42.14	7.27	47.75	68.21
9	plt. litter	0.053	+/-	0.043	81.40	27.14	178.21	254.54
10	rock	0.016	+/-	0.036		192.63	1264.89	1806.66
11	wattle	0.003	+/-	0.010		409.60	2689.60	3841.60
12	bare(dist)	0.044	+/-	0.031	69.46	19.76	129.75	185.32
13	wdebris	0.039	+/-	0.037	96.91	38.47	252.61	360.81
14								
15	AcMi	0.009	+/-	0.015		106.41	698.75	998.03
16	BrCa	0.295	+/-	0.145	49.21	9.92	65.13	93.03
17	BrTe	0.088	+/-	0.050	57.19	13.40	87.97	125.64
18	ErCi	0.032	+/-	0.034		46.26	303.75	433.85
19	EsCa	0.053	+/-	0.050	94.46	36.55	239.98	342.77
20	SiAl	0.053	+/-	0.056		46.05	302.41	431.93
21	LoPu	0.041	+/-	0.059		84.75	556.48	794.82
22	CaBu	0.007	+/-	0.014		182.11	1195.78	1707.95
23	mulch cover	0.320		0.118	36.90	5.58	36.63	52.32
24	plant cover	0.578		0.130	22.48	2.07	13.60	19.42
25	other cover	0.058		0.060		43.49	285.58	407.90
26	bare ground	0.044		0.031	69.46	19.76	129.75	185.32
27						Transects req'd		
28	Total Cover	0.956		0.031	3.20	0.04	0.28	0.39
30		Adjusted Transects Required				5	5	5
31					CL	*80%*	*90%*	*95%*

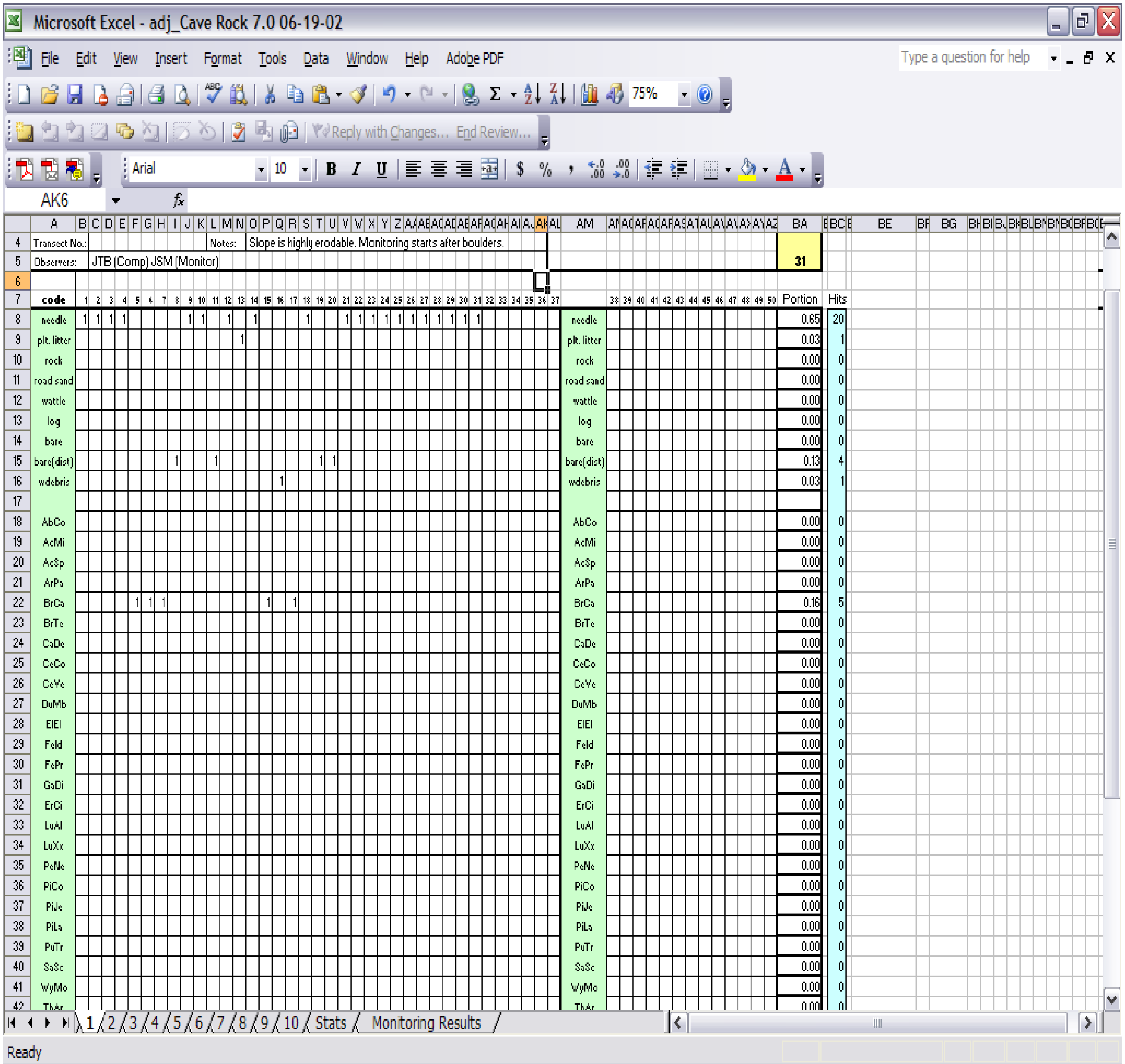
Transect Summaries — Measured cover per species per transect; Coefficients

	1	2	3	4	5	6	7	8	9	10	B (.20 ciw)	B (.10 ciw)
8	0.21	0.32	0.28	0.24	0.34	0.13	0.13	0.42	0.43	0.16	0.053	0.027
9	0.00	0.12	0.06	0.09	0.00	0.07	0.10	0.06	0.03	0.00	0.011	0.005
10	0.00	0.00	0.00	0.00	0.00	0.10	0.06	0.00	0.00	0.00	0.003	0.002
11	0.00	0.00	0.00	0.00	0.00	0.00	0.03	0.00	0.00	0.00	0.001	0.000
12	0.00	0.09	0.03	0.03	0.03	0.03	0.03	0.03	0.10	0.06	0.009	0.004
13	0.04	0.00	0.00	0.06	0.00	0.07	0.03	0.12	0.03	0.03	0.008	0.004
14												
15	0.00	0.00	0.03	0.03	0.00	0.00	0.00	0.00	0.00	0.03	0.002	0.001
16	0.42	0.44	0.28	0.24	0.16	0.30	0.45	0.18	0.03	0.45	0.059	0.029
17	0.13	0.03	0.09	0.12	0.19	0.03	0.06	0.03	0.10	0.10	0.018	0.009
18	0.00	0.00	0.06	0.00	0.00	0.10	0.03	0.06	0.03	0.03	0.006	0.003
19	0.04	0.00	0.03	0.03	0.03	0.07	0.06	0.00	0.17	0.10	0.011	0.005
20	0.00	0.00	0.03	0.12	0.16	0.07	0.00	0.09	0.07	0.00	0.011	0.005
21	0.17	0.00	0.09	0.06	0.09	0.00	0.00	0.00	0.00	0.00	0.008	0.004
22	0.00	0.00	0.00	0.00	0.00	0.03	0.00	0.00	0.00	0.03	0.001	0.001
23	0.21	0.44	0.34	0.32	0.34	0.20	0.23	0.48	0.47	0.16	0.064	0.032
24	0.75	0.47	0.63	0.59	0.63	0.60	0.61	0.36	0.40	0.74	0.116	0.058
25	0.04	0.00	0.00	0.06	0.00	0.17	0.13	0.12	0.03	0.03	0.012	0.006
26	0.00	0.09	0.03	0.03	0.03	0.03	0.03	0.03	0.10	0.06	0.009	0.004
28	1.00	0.91	0.97	0.97	0.97	0.97	0.97	0.97	0.90	0.94	0.191	0.096

1 / 2 / 3 / 4 / 5 / 6 / 7 / 8 / 9 / 10 / Stats / Monitoring Results

Figs D-1 and D-2: Excel statistical analysis spreadsheet example for cover point monitoring. Each site produced one sheet such as this one which is the summary and statistical analysis showing confidence level and individual cover levels. This information is then summarized in a table such as D-2, right.

Cover Monitoring Results for Cave Rock 2.1, 06-12-2002	
Mulch Cover	31.99%
Plant Cover	57.77%
Other Cover	5.83%
Bare Ground	4.41%
Total Cover	**95.59%**



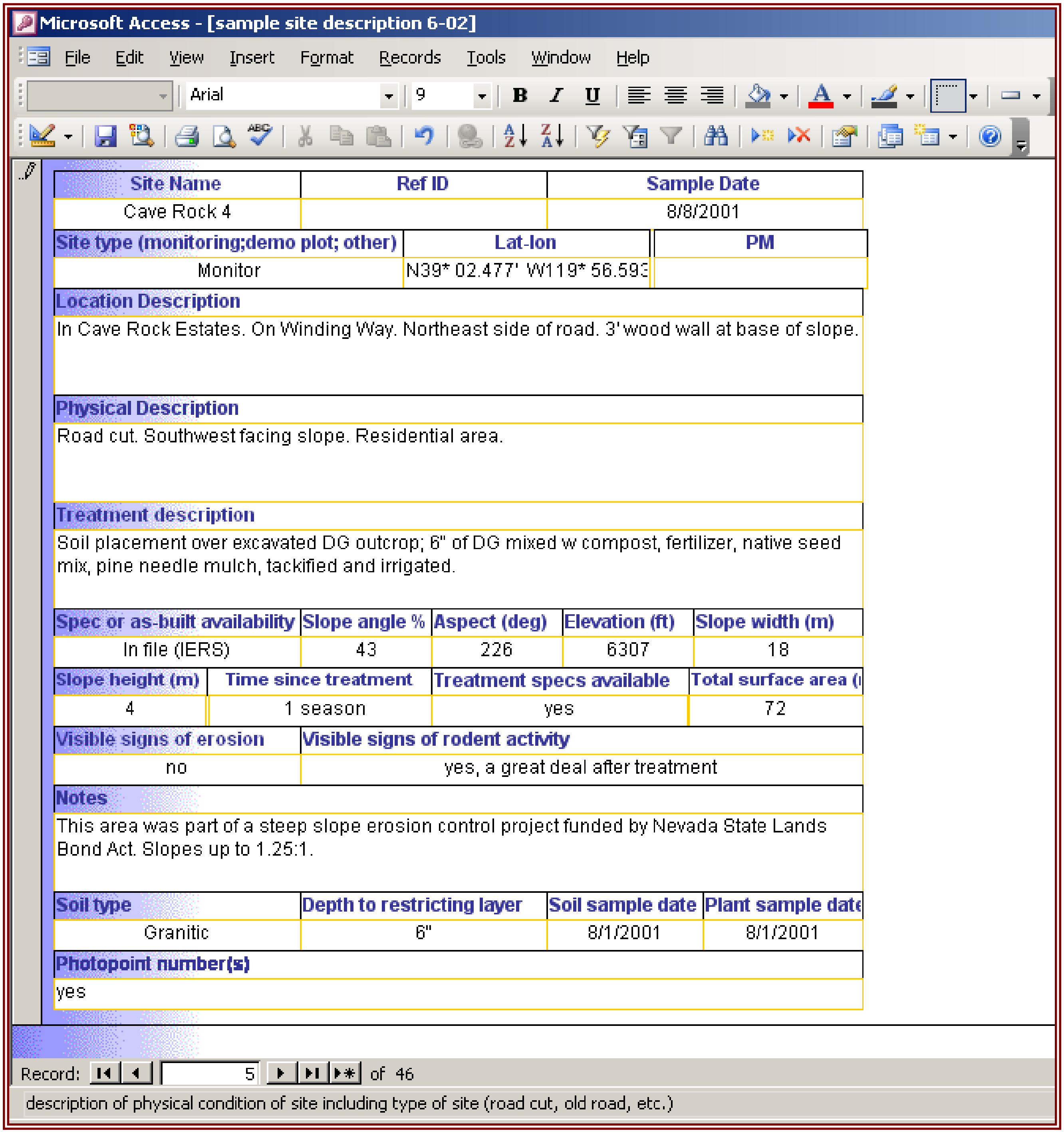
Transect No.: | Notes: Slope is highly erodable. Monitoring starts after boulders. | 31

Observers: JTB (Comp) JSM (Monitor)

code	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37		Portion	Hits
needle	1	1	1	1					1	1		1		1				1			1	1	1	1	1	1	1	1	1	1	1							needle	0.65	20
plt. litter													1																									plt. litter	0.03	1
rock																																						rock	0.00	0
road sand																																						road sand	0.00	0
wattle																																						wattle	0.00	0
log																																						log	0.00	0
bare																																						bare	0.00	0
bare(dist)								1			1								1	1																		bare(dist)	0.13	4
wdebris																1																						wdebris	0.03	1
AbCo																																						AbCo	0.00	0
AcMi																																						AcMi	0.00	0
AcSp																																						AcSp	0.00	0
ArPa																																						ArPa	0.00	0
BrCa					1	1	1								1		1																					BrCa	0.16	5
BrTe																																						BrTe	0.00	0
CaDe																																						CaDe	0.00	0
CeCo																																						CeCo	0.00	0
CeVe																																						CeVe	0.00	0
DuMb																																						DuMb	0.00	0
ElEl																																						ElEl	0.00	0
Feld																																						Feld	0.00	0
FePr																																						FePr	0.00	0
GaDi																																						GaDi	0.00	0
ErCi																																						ErCi	0.00	0
LuAl																																						LuAl	0.00	0
LuXx																																						LuXx	0.00	0
PeNe																																						PeNe	0.00	0
PiCo																																						PiCo	0.00	0
PiJe																																						PiJe	0.00	0
PiLa																																						PiLa	0.00	0
PuTr																																						PuTr	0.00	0
SaSc																																						SaSc	0.00	0
WyMo																																						WyMo	0.00	0
ThAr																																						ThAr	0.00	0

Figure D-3: this representative spreadsheet shows single transect data. Each transect is collected on a single spreadsheet which is then analyzed and summarized in the 'stats' spreadsheet as shown above. This process is fully automated so that when all transect data is collected, cover levels are automatically calculated.

APPENDIX E: SITE ASSESSMENT FORMS



Microsoft Access - [sample site description 6-02]

File Edit View Insert Format Records Tools Window Help

Site Name	Ref ID	Sample Date
Cave Rock 4		8/8/2001

Site type (monitoring;demo plot; other)	Lat-lon	PM
Monitor	N39* 02.477' W119* 56.593	

Location Description

In Cave Rock Estates. On Winding Way. Northeast side of road. 3' wood wall at base of slope.

Physical Description

Road cut. Southwest facing slope. Residential area.

Treatment description

Soil placement over excavated DG outcrop; 6" of DG mixed w compost, fertilizer, native seed mix, pine needle mulch, tackified and irrigated.

Spec or as-built availability	Slope angle %	Aspect (deg)	Elevation (ft)	Slope width (m)
In file (IERS)	43	226	6307	18

Slope height (m)	Time since treatment	Treatment specs available	Total surface area ((
4	1 season	yes	72

Visible signs of erosion	Visible signs of rodent activity
no	yes, a great deal after treatment

Notes

This area was part of a steep slope erosion control project funded by Nevada State Lands Bond Act. Slopes up to 1.25:1.

Soil type	Depth to restricting layer	Soil sample date	Plant sample date
Granitic	6"	8/1/2001	8/1/2001

Photopoint number(s)

yes

Record: 5 of 46

description of physical condition of site including type of site (road cut, old road, etc.)

Figure E-1: copy of Access Database data collection form showing information collected on each site.

APPENDIX F: TYPES OF MONITORING

UCD RANGELAND AND AGRONOMY

WATERSHED FACT SHEET NO. 15:
TYPES OF MONITORING

Introduction and Background

The term "*monitor*" is defined as to watch or check. Although it is not an explicit part of the definition, the term monitoring suggests a series of observations over time. This repetition of measurements over time for the purpose of detecting change distinguishes monitoring from inventory and assessment. While both inventories and assessments can be based on a single measurement or observation, they also can incorporate a series of observations to obtain a better estimate of a particular parameter. For example, the number of species of fish in a particular reach might be counted as part of an inventory of fish species, and several counts might be made in order to obtain a more accurate estimate. Similarly, maximum daily water temperature might be measured several times over the course of a summer to assess whether summer temperatures might be an important limitation to the quality of fish habitat under the existing conditions. However, if water temperatures are measured over several years to determine the effect of upstream management activities or climatic variations, this is clearly monitoring . The overlap in the definitions of assessment, inventory, and monitoring means that in some cases the primary distinguishing feature of monitoring will be the intent to assess change rather than the number or type of measurements.

Often an assessment or inventory serves as the first step towards establishing a monitoring project. Knowledge of the spatial and temporal variability is essential to developing an efficient monitoring plan. Inventory and assessment techniques overlap with monitoring procedures.

A number of federal and state agencies have defined the different types of monitoring carried out by their particular organization. Unfortunately, these definitions are not consistent, and this has often resulted in semantic confusion. In most cases a clear statement of the purpose of the monitoring will be the best method of defining the type of monitoring, and it then is simply a matter of attaching a mutually agreeable label to that particular type of monitoring.

It should be emphasized that the following seven types of monitoring are not mutually exclusive. Often the distinction between them is determined more by the purpose of monitoring than by the type and intensity of measurements. Regular sampling of coliform bacteria to meet health standards, for example, will produce data that also can be used to indicate long-term trends. The following table describes monitoring types according to the parameters being measured, the frequency of monitoring, the duration of monitoring, and the intensity of data analysis. At this point no consensus exists on the definitions of monitoring types, and this, together with the proliferation of monitoring terminology, means that each monitoring plan should explicitly define the monitoring terminology being used.

Most water quality monitoring projects will involve more then one type of monitoring. Distinct objectives attained through different types of monitoring , do not necessarily require distinct and independent collection efforts. There is often considerable overlap in terms of data needs and recognition of this can result in cost savings.

GENERAL CHARACTERISTICS OF MONITORING TYPES

Type of Monitoring	Number & Type of Water Quality Parameters	Frequency of Measurements	Duration of Monitoring	Intensity of Data Analysis
Trend	Usually water column	Low	Long	Low to moderate
Baseline	Variable	Low	Short to medium	Low to moderate
Implementation	None	Variable	Duration of project	Low
Effectiveness	Near activity	Medium to high	Short to medium	Medium
Project	Variable	Medium to high	> Project duration	Medium
Validation	Few	High	Medium to long	High
Complience	Few	Variable	Depends on project	Moderate to high

Definitions

- ***Trend monitoring***.
  In view of the definition of monitoring, this term is redundant. Use of the adjective "*trend*" implies that measurements will be made at regular, well-spaced time intervals in order to determine the long-term trend in a particular parameter. Typically the observations are not taken specifically to evaluate management practices (as in effectiveness monitoring), management activities (as in project monitoring), water quality models (as in validation monitoring), or water quality standards (as in compliance monitoring), although trend data may be utilized for one or all of these other purposes.
- ***Baseline monitoring***.
  Baseline monitoring is used to characterize existing water quality conditions, and to establish a data base for planning or future comparisons. The intent of baseline monitoring is to capture much of the temporal variability of the constituent(s) of interest, but there is no explicit end point at which continued baseline monitoring becomes trend monitoring. Those who prefer the terms "*inventory monitoring*" and "*assessment monitoring*" often define them such that they are essentially synonymous with baseline monitoring. Others use baseline monitoring to refer to long-term trend monitoring on major streams.

- ***Implementation monitoring***.
  This type of monitoring assesses whether activities were carried out as planned. The most common use of implementation monitoring is to determine whether *Best Management Practices (BMP'S)* were implemented as specified in an environmental assessment, environmental impact statement, other planning document, or contract. Typically this carried out as an administrative review and does not involve any water quality measurements. Implementation monitoring is one of the few terms which has a relatively widespread and consistent definition . Many believe that implementation monitoring is the most cost-effective means to reduce nonpoint source pollution because it provides immediate feedback to the managers on whether the BMP process is being carried out as intended. On its own, however, implementation monitoring cannot directly link management activities to water quality, as no water quality measurements are being made.
- ***Effectiveness monitoring***.
  While implementation monitoring is used to assess whether a particular activity was carried out as planned, effectiveness monitoring is used to evaluate whether the specified activities had the desired effect. Confusion arises over whether effectiveness monitoring should be limited to evaluating individual BMPs, or whether it also can be used to evaluate the total effect of an entire set of practices. The problem with this broader definition is that the distinction between effectiveness monitoring and other terms, such as project or compliance monitoring, becomes blurred.

  Monitoring the effectiveness of individual BMPs, such as the spacing of water bars on skid trails, is an important part of the overall process of controlling nonpoint source pollution. However, in most cases the monitoring of individual BMPs is quite different from monitoring to determine whether the cumulative effect of all the BMPs results in adequate water quality protection. Evaluating individual BMPs may require detailed and specialized measurements best made at the site of, or immediately adjacent to, the management practice. Thus effectiveness monitoring often occurs outside of the stream channel and riparian area, even though the objective of a particular practice is intended to protect the designated uses of a water body. In contrast, monitoring the overall effectiveness of BMPs usually is done in the stream channel, and it may be difficult to relate these measurements to the effectiveness of individual BMPs.

- ***Project monitoring***.
  This type of monitoring assesses the impact of a particular activity or project, such as a timber sale or construction of a ski run on water quality. Often this assessment is done by comparing data taken upstream and downstream of the particular project, although in some cases, such as a fish habitat improvement project, the comparison may be on a before and after basis. Because such comparisons may, in part, indicate the overall effectiveness of the BMPs and other mitigation measures associated with the project, some agencies consider project monitoring to be a subset of effectiveness monitoring. Again, the problem is that water quality is a function of more than the effectiveness of the BMPs associated with the project.

- ***Validation monitoring***.
  This refers to the quantitative evaluation of proposed water quality model. The data set used for validation should be different from the data set used to construct and calibrate the model. This separation helps ensure that the validation data will provide an unbiased evaluation of the overall performance of the model. The intensity and type of sampling for validation monitoring should be consistent with the output of the model being validated.
- ***Compliance monitoring***.
  This is the monitoring used to determine whether specified water-quality criteria are being met. The criteria can be numerical or descriptive. Usually the regulations associated with individual criterion specify the location, frequency, and method of measurement.

Monitoring Concepts for Rangeland Management

SHORT-TERM MONITORING

Short-term monitoring involves collecting and recording vegetation and other resource characteristic information within a year , mainly for day-to-day and annual management decisions. Short -term monitoring focuses on such questions as: Is the grazing occurring as planned? Are there outside influences on the vegetation ? What changes should be made nor or next year to better meet management objectives? Short-term monitoring also provide essential information for interpreting long-term monitoring studies.

Recommended short-term monitoring practices include:

- ***Vegetation evaluation***
  -Systematic observations or sampling during the growing season for cover, yield, and/or species composition.
- ***Climate records***
  - Precipitation, temperature, etc. (This may be accomplished by summarizing available USDC weather records.)
- ***Residue maps***
  -Identification of areas where too much or too little grazing is occurring by mapping *residual dry matter (RDM)* at high, low, and moderate levels after livestock are removed from pastures or during late September or early October. Actual use records of livestock grazing-Livestock numbers, types, and dates, animal condition score and/or weights (actual or estimated) in and out of pastures. The UC Cooperative Extension Pasture Inventory Program (George, Bell, and Lasarow 1987) can help you handle this information systematically.
- ***Unplanned disturbances***
  -Recording fires, wildlife use, insect and weed infestations, acts of vandalism, etc.

Long-term Monitoring

Long-term monitoring involves documenting measurements and observations for several years on study sites selected within the management area, grazing lease, pasture or areas of specific concern. Conducting measurements and/or observations over several years provides a trend. Site locations and types of data to be collected are determined by the management plan's objectives. Records must be carefully maintained, protected, and made available for planning. A long-term monitoring program should include:

- ***Trend transects***
  - Systematic measurements (every 3 to 5 years) of the vegetation or other resource characteristics.
- ***Trend photo points***
  - Permanently established points at which photos are taken annually of a general view and one or more close-ups of important resource characteristics.
- ***Aerial photos***
  - Regularly scheduled photos of the same area to show major vegetation changes in brush, trees, and grasslands

References

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

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

APPENDIX G: SITE MAPS AND PHOTO POINTS FOR CAVE ROCK EROSION CONTROL PROJECT