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An Integrated Science Plan for the Lake Tahoe Basin: Conceptual Framework and Research Strategies

Editors

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Front cover: Lake Tahoe view from Mount Rose Highway scenic pullout, looking northwest toward Tahoe City, California. Back cover: Lake Tahoe view from Mount Rose Highway scenic pullout, looking south. Both photographs by Peter Goin.

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Chapter 5: Soil Conservation[1]

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Introduction

Soil conservation as a research and management theme can mean many things to agencies and the general public. The historical concept was rooted in agriculture and agricultural production. Indeed, in 1957 the "modern" objectives of soil and water conservation identified by Stallings (1957) were to:

- Reduce the accelerated loss of soil that attends the use of land for agricultural crops.
- Find ways of reclaiming severely eroded land.

Soil conservation today conveys a much broader concept, and conservation management strategies go well beyond simply the protection of soil from processes of physical erosion to now encompass the protection and enhancement of overall soil quality. Improved soil quality prevents land resource degradation by resisting erosion and invasive species, strengthening the soil's capacity to support plant growth, favoring species diversity, preventing environmental contamination, and conserving water (Brady and Weil 2008).

The intent of this chapter is to identify the most pressing management questions, uncertainties, and pertinent research needed to address a wide spectrum of plant-, soil-, and water-related issues in the Lake Tahoe basin. In developing the organization and content for the soil conservation theme, the original outline considered a number of topical subtheme areas such as soil ecology, soil erosion, etc. However, input received from Tahoe Science Plan participants indicated that they were interested in cross-cutting issues rather than the topic-specific categories originally presented. In response, suggestions from the workshop were grouped into four new subthemes considered by the constituency to be of high priority and in need of resolution relative to current management concerns.

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We provide a brief introduction of each subtheme, which includes a description of the subtheme, what we know about it, and its relevance (perceived or real) to the overall science theme area and management strategies in the Lake Tahoe basin. In the subsection entitled "Knowledge Gaps" we provide a problem statement that describes the general issue, then in bullet format identify specific aspects relative to that issue where we recommend enhancing the knowledge base. The subsection entitled "Research Needs" presents a nonprioritized list of identified research topics.

Beyond the specific discussions of subthemes, we provide a conceptual model and identify a prioritized listing of the three most immediate near-term soil conservation research priorities within each subtheme.

Conceptual Model

Figure 5.1 illustrates four primary tiers of hierarchy: theme area, subthemes, components (response-based ecosystem components), and drivers (e.g., stressors, management activities, other external forces). The following subthemes were adopted as the primary categories or conditions of interest to agencies and the public:

- Key soil properties and conditions.
- Development and application of predictive models.
- Effects of climate change.
- Policy implications and adaptive management strategies.

A number of coupled processes were next identified as a set of complex **response indicators** potentially affecting one or more aspects of the four subtheme conditions. These **interactive components** are used to identify and express the degree of consistency with desired conditions and include (1) changes in soil physical and chemical properties, (2) altered hydrologic function and the corresponding effects on erosion, (3) nutrient cycling and discharge water quality, (4) the collective and independent short- and long-term effectiveness of best management practice (BMP) strategies, and (5) the evaluation of current and future policy thresholds in the context of scientific information and an ever-expanding knowledge base. Finally, expected linkages between primary and secondary drivers are presented as **agents of change**, natural or human caused, which can affect the condition of the components specified and their indicator values.

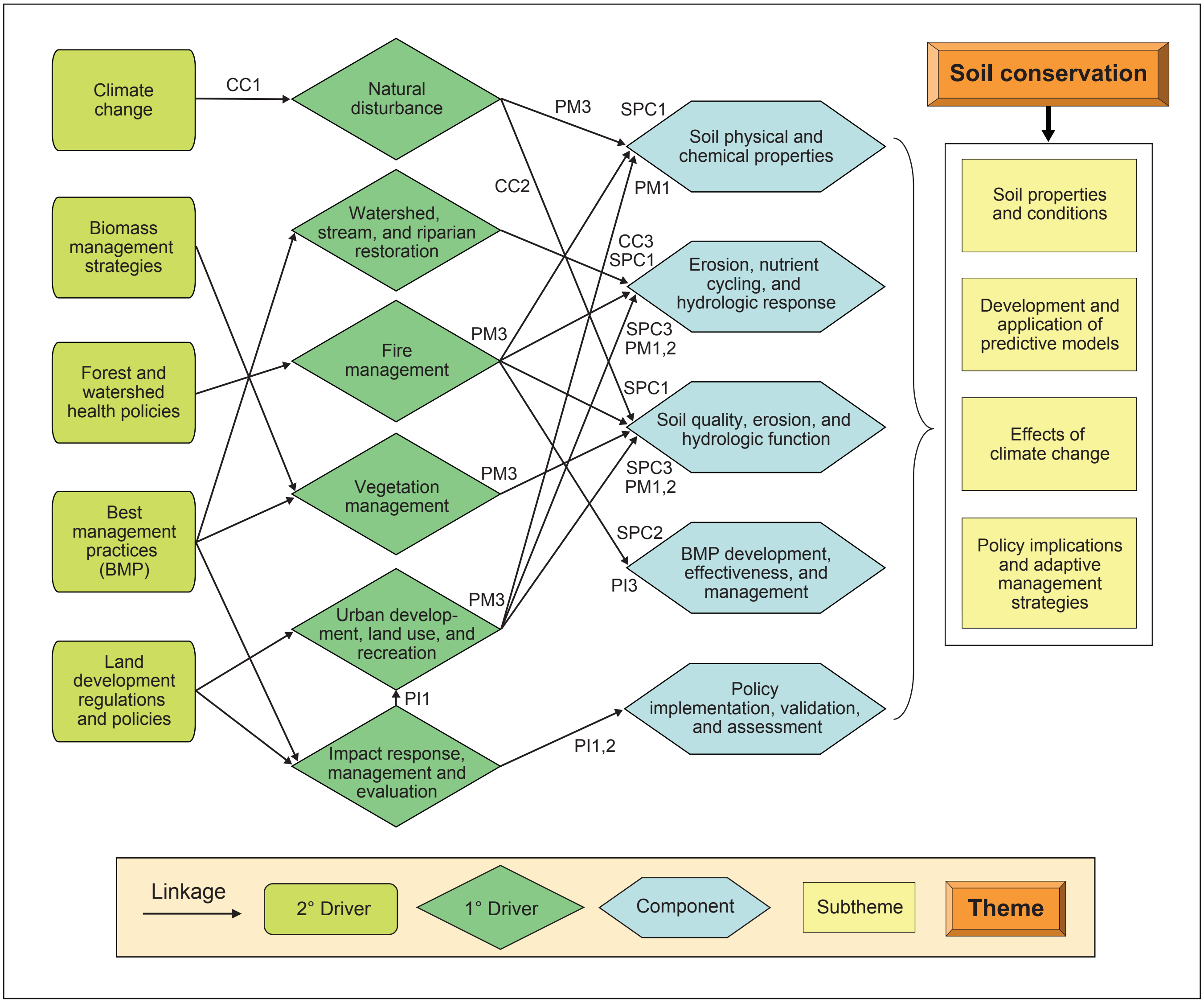

Figure 5.1—Conceptual model illustrating how the Soil Conservation research theme system is perceived, its scope, the primary factors, and how they relate to one another. Near-term priorities are indicated by alpha numeric symbols (e.g., CC1, PM3) and correspond to the descriptions presented later in the chapter.

Key Soil Properties and Conditions

Soil conservation is a dominant factor in existing land use policies in the Tahoe basin. These policies can benefit from the incorporation of key soil properties and conditions that influence soil ecology, soil erosion, source/sink nutrient budgets, physical and hydrologic properties, and model use and application. This approach can yield land use policies that have a sound foundation in science.

The profile characteristics and physical and chemical properties of soils are determined by the five factors of soil formation; **parent material**, **biota** (both vegetation and soil biota), **topography**, **climate**, and **time** (Jenny 1980). Primary minerals, or those that come with the soil parent material (e.g., volcanic or granitic origin), are generally unstable when exposed to ambient conditions at the Earth's surface. They begin to disintegrate and dissolve at varying rates according to their resistance to processes of physical and chemical weathering. The soil skeletal fraction consists largely of sand and silts as a result of physical disintegration. On the other hand, ions derived from the dissolution of primary minerals, including essential nutrients such as phosphorus (P), potassium (K), calcium (Ca), magnesium (Mg), sodium (Na), and many micronutrients, enter the soil solution and either leach to greater depths, become adsorbed to the existing secondary mineral fraction, are taken up by biota, or form more stable secondary minerals themselves. These secondary minerals consist largely of the colloidal (clay) size fractions and contribute substantially to soil chemical properties such as surface reactivity, cation exchange capacity, and anion adsorption (Miller and Gardiner 1998).

Two soil survey reports have been completed for the Tahoe basin; the original published in 1974 (USDA, NRCS, and FS 1974), and a more recent online "Web Soil Survey" published in 2007. The updated version (USDA NRCS 2007) of the soil survey includes some major changes that should be of interest to soil scientists and other specialists studying the Lake Tahoe environment. It presents information on a variety of key soil physicochemical properties, including particle size distribution (texture), structure, percentage clay, organic matter content, permeability, erosion hazard, pH, and cation exchange capacity, as well as delineations of origin (volcanic vs. granitic), flood frequency, frost-free days, mean annual precipitation, and depth to water table.

Soil Physical Properties

Soil texture is determined on the basis of the relative proportions of three general mass size fractions (USDA Classification); the sands (0.05 to 2.00 mm diameter), the silts (0.002 to 0.05 mm diameter), and the soil colloids or clays (<0.002 mm). The larger size fractions (sands and silts) typically settle rapidly and are fairly inert chemically. Soil colloids, however, can remain in suspension over long periods and can directly affect solution equilibrium chemistry as well (see later discussion). Water clarity in Lake Tahoe is largely controlled by absorption and scattering of light by biological and mineral particles that remain suspended within the water column. Of the inorganic fraction, it is the fine particle sizes (1 to 15 μm) that tend to have the greatest effect on lake water clarity because of their tendency to remain suspended within the water column and their light-scattering properties (Jassby et al. 1999, Swift and Perez-Losada 2006).

In terms of soil structure, particles may exist as unattached individual grains (single grain) at one extreme, or become tightly packed into large cohesive blocks (massive) at the other. In between, there exists an intermediate structural condition known as aggregates or peds (Hillel 1998). The interaction between soil texture and soil structure has a pronounced influence on a number of other physical properties such as erodibility, bulk density, porosity, water-holding capacity, and infiltration capacity. These properties in turn have a substantial influence on the soil's ability to support plant growth, the cycling of nutrients, water retention and percolation, and the susceptibility to rill erosion. For example, in addition to being subject to transport mechanisms, nonaggregated or weakly structured soils are more easily compacted upon disturbance (natural or anthropogenic). Compact soils (soils with higher bulk densities) have a lower total porosity and smaller pore sizes skewing the overall pore size distribution throughout the matrix. This typically results in a negative effect by causing lower infiltration rates, which when subjected to high-intensity precipitation, causes greater runoff. It is important to note, however, that for very sandy soils, compaction can also have a positive effect by increasing available water-holding capacity owing to a more compressed pore size distribution.

The process of erosion is of paramount importance to the Lake Tahoe basin. Different soil textures, soil structures, and environmental conditions affect soil erosion. Particulate detachment and transport are the fundamental processes by which erosion takes place. Detachment may be the result of raindrop or particle impact, cycles of freeze/thawing and wetting/drying, overland flow, wind transport,

Courtesy of California Tahoe Conservancy

Bank erosion in a Lake Tahoe basin neighborhood.

or mechanical disturbance. Transport is usually the result of water or wind action with colluviation playing a role on steeper slopes. It is generally thought that increased erosion in upland watershed areas of the Sierra Nevada is largely due to mechanical disturbance from logging, grading, grazing, or other anthropogenic activities that cause loss of vegetation, organic matter, and nutrients from top soil layers; soil compaction; reduced infiltration; and enhanced runoff (Grismer and Hogan 2005a). Several erosion "hot spots" arising from natural and anthropogenic activities exist within the Tahoe basin. Some of the most notable hot spots include upper Ward and Blackwood Creeks, logged areas of the Upper Truckee River watersheds, and areas of high disturbance such as ski resorts and road cuts. Fire aftermath (natural or prescribed) may also result in increased erosion rates (Certini 2005), especially if the burn area is left unattended.

According to the soil erodibility factor (K factor) used for the Universal Soil Loss Equation (USLE), it is the larger sand-sized particles (0.05 to >2.0 mm in diameter) that are the most susceptible to transport because of their size and mass. Smaller size fractions (<0.05 mm in diameter) are less easily mobilized owing to their colloidal nature, but when eroded are more difficult to trap owing to their smaller size.

Soil water repellency (often called hydrophobicity) is a common feature of soils in forested watersheds of the Sierra Nevada that has an effect on soil erosion and soil loss. These effects include reduced infiltration capacity, enhanced overland flow, and increased rainsplash erosion (Shakesby et al. 2000). Naturally derived soil water repellency in the Lake Tahoe area has been reported to be minimal or lacking during moist spring conditions, but most severe during the very dry conditions of late summer (Burcar et al. 1994). Fire-induced water repellency also is of concern. Following wildfire, a hydrophobic layer may exist either at the mineral surface or at some depth below. The depth and thickness of this layer is influenced by the amount of heat, ambient soil moisture content (Shakesby et al. 2000), and particle-size distribution, but does not often exceed 6 to 8 cm (Certini 2005). Whether natural or fire induced, hydrophobicity results in reduced infiltration, enhanced runoff, and, on occasion, mass wasting and deposition.

Recent research indicates that vegetative cover alone (i.e., grasses with 30 to 60 percent cover) may have minimal effects on decreasing erosion from disturbed sites (Grismer and Hogan 2004, 2005a, 2005b). Using woodchips or compost in conjunction with revegetation as a soil restoration method appears to be more effective for providing erosion control, increased infiltration rates, and restoration of hydrologic function (Grismer and Hogan 2005b). The use of compost, however, may also enhance the growth of weeds while decreasing the growth of native vegetation.


Jay Howard

Rain- and hail-induced erosion after the 2002 Gondola wildfire above Stateline, Nevada.

Soil Chemical Properties

Soil chemical properties are directly related to solid particle (organic and inorganic) surface chemistry, geochemistry, fertility, mineralogy, and microbiology/biochemistry. Soil fertility considers soil as a medium for plant growth, mineralogy examines the structure and chemistry of the solid phase, and biogeochemistry studies soil microbial and biochemical reactions (Bohn et al. 2001).

Soil solution is the equilibrium interface between the solid mineral and organic fractions and the atmosphere, biosphere, and hydrosphere. It is the source of mineral nutrients for all terrestrial organisms, and, as it mixes with ground water or drains to streams, lakes, or wetlands, can directly affect their chemistry. The integrating factor of time is also a factor: the importance of parent material to soil properties diminishes over time as the primary minerals disintegrate and are dissolved. Many Sierran soils are relatively young and thus the parent material still has substantial influence over soil properties. For example, soils derived from granitic sources are typically rich in basic cations such as Ca, K, Mg, and Na, whereas volcanically derived andesitic soils are typically more acidic and contain higher concentrations of ferromagnesium minerals (iron [Fe], aluminium [Al], manganese [Mn], Mg). Precipitation strongly affects soil leaching and mineral solubility, temperature affects mineral solubility, and both affect biota, which also has a major influence on soil properties.

Biota has a strong influence on soil properties by adding organic matter, which imparts important chemical properties to soils such as cation exchange capacity and water holding capacity, and nitrogen (N), the most commonly limiting nutrient for plant growth. The organic content of soils is important to a number of soil properties, but especially to aggregate stability, water-holding capacity, plant nutrient supply, and ion exchange. Humus is an intermediate product following considerable decomposition of plant and animal remains (nonhumus). It is amorphous, dark brown in color, insoluble in water, and because of its large specific surface and ability to acquire a positive or negative electrostatic charge in response to soil reaction (pH), exhibits strong ion adsorption and exchange properties. Nitrogen is generally not added with parent materials and their primary mineral components; its source is from the atmosphere, which is 78 percent nitrogen gas (N_2). Unfortunately, N_2 is not available to plants and must first be converted to either ammonium (NH_4) or nitrate (NO_3) forms and added to the soil either naturally through atmospheric deposition or biological N fixation or through the anthropogenic processes of fertilization or air pollution. Nitrogen is therefore unique among nutrients in soil in that it is largely associated with organic matter and has only minimal involvement with secondary minerals or adsorption to colloids.

Fire and fire suppression can have a substantial effect upon various soil chemical properties. A substantial portion of the Lake Tahoe basin is currently considered a high-risk environment for severe wildfire (Murphy et al. 2006b). This is due to a buildup of litter and “ladder” fuels that stimulate a high-intensity ground and crown fire. This shift may be the direct result of fire suppression, resulting in a change in fire regimes from regularly occurring low-intensity fires, characteristic of pre-European settlement, to large often catastrophic stand-replacing fires (Neary et al. 1999).

Fire has a twofold effect on N in the forest ecosystem, and specifically in soils. First, most N contained in material that burns is lost to the atmosphere via volatilization because of its low volatilization temperature. Thus, fire (either wildfire or prescribed fire) causes net losses of N from the terrestrial ecosystem, which, over time, can be important because N is often a growth-limiting nutrient for vegetation. These N losses can be readily restored if N-fixing vegetation, such as snowbrush (*Ceanothus velutinus* Douglas ex Hook.), bitterbrush (*Purshia* sp. DC. ex Poir.), lupine (*Lupinus argenteus* Pursh), and whitethorn (*Ceanothus cordulatus* Kellogg) is allowed to reestablish on the site, thereby providing N input to the system. In the case of shrub species such as snowbrush, however, it may take a decade for such inputs to reach peak values. It is important to note, however, that

N losses from repeated prescribed fire designed to suppress understory vegetation such as snowbrush can equal or exceed those in a wildfire over time, and this may be of concern in terms of long-term forest nutrition.

Secondly, heating of soil and partial combustion of the forest floor normally causes degradation of amino acids and proteins, resulting in an increase (sometimes quite substantial) in soil ammonium levels. This ammonium is basically equivalent to a dose of fertilizer and often contributes to lush growth of herbaceous vegetation after a wildfire. On the other hand, if the ammonium is converted to nitrate during nitrification, surface or ground-water pollution can occur. Wildfire has thus been found to increase the immediate mobilization of labile (readily available) nutrients (Miller et al. 2006, Murphy et al. 2006b). The effect is to increase the frequency and magnitude of elevated nutrient runoff concentrations during the first season following the wildfire event. At least some of this labile N may be transported offsite during precipitation or snowmelt, thus enhancing the nutrient loading of adjacent tributaries (Allendar 2002) and their final discharge into Lake Tahoe. Like N, elevated concentrations of soluble P also may be transported offsite during precipitation or snowmelt ultimately discharging into Lake Tahoe.

Whereas wildfire has been shown to cause a dramatic increase in labile nutrient mobilization (Johnson et al. 2004, Miller et al. 2006, Murphy et al. 2006b), this effect has not been identified for prescribed fires. Murphy et al. (2006a) found no significant increases in the leaching of ammonium, nitrate, phosphate, or sulfate following a prescribed Sierran burn on volcanic soils. Neither resin nor ceramic cup lysimeter data showed any effects of burning on soil solution leaching. Although Chorover et al. (1994) found increases in soil solution and stream water ammonium and nitrate following a prescribed fire on granitic soils at a western Sierrian site, Stephens et al. (2005) reported that prescribed fire in the Lake Tahoe basin had no effect on soluble reactive phosphate and only minimal effects on nitrate in streamwaters. In support of this latter finding, Loupe (2005) found controlled burning to result in a net decrease of inorganic N and P concentrations in surface runoff at a site near north Lake Tahoe. On this basis, Murphy et al. (2006a) concluded the most ecologically significant effects of prescribed fire on nutrient status at his site was the substantial volatilization of N from forest floor combustion.

Knowledge Gaps

Although a few broad comparative estimates are available (Carroll et al. 2007), historical erosion rates within the Tahoe basin are largely unknown. As a result, we have no means of knowing how current soil loss compares to historical conditions.

This information is recommended to help quantify the extent to which anthropogenic activities have impacted erosion and deposition. The alternative is to directly measure current impacts, but knowledge gaps also exist with this approach. For example:

- The basinwide distribution of developed pervious surfaces such as ski runs, unpaved roads, and gravel parking areas as potential sources of sediment have not been quantified.
- We do not have a quantitative understanding of how developed impervious surfaces (e.g., buildings, roads, or parking lots) have altered natural hydrologic processes leading to increased surface and subsurface discharge runoff and erosion.
- The extent to which jetties, piers, bulkheads, and dredging have altered natural littoral and eolian processes on near-shore soils are unknown.

It remains uncertain as to which erosion control and or site restoration methods are most effective at different locations throughout the Tahoe basin.

- Overall effectiveness in terms of hydrologic function per input effort required is not quantified for most methods at variable site locations.
- How long control measures will remain effective, whether or not they are self-sustaining, and if sustainable, the frequency requirements for maintenance are unknown.
- We do not know how the performance of erosion control methods varies among storm events (e.g., 20-yr vs. 50-yr vs. 100-yr) or changing hydrologic scenarios (e.g., rain-only events vs. rain-on-snow events).

The methods that control the runoff of fine particle sizes most associated with nutrient source/sink loading are not clearly defined.

- Whether or not all "native" soils are a source/sink for N and P remains unknown.
- Quantitative knowledge of equilibrium soil chemistry is recommended to support the proper design of control measures for the reduction of nutrient loading.

The fate and impacts of fertilizer use in the basin are not well understood.

- Fertilizer may or may not be a significant source of nutrients to the lake. The impact of residential fertilizer use is unknown.

How native and nonnative vegetation respond to soil amendments and other restoration activities remains an issue.

- It is unknown whether or not vegetative restoration practices will actually result in the permanent establishment of "native-like" conditions where little natural runoff and erosion takes place.
- Long-term vegetative succession characteristics following the application of soil amendments and other restoration practices are unknown, particularly with respect to whether or not a normal progression of plant community succession can be established, and, if so, how many years may be required for succession.

The presence or absence of vegetation may affect soil shear strengths and aggregate stability, but how and what shear strengths are associated with restored sites is an unknown issue.

- The most effective type of vegetative cover for use at various locations relative to indigenous soil types has not been specified.
- The effects of restoration efforts and vegetative cover on soil aggregate stability are poorly understood.
- What natural aggregate stability is associated with undisturbed sites and what aggregate stability value should be most suitable are not known.

Snowmelt-derived erosion is a poorly understood process and has not been quantified across the basin.

- Most erosion studies have focused on situations and locations such as road cuts, skid trails, and construction, or extreme events.
- Only a few studies (Granger et al. 2001, Riebe et al. 2001) have attempted to characterize baseline erosion from watersheds on an overall basis, including that derived from snowmelt cycles.

The shift from low-intensity fire to catastrophic wildfire has the potential to affect many aspects of soil ecology. Obtaining sound data on the effects of prescribed fire is more practical, but the results may not apply to the effects of wildfire.

- Wildfires have no prefire plan, therefore pretreatment and suitable control sites are rare. Hence, information on the effects of wildfire on organic matter, nutrient cycling, and biological response is scarce.
- Fire suppression has increased organic matter accumulation above and within the soil, and the potential effect on nutrient cycling and discharge to Lake Tahoe is uncertain.

- Information gaps remain concerning postwildfire vegetation recruitment as well as long-term succession and ecological impacts.
- A more comprehensive understanding of pre-European fire regime nutrient cycling conditions would be useful to the development of vegetation management strategies.
- A comprehensive assessment of the effects of both wildfire and prescribed fire and postfire N-fixing vegetation on long-term N budgets is needed.

Little is known about the management implications of soil water repellency in the Lake Tahoe basin.

- The spatial distribution and intensity of soil hydrophobicity has important hydrologic recharge and nutrient "hot spot" implications in Sierran soils (McClain et al. 2003).
- Temporal variability of the effect of soil hydrophobicity on overland flow is unknown, as are individual event-based effects (e.g., how rapidly the effects of soil water repellency dissipate during summer storms or snowmelt cycles remains unknown).
- The role of soil hydrophobicity in soil erosion has not been well studied as it is challenging to isolate the effect of hydrophobicity from those of other erosion factors.
- Most measurements are performed on small-scale areas (<5 to 10 m^2), which yield limited information on spatial variability. These small-scale measurements may not give a reliable indication of the detachment and transport of sediment and nutrients over an entire slope or catchment (Shakesby et al. 2000).

There is a lack of information regarding potential impacts from trace element contamination in the basin.

- Little is known regarding the status of trace elements.
- Fate, behavior, and the related management options are largely unknown.

Research Needs

- Characterize or quantify historical vs. current and natural vs. anthropogenic soil loss on a watershed scale, including intervening zones. Detailed characterization of control site parameters coupled with predictive model estimations would facilitate such efforts.
- Identify the locations, practices, and features that have disrupted the natural littoral and eolian processes sustaining barrier beaches and marshes and influencing beach and dune formation. Where appropriate, develop and evaluate retrofit designs and restoration and management techniques.

- Quantify an aggregate stability index, the hydrologic function, and complete soil nutrient status for soils on native, disturbed, and restored sites. This would provide critical information on the need for restoration and the degree to which we can expect attainment.
- Do a quantitative assessment to determine which restoration methods are most effective in controlling runoff transport of fine particles most associated with nutrient loading and their equilibrium chemistry.
- Evaluate amended or otherwise restored soils in terms of their ability to maintain hydrologic function, productivity, and erosion control over time.
- Identify appropriate vegetation that will best achieve maximum erosion (and potentially nutrient) control at a realistic cost.
- Structure project monitoring and assessment to provide relevant research data pertinent to erosion model development, improvement, calibration, and validation for the Lake Tahoe basin.
- A quantitative assessment of erosion from snowmelt is recommended on different disturbed, native, and restored soils throughout the basin.
- Conduct research on soils and nutrient cycles in natural forests to better understand fire suppression and its role in soil ecology, plant growth, and nutrient discharge. Ideally, sites would be established to measure nutrient cycling, which includes inputs such as plant-soil fluxes through litterfall, crown wash, and root turnover as well as losses from leaching, runoff, wind, or fire.
- Conduct research to understand the effects of wildfire where a suitable adjacent control site is available, especially if prefire data are available (e.g., the Gondola wildfire, Stateline Nevada). Assessment of the immediate and long-term effects of prescribed fire on erosion, hydrophobicity, and runoff rates is recommended, particularly factors that affect the replacement of lost N such as through N-fixation. Ideally, long-term inventory plots would be established to include vegetation and soils to follow the progression of change over time.
- Further quantify the spatial distribution of soil water repellency on a larger scale to determine the distribution of areas of recharge versus those that generate overland flow. Develop a more complete understanding of the factors (i.e., temperature, moisture, vegetation, and litter) that determine the formation, persistence, and dissipation of hydrophobicity to predict seasonal and long-term effects on recharge runoff and erosion.

- Complete, update, and continue refinement of Tahoe basin ecological site descriptions to assist agencies in the development of effective management strategies. An ecological site has specific characteristics that differ from other kinds of land in its ability to produce a distinctive kind and amount of vegetation. Ecological site descriptions include knowledge about site characteristics, plant communities, site interpretations, and other supporting information about such sites and their interrelationships to one another on the landscape.
- Quantify the trace element status of plants, soil, and water in the Tahoe basin.

Development and Application of Predictive Models as Related to Soil Conservation

The Bailey Land Classification System (Bailey 1974) was originally developed to group basin lands into broad classes of similar estimated erosion hazard, then rank each class as to relative environmental sensitivity to land development. It was soon apparent, however, that the Bailey System was inadequate to effectively evaluate the potential erosion hazard for individual parcels. The Individual Parcel Evaluation System (IPES) (TRPA 1986) was therefore developed to provide onsite sensitivity evaluation. Because no site-specific data were readily available, the IPES system used empirical models as the basis for estimating erosion potential. The use of such predictive models when properly applied and interpreted within the constraints of their inherent limitations can provide important tools to understanding and predicting the potential outcome of management strategies and programs. Models related to soil erosion, nutrient cycling, and hydrology can all help to inform actions aimed at soil conservation. The updated version (USDA NRCS 2007) of the soil survey includes a plethora of recent information on key soil physicochemical and biological properties that should be of interest for purposes of model updates to modeling specialists studying the Lake Tahoe environment. Advancing the development and standardized use of predictive models in the Tahoe basin remains a management priority.

Soil Erosion Models

The USLE has been the dominant prediction tool for soil erosion by water for decades. Originally designed to predict sheet and rill erosion on croplands, it has been applied in the United States and abroad for conservation planning to estimate the impact of erosion on the quality of the surrounding landscape (Yoder and Lown 1995).

The USLE equation,

$$A = RKLSCP$$

is based on empirical relationships where A is defined as the soil loss factor, R represents the rainfall erosivity factor, K is the soil erodibility factor, L is the slope length factor, S is the slope steepness factor, C is the cover management factor, and P represents the support practices factor (Nearing et al. 1989, Renard et al. 1991, Reyes et al. 2004). The USLE, however, was not designed to predict soil deposition, sediment yield from a watershed (as it does not include deposition), soil loss from single storm events, soil loss from concentrated channel flow in large rills or ephemeral gullies, gully or streambank erosion, or movement of sediment in streams (Hudson 1995; Renard et al. 1991, 1994).

In the mid-1980s, the U.S. Department of Agriculture (USDA) worked to improve USLE by updating and revising the factors involved. This work resulted in the Revised Universal Soil Loss Equation (RUSLE). The RUSLE maintains the same equation structure of USLE, but each feature has been updated using more recent, larger, and more complete data sets (Hudson 1995; Nearing et al. 1989; Renard et al. 1991, 1994; Reyes et al. 2004). At the same time, the Watershed Erosion Prediction Project (WEPP) was being developed in order to produce a more process-based model that would eventually replace RUSLE for upper watershed applications on nonagricultural lands.

Improvements to RUSLE included more data from the Western United States, providing more complete isoerodent maps and thus more accurate R-values for this region. In addition, the R-factor took into account ponding of water on flat slopes where intense rainstorms occurred. Ponded water decreases soil erosion owing to raindrop dispersion, thus the R-factor is decreased. The erodibility nomograph is often used to estimate K-values, but may not be appropriate for all soils. The RUSLE allows users to identify when the nomograph is applicable and when a different method should be applied. The RUSLE also allows K to vary seasonally and accounts for the presence of rock fragments in the soil (Hudson 1995; Renard et al. 1991, 1994). Even so, K-value applicability in the Lake Tahoe basin is questionable. Hence, refining the data input for K-values to make them more pertinent to Lake Tahoe basin conditions would increase the applicability of RUSLE as a predictive tool for the basin.

A major change with the upgrade to RUSLE was the improvement of the L-factor. Choosing a slope length value was originally dependent on the judgment of the user, which resulted in different users choosing different slopes for similar conditions. The RUSLE provides better guidelines that help users to recognize important attributes of field conditions and generate greater consistency when choosing slope length. The slope steepness factor was also revised, and, in most cases, resulted in reduced soil loss predictions (Hudson 1995; Renard et al. 1991, 1994). Of all USLE factors, the P-factor was the least dependable as it represents broad effects of land use practices. Extensive data have been examined to reassess and improve P-factor values for the use of different land use practices (e.g., contouring, terracing, and rangeland practices) for RUSLE application (Hudson 1995; Renard et al. 1991, 1994; Yoder and Lown 1995). Even with these important modifications, however, limitations remain. Like the USLE, RUSLE is unable to predict erosion rates for single storm events or for a single calendar year (Nearing 1989, Yoder and Lown 1995). Furthermore, neither equation estimates deposition or sediment yield at a downstream site or clearly represents fundamental hydrologic and erosion processes (Renard et al. 1991). Ephemeral gully erosion is not included, nor are specific sediment characteristics (Renard et al. 1991).

The WEPP was developed to provide a new technology for modeling erosion for prediction purposes based on what is currently understood about erosion processes. It is a process-based model that offers three versions, each suitable for a different scale. The profile version is the replacement of USLE as a predictor of uniform hillslope erosion, including deposition as an additional component. The watershed version is applicable at the field scale and incorporates areas where more than one profile version applies. The grid version can be applied to areas with boundaries that do not match watershed boundaries, or it can be broken into smaller areas where the profile version may be applied (Flanagan et al. 1995, Hudson 1995, Laflen et al. 1991b).

Major determinants of the erosion process are soil resistance to detachment, stream power (transport), and deposition. Hydrologic processes included in WEPP are climate, infiltration, and a winter component that includes soil frost, snowmelt, and snow accumulation. Plant growth and residue processes estimate plant growth and decay above and belowground. The water balance component uses climate, plant growth, and infiltration to quantify daily potential evapotranspiration, which is necessary to compute water status and percolation. The hydraulic component computes shear forces exerted on soil surfaces. Processes that take place in the soil are also considered, including various soil parameters such as roughness, bulk density, wetting-front suction, hydraulic conductivity, interrill and rill erodibility, and critical shear stress. Tillage, weathering, consolidation, and rainfall impact are also considered (Flanagan et al. 1995, Hudson 1995, Laflen et al. 1991a).

The WEPP, in this respect, is able to estimate spatial and temporal distributions of soil loss, although it has not necessarily provided more precise or realistic estimates of erosion rates. Because the model is process-based, it can extrapolate a broad range of conditions and take into account the variability of topographic conditions of hillslopes (Flanagan et al. 1995). Although process-based models like WEPP may offer more power than an empirical model like the USLE and RUSLE, WEPP requires more complex technology, demanding expanded databases with more advanced computer resources (Renard et al. 1994).

Nutrient Cycling Models

Two models have shown promise for the characterization of nutrient cycling in Sierran systems (Johnson et al. 2000): the Nutrient Cycling Model (NuCM) and the Nutrient Cycling Spread Sheet model (NuCSS).

The NuCM is able to represent the cycling of N, P, K, Ca, Mg, and sulfer (S) on daily, weekly, and monthly time scales at the forest stand level. It also includes the fluxes of major cations (H^+, NH^{4+}, Ca^{2+}, Mg^{2+}, K^+, Na^+), anions (NO^{3-}, SO_4^{2-}, PO_4^{3-}, Cl^-, HCO_3^- , and organic anions), and silicon (Si) in precipitation, soil solution, and throughfall. Throughfall describes the water that falls through the vegetation canopy to the ground surface generating erosive power. The NuCM was designed to simulate the effects of atmospheric deposition, harvesting, change in species composition, precipitation, elevated temperature, and increased carbon dioxide (CO_2). It places heavy emphasis on elements that affect soil solution chemistry, tracking nutrient pools and fluxes associated with soil solution, the ion exchange complex, minerals, and soil organic matter. This model may be most appropriate for determining decadal-scale changes in nutrient pools and soils rather than intra-annual variations in soil solution chemistry (Johnson et al. 2000).

The NuCSS model is a simplified model, but remains more complex than a simple nutrient budget calculation. This model simulates biomass production, organic matter decomposition, N mineralization, cation adsorption, weathering, and leaching. The model estimates a target biomass and associated nutrient uptake using the soil nutrient pools. The user can assess if the available soil nutrients will support the target biomass production (Verburg and Johnson 2001). A key feature of this model is the ease of calibration and, consequently, the simplicity of extrapolation over many sites.

Hydrologic Models

Nutrient fluxes in the Sierra Nevada Mountains are both spatially and temporally variable (Johnson et al. 2001), and a better means of predicting changes in the amount of biologically available nutrients discharged from upper watersheds is needed. The ability to better assess what is occurring spatially in terms of surface runoff alone could offer a linkage in balancing the overall nutrient budget for eastern Sierra Nevada watersheds. One approach is to develop a methodology for delineating a spatially explicit water balance that adequately estimates the potential for surface runoff over large areas using available input/output spatial data (Carroll 2006).

Most recent hydrologic applications involve some use of geographic information systems (GIS) for the ease of estimating model parameters. For example, GIS has been used to estimate and organize important hydrologic modeling parameters such as soil type, land use, slope, flow direction, elevation, drainage network, rainfall, evapotranspiration, and vegetation (Alemaw and Chaoka 2003, Bourletsikas et al. 2006, Jain and Singh 2005, Jain et al. 2004, Schumann et al. 2000). It can also be taken a step further: Liu et al. (2003) applied GIS to better estimate complex parameters requiring multiple spatial inputs such as a potential runoff coefficient as determined from slope, soil type and land use, and flow velocity and dispersion as determined from slope, hydraulic radius, and vegetation coverage. Much of this information may be found in the 2006 soil survey for the basin (USDA NRCS 2007).

Once data have been compiled, there are many variations on how they could be applied to hydrologic modeling. Fluvial transport of sediments occurs when water velocities are strong enough to overcome shear strength of the soil, transporting sediment downstream. Fine particles are often transported as suspended load, moving downstream while suspended in the water. Sufficiently larger particles may be transported as bedload, settling on the river or streambed, but still moving downstream. Areas that lack vegetation because of wildfire or other anthropogenic factors are more susceptible to water erosion and consequent downstream transport. Surface waters often transport these soils to a lower land area or receiving water body, such as Lake Tahoe. If possible, such a model would help researchers to more fully understand the magnitude and sources of nutrients and sediments that are being transported into tributaries and surrounding reservoirs and lakes (Carroll 2006).

Knowledge Gaps

Different agencies in the Lake Tahoe basin use different methods to predict soil erosion and to assess the need for erosion control measures.

- The issue remains whether any of the erosion models and equations is adequate for use in the Tahoe basin. The USLE was originally developed to predict erosion rates on agricultural lands with relatively mild slopes, thus its applicability for the basin is questionable. The RUSLE may compensate for some deficiencies of USLE but may still be inadequate.

- Although WEPP may be the most inclusive model by incorporating a climate and soil database, it is by far the most complex. There needs to be consistency among agencies as to model use and application.
- In the event that the current models are not adequate predictors of soil erosion for the Tahoe basin, appropriate modifications or adjustments are needed to make the existing models more functional. If this is not an option, starting from scratch and developing a new model that is simple, accurate, and appropriate for the basin may be necessary.

There is a particular need for generating refined erosion estimates for single-storm episodes as compared to seasonally weighted or seasonally adjusted annual erosion loads for purposes of programmatic modeling, BMP interpretive assessment, and design criteria. This is particularly true in the Lake Tahoe basin, where there is large variability among storm systems, and single events can result in major runoff.

- Modeling single-storm episodes would be useful for planning and modeling applications, especially for BMP design and implementation associated with new development or redevelopment.

From a management perspective, there is a lack of information on the effects of sediment transport and delivery, pertinent soil parameters, the effects of diminished impervious cover, fire effects (wildfire and prescribed), and the effects of fuel reduction on soil erosion. Information is also lacking on the need for specific erosion control practices.

- Hydrophobic soil conditions have been shown to increase a soil's vulnerability to erosion by increasing aggregate instability, reducing infiltration, and increasing overland flow (Robichaud 2000, Shakesby et al. 2000). Management options to deal with these vulnerabilities have not been defined.
- The increased potential for soil erosion following fuel reduction activities, as well as site susceptibility and response to a subsequent catastrophic event, has not been quantified.
- Fire suppression efforts, recreational development such as ski resorts, and recreational activities such as mountain biking or off-highway vehicle use, can all exacerbate soil erosion as well as soil compaction (Backer et al. 2004). The significance of these anthropogenic activities is not well understood, especially with respect to erosion modeling and their importance as input parameters.

There is no hydrologic model specific to the needs of the Tahoe basin.

- A spatially explicit water balance model, specific to the needs of Sierran forested watersheds, is clearly needed to more fully understand nutrient and sediment transport.
- Furthermore, there are several unusual factors that can affect surface water modeling and model output in the basin such as the spatial distribution of hydrophobicity, frequency and presence of frozen soils, and frequency and intensity of rain-on-snow events that are not addressed in most models currently in use.

Erosion, nutrient cycling, and hydrologic models have yet to be tested against the effects of fire and fuel reduction.

- The effect of fire suppression, wildfire, and prescribed fire for fuel reduction is currently being studied to some extent, but the potential effects of impending climate change are a major unknown.

Research Needs

- Evaluate the accuracy and application of models on a site-specific basis, to determine if the models currently in use are adequate in predicting soil erosion and sediment delivery within the Tahoe basin.
- Determine the role and impacts on soil erosion of hydrophobic soils, fire and fire suppression efforts, and the effect of recreational activities.
- Gain a better understanding of flow patterns, fine and coarse sediment loading, deposition, erodibility, infiltration, slope, and hydrophobicity.
- Establish improved engineering guidelines, predictive tools, and cost-effective management approaches for the control of nutrient and sediment transport from upper watersheds and other high-impact areas of the Tahoe basin.
- Develop site-specific parameterization and model calibration. A prioritization is recommended of which soil parameters are important, what should be measured, and what information is needed to parameterize and calibrate the models.
- Make models more applicable to the basin by improving data input whenever possible, such as the K-factor in USLE and RUSLE equations.
- Understand and quantify the effects of fuels reduction activities on soil conservation. This necessitates recharacterization of infiltration, runoff, nutrient cycling, erosion, and general growing conditions for revegetation at the watershed and subwatershed scales.

- Conduct quantitative evaluation and assessment of potential soil loss from hillsides and sediment trapping within stream environment zones as a result of catastrophic events such as wildfire, rain-on-snow, and excessive rainfall events.
- Develop a spatially explicit water balance model, specific to the needs of Sierran forested watersheds, to more fully understand sediment and nutrient transport, the goal of which is to better assess the linkage between overland flow sediment and nutrient transport and discharge water quality. Applying the appropriate water balance information, localized point source surface runoff and nutrient data could then be used to quantify discharge loads at the watershed scale.

Effects of Climate Change as Related to Soil Conservation

Global climate change is in part the result of greenhouse gases accumulating in the atmosphere. Predictions for the next century include a 3-°C rise in global temperatures (Roos 2005). Warmer temperatures would increase global evaporation and therefore increase global precipitation, much of which is predicted to occur in northern latitudes (Roos 2005).

Depending on the models that are used, predictions for precipitation quantity and intensity are quite variable for the Sierra Nevada. In some predictions, precipitation events will increase in intensity leading to large-scale flooding. In other models, the Lake Tahoe area will be subject to warmer temperatures and more evapotranspiration, and increased precipitation will be more common farther to the north outside the basin. One analysis using General Circulation Models found Lake Tahoe to be one of the few areas where precipitation quantities remained about the same, even with a doubling of CO_2 in the atmosphere (Phillips et al. 1993).

There is general agreement, however, that with warmer temperatures, snow elevation levels will be higher. The Lake Tahoe basin has elevations ranging from roughly 1885 to 3070 m. Snow levels in the area typically range from 1520 to 2432 m during the winter months. It is estimated that for every 1-°C rise in air temperature, the snow level will rise approximately 152 m (Roos 2005). As the basin sits right in the range of the average snow level, a rising snow level means less snowpack for the Lake Tahoe region. More rain and less snow throughout the winter will have important effects on watershed and regional hydrology. Soil quality and soil erosion are the two areas pertinent to soil conservation that will be affected by climate change and its effects on weather patterns and hydrology.

Soil Quality

Snowpack in alpine areas can greatly influence microbial communities. A thick layer of snow acts as insulation to subsurface biota, keeping temperatures hovering around freezing instead of fluctuating with the air temperature to well below freezing (Nemergut et al. 2005). A thin snowpack or none at all leaves these communities vulnerable to the sometimes harsh Tahoe climate. During the winter months, these microbial communities are responsible for a large portion of the plant matter decomposition, thereby mineralizing and immobilizing N (Nemergut et al. 2005). Harsh weather diminishes their numbers and therefore the amount of decomposition that occurs. Slowed decomposition rates lead to fewer nutrients available for uptake the following year. Longer growing seasons will also lead to increased nutrient demand by vegetation, not only of N but carbon as well (Euskirchen et al. 2006). Ultimately, a diminished or more variable snowpack could lead to large duff layers and nutrient-deprived soils.

Soil Erosion

The main issue to confront when discussing soil erosion and climate change in the Lake Tahoe basin is the shift from large snowfall events to large rainfall events. The Lake Tahoe basin receives an average of 10.7 m of snow annually with an average of 3.2 m of annual snow at lake level. However, analysis presented in the "Water Quality" chapter found that the fraction of precipitation that falls as snow rather than rain is decreasing.

Current regulations require drainage structures and erosion control mechanisms to be able to withstand a 20-year storm, or a storm producing 2.54 cm of rainfall in 1 hour. If more winter precipitation is received as rainfall rather than snow, current structures may not be able to withstand the strain. Large rainfall events could erode slopes and flood drainage control structures allowing surface water laden with sediments and nutrients to discharge directly into Lake Tahoe. More rain during the winter also increases the possibility of rain-on-snow events. Recent history, such as the flood of 1997, has shown how catastrophic a large rain-on-snow event can be.

Another issue with variable rainfall is its effect on soil moisture. Rapid melting of a smaller snowpack would lead to a decrease in soil moisture during summer months owing to an earlier runoff. Sarah (2005) reported that less rainfall and therefore less soil moisture is associated with an increase in microparticle percentage and a decrease in aggregate stability. Hence, a decrease in snowpack could ultimately lead to increased instability of slopes and a higher incidence of erosion in the Lake Tahoe basin. Better characterization of amount, rate, duration, and seasonal occurrence of rainfall precipitation could help to delineate shifts in the local climatic precipitation phase and the potential impact on erosion, model estimations, and BMP design criteria.

Knowledge Gaps

How soil biota is affected by a decrease in snowpack as a result of climate change and the consequent result on soil nutrient content is uncertain.

- There is limited information about how climate change will affect microbial communities in the soil, their health, and their functionality.
- There is limited understanding of how climate change will affect the breakdown of plant material.
- Research is recommended to determine if soil nutrient contents will ultimately be affected by microbial community health and increased plant matter production.

How a change in frequency and intensity of rainfall will affect erosion rates is unknown, specifically excessive rainfall and rain-on-snow events.

- We do not understand how episodic events, such as flash floods, will affect Total Maximum Daily Loads (TMDLs) in Lake Tahoe. The ability to predict the recovery time from these natural disasters as well as anthropogenic disasters could benefit many agencies.
- We do not know the relationship between increased intensity and frequency of precipitation events and the resulting erosion rates.

A tool/data set is recommended to modify precipitation data used in sediment loading models to predict the effects of climate change. How this can be used to determine TMDL and the effect of different storm events has yet to be determined.

- Several models are available, many predicting different futures for the Lake Tahoe basin. If model results contain uncertainty, then this uncertainty should be quantified and accounted for as part of the input to subsequent models.
- We are not certain what will happen with climate change: therefore it is extremely difficult to plan for the future of the Tahoe basin. Development and evaluation of alternative scenarios is one objective approach that could help to inform managers of the future possibilities.
- Current regulations only require new drainage control and erosion mechanisms to be capable of handling a 20-year storm event. What happens with a 50-year storm? What happens if there is frequent repetition of 20-year storm events?

How soil stability is affected by climate change is unknown.

- If soil moisture decreases during summer months owing to decreased supply from accelerated winter snowmelt, there could be a resultant decrease in soil aggregate stability.
- If soil moisture increases owing to increased precipitation events throughout the year, soil aggregate stability could increase, but we could see an increase in surface soil removal or an overall decrease in slope stability.

Research Needs

- Study microbial communities and their relationship to climate change and soil nutrient flux in the Lake Tahoe basin. Determine their niche and if climate change will remove certain species from the Tahoe region. This information would include a better understanding of their temperature range, soil moisture requirements, and tolerance to frozen soils. All of this ultimately would concentrate on understanding the effects microbial community health has on soil nutrient cycling.
- Explore the relationship between possible intense summer and winter rainfall storms and erosion rates. Ideally, this research also would look into the rate of snowmelt during rain-on-snow events and the resultant erosion. Do frozen soils help to protect soil surfaces from erosion or increase erosion of surface layers?
- Examine the ability of stormwater management practices such as BMPs, drainage control, and erosion control to diminish sediment and nutrient transport to Lake Tahoe. Do structures designed for a 20-year storm function to their intended design? Do these structures remain functional but at a diminished capacity during a 50-year storm, or do they fail entirely? Future designs could be developed to account for the possibilities that global climate change brings.
- Run all models for the wide range of possible changes in precipitation that may accompany global climate change. New models such as the Channel Change GIS Simulation Model (CHANGISM) described by Hooke et al. (2005) can be used to determine the effect of global climate change on stream environment zones (SEZs) and the implications on nutrient and sediment loading into Lake Tahoe.
- Test the implications of climate change on soil stability. Aggregate stability, surface soil stability, and overall slope stability would all be tested with different possible moisture regimes to determine what the ultimate effects of global climate change could be on soil erosion potential. In addition,

quantifying the sources of sediment would be useful for identifying and initiating management strategies at the most serious locations.
- Explore future ecosystem scenarios. There is concern that long-term restoration may not be possible owing to the emergence of heretofore nontypical ecosystems.

Policy Implementation and Adaptive Management Strategies as Related to Soil Conservation

Public input into the management and conservation of Lake Tahoe basin resources has taken many forms since decline in Lake Tahoe water clarity became a broadly recognized environmental concern. Surveys have been conducted regarding the public knowledge base on environmental issues, and regular news releases and reports have been issued to further educate the public on BMPs and other environmental issues in their community.

Lake Tahoe also has been a longstanding subject of interest for researchers. Educational and research institutions such as the University of Nevada, Reno, the University of California, Berkeley, the University of California, Davis and the Tahoe Environmental Research Center (TERC), the Pacific Southwest Research Station, the U.S. Geological Survey, and the Desert Research Institute all have contributed time, money, and effort to monitoring and studying many aspects of the lake and surrounding watersheds.

The Lake Tahoe Interagency Monitoring Program (LTIMP), a longstanding cooperative program created to acquire and distribute water quality information, has been collecting data on Lake Tahoe and its watershed since 1980. Many federal, state, and local agencies, as well as several nongovernmental agencies are active entities whose interests are directed toward protecting Lake Tahoe water quality by promoting preservation, restoration, sustainability, and environmentally sound development.

The balance of Lake Tahoe's ecosystem is delicate. Excellent communication among the scientific community, the public, and policymakers is recommended for Lake Tahoe to benefit from all of the efforts that go into protecting this precious resource. One aspect of adaptive management is the integration of current research into policy and management decisions and implementation. Current regulations in the Lake Tahoe basin regarding soil conservation, including BMPs to control erosion and sediment transport, protection of sensitive areas such as steep slopes and SEZ, and the mitigation of impervious coverage, can all benefit from a basinwide adaptive management framework.

Resource and regulatory agencies—

The monitoring of water quality management projects has been listed as a primary function of the Lahontan Regional Water Quality Control Board (LRWQCB). The Nevada Division of Environmental Protection (NDEP) and its water quality subsidiaries also oversee water quality issues on the Nevada portion of the basin (NDEP 2007). Both the LRWQCB and the NDEP are leading the effort to develop TMDL pollution budgets for Lake Tahoe. However, both of these state agencies rely heavily on the ordinances set forth by the Tahoe Regional Planning Agency (TRPA) to enhance water quality in the Tahoe basin.

The TRPA oversees much of the implementation and regulation of the water quality planning in the Lake Tahoe basin. Their established “Goals and Policies” call for application of land capability ratings in the planning for new construction and the authorization of additional impervious cover. Likewise, the “Code of Ordinances” ensures SEZ habitat is protected, and the repair of damaged SEZ habitat is authorized. Furthermore, chapter 25 of the TRPA Code of Ordinances calls for the BMP Retrofit Program, in which private and commercial landowners must install stormwater and erosion control BMPs with a capacity to assimilate the stormwater runoff from a 20-year storm event.

The U.S. Forest Service Lake Tahoe Basin Management Unit (LTBMU) manages soil conservation and water quality preservation on Forest Service lands. Monitoring is conducted on many LTBMU projects. The LTBMU has several monitoring programs such as the BMPs evaluation program, fuel reduction project soil monitoring, road decommissioning and BMP-upgrade program monitoring, trail decommissioning and BMP-upgrade monitoring, off-highway vehicle program monitoring, and urban erosion control grant program monitoring (USDA FS 2005). Results from monitoring projects are compiled and reported anually. The 2006/2007 Annual Monitoring Report was recently completed. This report presents a summary of data collected in calendar year 2006, as well as results of analysis conducted fall 2006 through spring 2007. The report contains much information regarding efforts related to monitoring of fuel reduction program, soil and water BMPs, restoration projects, and status and trend of biological resources. It is anticipated that the 2007/2008 Annual Monitoring Report will be completed on schedule, by late summer 2008. The findings identified in these reports have been used to make decisions in terms of which practices will be continued and what modifications in implementation or construction may be necessary. These Annual Progress Reports published by the U.S. Forest Service can be accessed by the general public through the following link, http://www.fs.fed.us/r5/ltbmu/ by clicking on the publications tab and then scrolling to LTBMU Monitoring Reports.

The U.S. Geological Survey (USGS) is another federal agency involved in the management of the Lake Tahoe basin. The USGS has provided numerous resources to help understand and conserve the basin's ecosystems, and, among other things, they provide various geographic and cartographic data useful to resource managers. Such resources include a bathymetry map, a digital elevation model, a digital orthophoto quadrangle, a digital line graph, a digital raster graphic, numerous satellite images, a digital soil map, and a digital census map. The USGS is also one of the principal partners in the LTIMP stream monitoring program.

The California Tahoe Conservancy (CTC) is a state agency developed to create and implement programs that improve and protect the environmental quality of the Lake Tahoe basin. Protection of the clarity and quality of the lake's waters is a primary objective of CTC. Additional goals and programs are geared toward the preservation and protection of wildlife and wildlife habitat, environmentally sensitive land, SEZ habitat, forest habitats, and recreation opportunities (CTC 2006). The CTC is only active in the California portion of the basin.

The Natural Resource Conservation Service (NRCS) is an agency within the USDA that provides data, information, and technical expertise on natural resources. Their primary customers are those who manage and use natural resources on nonfederal lands including farmers, private organizations, and nonprofit organizations (USDA NRCS 2007). An important recent contribution has been the 2006 update of the Soil Survey of the Tahoe Basin Area (USDA NRCS 2007).

The Nevada Tahoe Conservation District (NTCD) is a subdivision of the state of Nevada whose mission is to "promote the conservation and improvement of the lake Tahoe basin's natural resources by providing leadership, education, and technical assistance to all basin users" (NTCD 2003). The NTCD is active in the Nevada portion of the basin and is involved in a number of projects including erosion control, water quality, the Backyard Conservation Program, and a stormwater planning initiative.

The Tahoe Resource Conservation District (TRCD) is a conservation district for the state of California that is active on the California side of the basin. Programs within TRCD include the Backyard Conservation Program, an invasive weeds program, a schoolyard restoration program, a watershed program, and most recently an aquatic invasive species program. The TRCD works in close cooperation with the NTCD (TRCD 2007).

Best Management Practices

Best management practices have been developed to minimize wind and water erosion, uncontrolled surface runoff from urban areas, and ultimately sedimentation and nutrient loading into Lake Tahoe. Urban runoff is considered a greater source of sediment and nutrients than undisturbed areas and is therefore of primary concern (LRWQCB and NDEP 2008a, 2008b, 2008c; Schuster and Grismer 2004; TRPA 2001a, 2001b). In 1992, the TRPA implemented the BMP retrofit program requiring all property owners to upgrade their property with BMP technology. Best management practices can be divided into three categories: temporary construction, permanent drainage control, and permanent surface stabilization.

Temporary construction BMPs deal with the exposure and disturbance of soils and vegetation on a construction site. They are therefore temporary solutions designed to minimize the impacts of the immediate disturbance activities. Often included are temporary structures to stabilize and protect areas such as boundary fencing to protect environmentally sensitive areas from encroachment: fiber roll barriers, filter fences, drop inlet barriers, and gravel bags all of which act as sediment barriers; and erosion control blankets, mulches, and tackifiers to maintain unstable slopes (TRPA 1988). Construction sites also participate in activities such as traffic control where traffic is kept to areas that will have the same use postconstruction, stabilization of construction entrances to minimize transport of sediments outside of the construction zone by vehicle traffic, and dust control by maintaining surface cover by moistening, vegetating, or mulching exposed surfaces (TRPA 1988, White and Franks 1978). Construction sites disturbing more than 1 acre of soil are required to file a Storm Water Pollution Protection Plan (SWPPP) as mandated by the National Pollutant Discharge Elimination System (NPDES) under the Clean Water Act (NDOT 2006, SWRCB 1999). The SWPPP specifies which BMPs will be applied to prevent all construction pollutants and erosion products from entering stormwater and exiting the construction site (SWRCB 1999). It also is required that this plan detail maintenance procedures and self-inspections that will be conducted to ensure the optimum performance of applied BMPs (NDOT 2006). The filing of the SWPPP is implemented and enforced by the LRWQCB and the NDEP.

Permanent drainage control is used to minimize the effects of impervious areas and diminish the capacity of surface runoff carrying nutrients and sediments to move offsite. The continual growth of impervious area such as rooftops, driveways, compacted soils, patios, and decks is a side effect of urbanization. Numerous BMPs have been designed to address the problems associated with large areas of reduced or zero infiltration and the production of large quantities of surface runoff. The first step is the installation of conveyance systems, such as slotted drains, swales, subsurface drains, gutters, downspouts, deflectors, gravel trenches, or gravel armor, which all intercept runoff perpendicular to the direction of flow and then divert it to an infiltration system (TRPA 1988). Next is the installation of surface infiltration systems such as naturally flat vegetated areas, infiltration trenches, drywells, gravel armoring layers, retaining ponds, and planter boxes (TRPA 1988). These systems retain water, allowing sediment to settle and the water to infiltrate into the soil, which has inherent cleansing abilities for some nutrient components.

Permanent surface stabilization is designed to reduce the impacts of unstable, steep, or exposed soil surfaces. Compacted soils that do not infiltrate can be paved to avoid erosion or vegetated to improve infiltration (TRPA 1988). Vegetation also can be used to stabilize slopes. Other methods of slope stabilization include willow wattling, terraces, retaining walls, mulching, and erosion control blankets (TRPA 1988). Which method(s) are most appropriate depends largely on the steepness of the slope.

One of the most recent soil conservation issues is the defensible space program and the need for BMP implementation within the 0- to 30.5-m range by private homeowners. Guidelines are currently being developed for any person who owns, leases, controls, operates, or maintains a building or structure adjoining any mountainous area, forest-covered lands, brush-covered lands, grass-covered lands, or any land that is covered with flammable material. Such a defensible space perimeter would provide firefighters a working environment helping them to protect buildings and structures from encroaching wildfires as well as minimizing the chance that a structural fire would escape to the surrounding wildland. A key concern is the development of appropriate management strategies that maximize defensible space but at the same time function to minimize erosion and the degradation of runoff water quality.

BMP Effectiveness

To some extent, most BMPs are effectively reducing erosion and thereby reducing total sedimentation and nutrient loading to the lake. A study was conducted from 1974 to 1977 comparing sediment yields from two development sites in or near the Tahoe basin: Northstar-at-Tahoe and Rubicon Properties Unit Number Two. Construction of one site (Northstar-at-Tahoe) included erosion control methods and the other (Rubicon Properties) did not. Sediment yield from Northstar-at-Tahoe increased by about 100 percent above the very low background levels associated with predevelopment conditions, whereas sediment yield from the Rubicon Properties site was found to be approximately 10,600 percent above background levels well after development (White and Franks 1978). Evaluation of the sample plot at Rubicon Properties led researchers to believe that implementation of erosion control methods similar to those at Northstar-at-Tahoe would help reduce sediment yields to approximately 100 percent above background levels at Rubicon; however, data to this effect could not be found.

Identification as to which BMPs are most effective and to what degree for any given scenario is therefore important. Best management practice effectiveness is a function of three factors: design, construction, and maintenance. Choosing the most effective BMP requires sufficient knowledge of BMPs and their applicability depending on location and other site-specific conditions within the basin. Cost effectiveness is an additional issue to be considered when choosing the most appropriate BMP. A BMP that is the most effective in reducing sediment yield may not be cost effective owing to site conditions, materials, or labor requirements; hence, it may not be practically feasible. Alternatively, a BMP might be both cost and functionally effective in reducing sediment yield, but require excessive maintenance reducing its viability as a long-term method of erosion control. It is essential that each aspect be considered when selecting the most appropriate BMP. The question of which BMPs are most effective is best determined by having a full "toolbox" of BMPs from which to choose, and then having the knowledge and experience to apply the correct BMP to match onsite situations.

Although it is considered best to minimize disruption and keep native vegetation intact whenever possible (Gray et al. 1980, Lynard et al. 1980, TRPA 1988), this is seldom feasible during construction activities. In such construction zones, revegetation and gravel mulches have been shown to be an effective means of erosion control on disturbed, bare soils. On the other hand, simple sprinkling has been found to be an inefficient practice (TRPA 1988). It requires large amounts of water, needs several applications daily, and creates sediment-laden water. In terms of sediment traps, straw bales do not trap much sediment and create a noxious weed hazard, and sandbags can tear and add additional sediment to flow (TRPA 1988). Fiber rolls and filter fences can be efficient sediment traps when installed correctly but unfortunately they seldom are (TRPA 1988). Therefore, temporary construction BMPs run the risk of frequently being ineffectual and require great vigilance on the part of authorities to make sure that they are being implemented and maintained correctly.

For permanent drainage control, conveyance systems are used to direct surface runoff to a point of infiltration within the property line. Infiltration effectiveness is assumed but is unknown. Slotted drains are most effective for conveyance on driveways, but are quite costly, and swales cannot be installed on slopes greater than

5 percent (TRPA 1988). Berm construction is no longer a recommended practice because they lose functionality over time owing to the harsh Tahoe climate. The most appropriate infiltration systems for use are often determined by soil characteristics such as bulk density, water-holding capacity, hydraulic conductivity, and soil water repellency. Vegetation is often used to enhance the efficiency of certain drainage structures such as swales or channels by reducing flow velocities and thereby allowing time for greater infiltration. Gravel and other infiltration trenches are typically inappropriate structures on slopes, and gravel armor is only effective when used on highly permeable soils (TRPA 1988).

The use of native vegetation has always been considered an effective means of retaining surface stabilization (Lynard et al. 1980). Once soil is bared, however, the combination of vegetation and mulch has been proven an effective method of stabilizing it (Grismer and Hogan 2005a, 2005b). Erosion control blankets, seeding and fertilizing, and wood fiber coating have all been found to be effective slope stabilizers; however, seeding alone was highly ineffectual (Leiser et al. 1978). Establishing vegetation on a steep slope can be quite difficult. It has been noted that high vegetation mortality can be the result of unstable slopes (Leiser et al. 1978). In this case, it is generally recommended that vegetation efforts can be supported with some kind of slope stabilization (Lynard et al. 1980). A combination of wattling and willow cuttings were found to decrease sediment yields from a road cut from approximately 83 m^3/yr to almost nothing (Leiser et al. 1978). In fact, in a 1978 U.S. Environmental Protection Agency report it was noted that contour wattling should be applied more often (White and Franks 1978).

BMP Maintenance

Different erosion control structures require different levels of maintenance to remain effective, although regular maintenance is often important. For example, regular cleaning of conveyance structures is necessary to remove accumulated debris (TRPA 1988), and infiltration systems require regular cleaning to maintain maximum storage capacity. Although no clear maintenance schedule is given for conveyance and infiltration structures, it is recommended that they be examined after each storm to determine if cleaning is necessary. Organic mulches are best replaced yearly owing to decomposition loss. Mortality loss of vegetation coverage is best compensated for with the establishment of new vegetation (TRPA 1988). Vigilance is a major aspect to the maintenance of effective BMP structures. This is highly dependent on the level of devotion, regardless of whether the application is at the jurisdictional, the individual property owner, or the responsible regulatory agency scale.

Stream Environment Zones

Stream environment zones are wetland, flood-plain, and riparian areas that influence the surface water quality in the Lake Tahoe basin. They have traditionally been considered an important means of reducing nutrient and sediment loads and surface water velocity before discharge into Lake Tahoe. In 1982, the TRPA stipulated that SEZ habitat should be protected in its natural state, that all disturbed SEZs in undeveloped areas would be restored, and that at least 25 percent of the disturbed SEZs in developed areas would be restored (TRPA 2001a, 2001b). From 1980 to 1986, 61 ha of SEZ were restored; 28 ha were restored from 1987 to 1991; 41 ha were restored from 1992 to 1995; and 62 ha were restored from 1996 to 2001. In order to attain its SEZ habitat threshold, TRPA (2001a, 2001b) set a goal of restoring 253 ha of SEZ habitat by 2006, of which 148 ha of SEZ were restored (TRPA 2006a, 2006b) by that date. Threshold attainment is reevaluated every 5 years.

Impervious Coverage

Impervious coverage is land that is unable to infiltrate surface water owing to paving, soil compaction, or structural coverage. Impervious coverage leads to increased surface water runoff, thereby increasing flow velocities, erosion potential, and sediment transport, as well as the production of other pollutants such as vehicle oil and grease, tire dust, and hydrocarbons from pavement. In 1982, the TRPA adopted the threshold policy that impervious coverage will comply with the land capability classification system set forth for the Lake Tahoe basin by Bailey in 1974 (TRPA 2001a, 2001b). This land capability classification determined how much impervious coverage an area can handle based on its perceived hydrologic characteristics and is currently applied to all parcels developed before 1987. Bailey classifications were originally determined from soil and hydrologic features characterized by the original Tahoe basin soil survey report (USDA SCS and FS 1974), but may require revision based on the now updated soil survey (USDA NRCS 2007) to remain consistent. In 1987, the TRPA implemented the Individual Parcel Evaluation System (IPES) as its method for determining allowable impervious coverage on vacant or undeveloped lots. A numerical value is assigned to each parcel, which is calculated from its relative erosion hazard, runoff potential, degree of difficulty to access the building site, SEZ, condition of the watershed, ability to revegetate, need for water quality improvements in the parcel vicinity, and proximity to Lake Tahoe. The IPES field evaluation team determines the parcels most eligible for development (those with the highest IPES score) and ranks them accordingly for each jurisdiction.

The Tahoe Environmental Geographic Information System (TEGIS) was developed in 1987 to track the amount of impervious coverage. Research with the Desert Research Institute and TRPA has proved effective in being able to use satellite imagery and aerial photography to improve this database. However, it was not detailed enough to be applied in the 2001 TRPA monitoring of threshold attainment. Instead, project reviews, compliance records, and files were used to establish comparisons for the levels of new and old impervious coverage. From this it was determined that as of 2001, the Tahoe basin was not yet in attainment with the land capability threshold. Furthermore, it was believed that attainment could not be achieved by 2006. To our knowledge, no set schedule for attainment has been established (TRPA 2001b).

Although attainment of the impervious coverage threshold has yet to be met, there is some evidence that the IPES program may be helping to reduce sediment loads discharging into Lake Tahoe. A study conducted by the Desert Research Institute in 1999 reported that 9 of 10 Lake Tahoe tributaries have seen a decrease in suspended sediments since the implementation of the IPES program in 1989 (TRPA 2001b). This study has yet to be published in a peer-reviewed journal, and it is currently unknown whether or not the relationship was coincidental. Without detailed information, it is difficult to determine if the reduction in suspended sediments was actually related to the IPES program, or the result of other management strategies, climatic variation, or a combination of related factors.

Implementation and Regulation

Despite TRPA's efforts in regulatory management for water quality protection, our experience in the Tahoe basin suggests there is a serious lack of community participation and understanding as to the importance of monitoring for BMP effectiveness and the relationship between impervious cover restrictions and SEZ protection that are pertinent to soil conservation (i.e., the reduction of nutrient and sediment loading) and the enhancement of stream and lake water quality. Although the monitoring of water quality management projects has been listed as a primary function of the LRWQCB, such evaluations have been difficult to conduct, and there does not appear to be much available to the general public regarding the efficiency of programs that have been implemented. As of June of 2006, an estimated 36,000 properties of the approximately 42,000 developed parcels in the Tahoe basin remained in noncompliance (Fehd 2006). With a reported rate of 150 to 175 free evaluations available per month (Fehd 2006), and the limited construction season (May–October), it appears unlikely that this goal will be reached. The public might be more active in their participation if the required BMPs could be quantitatively demonstrated as the most effective of the BMP tools and, if applied, how much their individual involvement could directly improve water quality.

Although there are gaps in monitoring and reporting of water quality protection efforts in the Lake Tahoe basin, there have been some successes as well. The LTBMU actively monitors management practices, facilitates the implementation of new research into policy, and actively participates in the dissemination of research results. The Annual Progress Report published by the USDA Forest Service, as well as the individual reports compiled for each monitoring project, allow interested members of the public the opportunity to educate themselves on topics concerning the preservation of Lake Tahoe's water quality and surrounding soils. The use of monitoring results in decision and policymaking are fundamental to the success of adaptive management.

Regional Planning

Regional planning has been enhanced by the Environmental Improvement Program (EIP). The EIP was established in concert with the 1997 Lake Tahoe Presidential Forum. It outlined a 10-year plan investing $980 million into the Tahoe basin (TRPA 2006b). These investments have aided soil conservation efforts through the acquisition of sensitive lands, restoration of sensitive areas, treatment and removal of unpaved roadways in forested areas, funding of monitoring assessment programs, and the establishment of and technical assistance to EIP partners. For example, the new NRCS Soil Survey is counted as a federal contribution of technical assistance under the EIP. The list of EIP partners is extensive and includes almost all research, governing, and public institutions involved in maintaining Lake Tahoe basin environmental integrity (TRPA 2001b).

The 20-year regional plan guiding TRPA programs expired at the end of 2006. It was subsequently determined that the public was very confused on environmental issues, that they lacked understanding of regulatory policy, and they did not grasp how their individual actions could have substantial impacts on the fragile Lake Tahoe ecosystem (Pathway 2006, 2007). Consequently, it is extremely important that members of all components of the community are involved in the development of a new regional plan.

Knowledge Gaps

Regulatory compliance and the effectiveness of management strategies on privately owned portions of the Lake Tahoe basin are unknown.

- Government agency monitoring of the effectiveness of their programs is inconsistent and does not make public the results or findings of fact.
- Because there is a lack of understanding as to the relationship between BMP effectiveness and the enhancement of stream and lake water quality,

Tahoe residents are not always predisposed to comply with existing regulations.

- The agencies have not explored the full suite of opportunities available to regulate and monitor the effectiveness of existing policy ordinances.
- The status of the environment and resources relative to the existing thresholds is largely unknown.

Agency identification of key management questions of specific interest and their relationship to short- and long-term goals based on specific management objectives is lacking.

- Although a number of basinwide key management questions have been identified, each agency appears to have its own specific issues, goals, and agendas. These are often conflicting and repetitive when separately addressed.
- Reexamination of the historical application of model-based policy is important, particularly in the context of new quantitative data and technologies. The foundation for current thresholds appears to reside in part within the context of the original Bailey Land Capability Classification (Bailey 1974). The Bailey system was based on the original "Tahoe Basin Soil Survey, California and Nevada" (USDA SCS and FS 1974), which has now been updated by the "Soil Survey of the Tahoe Basin Area, California and Nevada" (USDA NRCS 2007). We suggest this classification system and any related thresholds be reevaluated in the context and guidance of findings presented in the new Soil Survey

Underlying ecosystem processes of relevance to soil conservation are largely unknown, and such knowledge would help to facilitate the broad application of adaptive management strategies across projects within and among contributing watersheds.

- Clear identification of where research and agency monitoring programs can be strengthened and integrated would benefit from full assessment. To implement more cost-effective data collection, better integration of science information (i.e., research and monitoring) into the decisions affecting the implementation of capital programs is recommended.
- There is no standard method of measurement and monitoring protocols from which data reporting and interpretive analysis can be applied basinwide. This makes it more difficult to compare results from different activities or similar activities at different locations throughout the basin.

The decrease in Lake Tahoe's clarity has been largely attributed to a combination of fine sediment suspension and enhanced biomass production from N and P nutrient loading.

- Most published erosion control studies in the basin have focused on reporting total sediment yields alone. More work is specifically recommended to determine how erosion control measures affect fine sediments and their related equilibrium nutrient chemistry. One erosion control study reporting on nutrients and fine sediment showed erosion control structures to be effective in removing coarse particulates, but not nearly as effective when dealing with fine sediments and nutrients (Garcia 1988).
- Which colloidal-size particles, their associated mineralogy, and their equilibrium chemistry are most important to bio-available nutrient contributions and physical light scattering remains unknown. Better quantitative evaluation in this regard is critical to the development of programmatic, investigative, and management approaches that focus on what the literature now indicates as contributors to diminished water clarity.

Revegetation of unstable slopes has had mixed success owing to a lack of uniform application of approaches that are based on well-founded principles.

- Revegetating slopes has been more costly owing to the rarity and unpredictable availability of native vegetation seed stock and seedlings in nurseries.

Broader knowledge of the overall effectiveness of multiobjective BMPs applied in the Tahoe basin is needed to educate the public and evaluate the suitability of regulatory policy.

- Published research on basinwide BMP effectiveness is limited.
- Although BMP effectiveness research is currently being performed by several agencies in the Tahoe basin, consistency in parameter measurement and reporting of results is seldom achieved (Lynard et al. 1980, Schuster and Grismer 2004).

Best management practice effectiveness is usually tested as a whole for several BMPs implemented on one site.

- Determining which BMPs are truly the "best" would require (1) matching the correct BMP to site conditions and (2) testing them against one another rather than comparing their cumulative site effects.
- Collective BMP effectiveness in different situations and combinations has not been evaluated.

Urban development and anthropogenic activities typically reduce native soil capacity.

- BMPs for protecting and rehabilitating soils affected by urbanization are not well defined in terms of design, function, or effectiveness.

Erosion control structures are being implemented throughout the basin on construction sites and residential and commercial lots.

- The number of erosion control structures actually monitored for compliance and effectiveness is unknown.
- Whether or not appropriate structures are being implemented in each site and location is uncertain.

It has been suggested that many temporary sediment traps used on construction sites are frequently installed incorrectly.

- Regular inspection of construction sites for compliance and real-time enforcement would assist in the performance evaluation of management strategies.
- Inspection, maintenance, and enforcement of monitoring protocols as outlined in the SWPPP would be helpful.

Wood fiber, pine needles, and other organic materials are frequently used as mulch when stabilizing bare soils.

- Thick pine needle mats have been shown to be a possible contributor to high levels of biologically available N and P in surface runoff.
- Little is known about the nutrient release effects of woodchips when used as mulch layers or when incorporated into the soil.
- The creation of defensible space through vegetation management usually means reducing the amount of fuel around the building or structure, providing separation between fuels, or reshaping retained fuels by rearranging the trees, shrubs, and other fuel sources such as plant-residue groundcover in a way that makes it difficult for fire to transfer from one fuel source to another.
- Vegetation removal for defensible space can cause soil disturbance, soil erosion, regrowth of new vegetation, and introduce nonnative invasive plants. Areas up-gradient of water riparian areas, such as streams or ponds, are a particular concern for protection of water quality when developing a defensible space protocol.

Tahoe Regional Planning Agency threshold standards remain in non-attainment status.

- Goals for the attainment of established threshold standards continue to be set, but it remains difficult to achieve attainment.
- Threshold indicators are typically monitored for attainment only, and not for determining the effectiveness of the threshold in protecting Lake Tahoe water quality.

The application of new knowledge to improve management policies and practices would require active communication between researchers and policymakers.

- Some agencies may be diligent in their monitoring and integration of results into management decisions, whereas others may not be so diligent.
- There is inconsistency regarding the incorporation of pertinent new findings into the policymaking process.

Research Needs

- Include N and P nutrient forms, fine sediments, and their associated equilibrium chemistry as specific parameters in quantitative analysis for BMP, SEZ restoration, and impervious coverage reduction effectiveness studies.
- Develop standardized monitoring protocols for the monitoring of BMP effectiveness, SEZ restoration, and impervious-coverage reduction in the Tahoe basin. Findings could then be reported in peer-reviewed journals for enhanced credibility.
- Measure the effectiveness of BMPs as separate entities rather than a program as a whole. Similar slope stabilization, infiltration, or sedimentation techniques could be tested against each other in similar and divergent environments as a means of ascertaining why some work better than others in one locale vs. another.
- Determine the depth of understanding and actual participation of Tahoe basin residents in the maintenance of their privately managed BMPs.
- Monitor and compare several combinations of BMPs in a variety of settings, including urbanized sites. This creates the perfect scenario in which to investigate the range of functions for commonly applied BMPs in the Tahoe basin and their ability to protect and restore important soil properties such as infiltrability, stability, soil moisture storage, and capacity to support revegetation. This could also be used to determine compliance maintenance schedules for BMP upkeep.

- Monitor construction sites to determine compliance and ability to effectively install and maintain temporary BMPs.
- Conduct research to quantitatively demonstrate how sound adaptive management practices, even at the individual scale (e.g., homeowner BMPs), benefits and enhances the Tahoe basin environment and improves water quality.
- Develop a horticulture program geared toward the propagation, seed bank development, and seedling establishment techniques for native vegetation to stabilize slopes in the Tahoe basin.
- Monitor established environmental thresholds to assess attainment as well as effectiveness. Realistic goals could then be set for attainment of these thresholds when proven effective in the reduction of nutrient and sediment loading to the lake and the enhancement of water clarity.
- Quantitatively compare Bailey's Classification System and the IPES to naturally functioning systems with no impervious coverage to determine the level of effectiveness the reduction in impervious coverage is having. Furthermore, these studies could assist in integrating information from the new soil survey into these existing systems, and reassessment research could be performed to better understand the regulatory implications of any new findings.
- Determine the potential social and environmental benefits of relocating existing land coverage to hillsides or intervening zones having equal or greater infiltration capacity, deeper ground water, and greater potential for subsurface filtration.
- Research and monitor existing regulatory programs such that their true effectiveness and applicability can be more quantitatively assessed. Research on BMPs and regulatory programs from other areas may be beneficial.
- Reevaluate or monitor the use of wood fiber, pine needles, and other organic materials and its relationship to defensible space, overall applicability and site-specific effectiveness.
- Compile comprehensive data syntheses of results from previous findings and also current research projects, monitoring programs, and impending adaptive management strategies. A single database would be the optimal place to look for environmental information, management strategies, and problem-solving options in the Lake Tahoe basin.

- A standard protocol for the measurement and monitoring of Tahoe basin (eastern Sierran) ecosystems is recommended. Use of these protocols by all Lake Tahoe basin participants would facilitate the comparison of basin-wide soil conservation projects and the compilation of results from projects conducted at different locations by different institutions and/or the private sector.

Near-Term Soil Conservation Research Priorities

Following are a prioritized listing of the three most immediate near-term soil conservation research needs within each subtheme category. This approach was taken because different agencies may be more focused on the components of a given subtheme rather than the broader category of Soil Conservation as a whole.

Key Soil Properties and Conditions (SPC)

Research Priority No. 1 (SPC1): Further quantify the distribution of various watershed properties such as soil water repellency, biologic and inorganic nutrient pools, infiltrability, and water balance parameters on a larger spatial scale. The impact of natural and anthropogenic activities such as development (impervious vs. pervious), forest management (fire suppression vs. mechanical or prescribed fire biomass reduction), vegetation (native vs. non-native species), restoration (physical and chemical amendments vs. reduced fertilization), and features that have disrupted natural littoral and eolian processes on soil health at the watershed scale (including the intervening zones) remains poorly understood.

Research Priority No. 2 (SPC2): Assess which restoration methods are most effective in controlling event-based runoff. Also, the transport and equilibrium chemistry of fine particles most associated with nutrient and sediment loading should be more quantitatively assessed. Project success and longevity should be evaluated relative to the sustainability of hydrologic function, productivity, and erosion control over time.

Research Priority No. 3 (SPC3): Characterize to the extent feasible and quantify where possible, historical vs. current and natural vs. anthropogenic induced declines in soil status and resulting soil loss at the watershed scale. Research on soils in natural as well as disturbed settings is recommended whenever possible, with sites established to measure soil conservation parameters including inputs such as plant-soil nutrient fluxes through litter-fall, crown-wash, and root turnover as well as losses from erosion, leaching, runoff, wind, or fire. Research would focus on sites where a suitable control portion is available, especially if event (e.g., prewildfire or pretreatment) data are available.

Knowledge advancement potential—

The fate of Sierran ecosystems in a changing environment will have a direct impact on soil health, fire hazard, biomass mitigation strategies, erosion, and water quality. Manipulative research projects that include random assignment of treatments and replication are challenging to perform in the Tahoe basin. And yet a crucial research need is to identify and quantify key indicator parameters in a variety of historical and current ecological settings, under various manipulations, and over time. In such cases where robust experiments are possible, restoration methods that are most effective in controlling runoff and transport of fine particles, as well as those most effective in the reduction of nutrient discharge loading and its direct effect on water clarity, can be better assessed. This would allow a more complete understanding of the environmental factors (i.e., temperature, moisture, vegetation, and litter) that determine the formation, persistence, and dissipation of seasonal and long-term effects on runoff water quality and erosion. In this context, similar slope stabilization, infiltration, revegetation, or sedimentation techniques could be tested against each other in similar and divergent environments as a means of ascertaining why some work better than others in one locale vs. another. Research focused on the identification, monitoring, evaluation, tracking, and adaptive management of individual and collective BMP systems—and linking them to GIS layers at the watershed and basin scale—would go a long way toward addressing the concerns of stakeholders and agencies alike. Being able to track and revisit BMP strategies would further facilitate true adaptive management.

Development and Application of Predictive Models (PM) as Related to Soil Conservation

Research Priority No. 1 (PM1): Successful model application dictates the need for site-specific parameterization and model calibration. Model use and application can then become more consistent and interpretive assessment more uniform among agencies basinwide. Research and monitoring protocols are recommended to provide relevant information for predictive model development, improvement, calibration, and field validation specific to the Lake Tahoe basin. A prioritization of which soil, vegetation, and hydrologic parameters are important, what should be measured, and what information is needed to parameterize and calibrate the models should be established.

Research Priority No. 2 (PM2): Develop a spatially explicit water balance, nutrient cycling, and erosion potential model to better understand current sediment and nutrient transport at the watershed scale and under conditions of potential changes in hydrologic and soil parameters. The role of hydrophobic soils should be further studied to determine the spatial distribution of recharge areas vs. those that are overland flow generating and their influence on soil erosion model output estimates. A prioritization of which parameters are important, what should be measured, and what information is needed to parameterize and calibrate the models should be established.

Research Priority No. 3 (PM3): Develop a better understanding of how various factors or stressors change soil status in Tahoe basin watersheds to assist forest managers in preparing management plans and make predictions about ecosystem response to natural (e.g., fire, insect attack, drought, or erosion) and anthropogenic (air pollution, harvesting, development, or climate change) perturbations. For example, a comprehensive assessment of the effects of both wildfire and prescribed fire, and postfire vegetation, on long-term response in biological and physicochemical soil parameters is needed to better understand fire and its role in restoration ecology.

Knowledge advancement potential—

Because regulatory policies may be based on the subjective judgment of "risk potential" rather than on a sound quantitative decision-support system, the application of predictive models can provide important tools to understanding and estimating the potential outcome of management strategies and programs. Successful model application, however, is accomplished through site-specific parameterization and model calibration. Establishing a means for prioritizing which ecosystem parameters are important, what should be measured, and what information is needed to parameterize and calibrate the models. In the event that the current models are not adequate predictors, appropriate modifications or adjustments are needed to make the existing models more functional. If this is not an option, starting from scratch and developing a new model that is simple, accurate, and appropriate for the Tahoe basin may be necessary. Model use and predictive application is recommended to enable consistency among agencies basinwide wherein the acquisition of a more robust quantitative database could provide the foundation for policies of future management strategies.

Effects of Climate Change (CC) as Related to Soil Conservation

Research Priority No. 1 (CC1): There is concern that anthropogenic activities over the last century have resulted in nontypical ecosystem structure throughout the basin of which the distribution, character, variability, and potential response to climate change have not been evaluated. Consequently, strategic efforts directed toward long-term site restoration in response to a quasi-natural state will be the more likely scenario. Quantitative assessment of what we can and cannot hope to accomplish on a long-term basis is recommended.

Research Priority No. 2 (CC2): More comprehensive localized point source precipitation, surface runoff, erosion, and nutrient transport data is recommended to quantify potential discharge loads as a function of amount, type (snow vs. rainfall), frequency, and precipitation intensity. Research and monitoring projects should be designed to address potential changes in hydrologic parameters as a result of climate change.

Research Priority No. 3 (CC3): Investigate the implications of climate change on slope stability parameters. Surface soil stability, compaction, soil structure and aggregate stability, infiltrability and runoff, and potential for mass wasting should all be tested under scenarios of different temperature and moisture regimes to estimate the potential effects of climate change on soil erosion in the Lake Tahoe basin.

Knowledge advancement potential—
The implications associated with climate change cannot be ignored. Predictions for changes in precipitation quantity and intensity are quite variable for the Sierra Nevada. One scenario is that precipitation will increase in intensity leading to large-scale flooding. Another is that the Lake Tahoe area will be subject to overall warmer temperatures and more evapotranspiration, whereas increased precipitation will be more common farther to the north. There is general agreement, however, that with warmer temperatures, snow elevation levels will be higher with less accumulation, which will lead to longer fire seasons. New approaches are recommended for examining shifts in the quality and amount of hydrologic inputs to support management strategies involving biomass reduction, drainage control, and practices to diminish sediment and nutrient transport to Lake Tahoe. It is recommended that future planning for the production of resilient, spatially heterogeneous and diverse forest structure be designed to account for potential changes in hydrologic function in response to different moisture regimes to determine what the ultimate effects of climate change could be on management protocols for sensitive areas at the watershed and locale scales.

Policy Implications (PI) and Adaptive Management Strategies as Related to Soil Conservation

Research Priority No. 1 (PI1): Monitor and study established environmental thresholds for attainment and for performance effectiveness. It is recommended that regulatory agencies and land managers develop a protocol for periodic review, verification, and update of processes, quantitative thresholds, and policy relevance.

More research and monitoring of existing regulatory programs is recommended, such that their overall effectiveness and applicability can be more quantitatively assessed relative to their actual reduction of nutrient and sediment loading to the lake and the subsequent enhancement of water clarity. Develop a basinwide protocol for "Standard Methods of Ecological Measurement and Monitoring in the Tahoe Basin."

Research Priority No. 2 (PI2): Continued research that addresses critical natural resource issues and critical management questions relevant to soil conservation in the Lake Tahoe basin is essential. This exercise can begin by identifying a list of agency-specific management questions pertinent to soil conservation relative to key soil properties and conditions of interest. For example, what are the appropriate management strategies that maximize defensible space protection, but at the same time function to minimize erosion and the degradation of runoff water quality? It is then important to take advantage of unique opportunities and small-scale experimental field trials to quantitatively evaluate potential impacts. To ensure its credibility and applicability, such research would make every effort to be scientifically defensible, applicable to the Tahoe basin or similar ecological settings, and publishable in peer-reviewed journals.

Research Priority No. 3 (PI3): Restoration and BMP strategies are generally implemented to mitigate known adverse impacts from either natural events or anthropogenic activities. Choosing the most effective strategy therefore will benefit from a thorough knowledge of the mitigation objective, process mechanics, both short- and long-term functionality, and whether or not these components will differ depending on location within a given watershed or the Tahoe basin in general. Performance evaluation is commonly assessed on a collective (e.g., projectwide) rather than individual (e.g., specific management activity) process basis. Complete evaluation of which strategies are truly the most effective in meeting specific restoration objectives would require testing each management activity against one another as well as assessing their cumulative effects. Management strategies implemented for one purpose (e.g., defensible space) may or may not have an effect on other issues of concern and ascertaining why some work better than others in one locale vs. another (or not at all) is a critical issue.

Knowledge advancement potential—

If greater confidence in performance effectiveness can be developed, consistency will likely follow. With new technology comes the opportunity for innovative soil conservation strategies that could alter or refine historical threshold values. In the past, technological advancement and expansion of the knowledge base was much slower. Today, it is not unusual for substantial new advancements to take place on a 5-year rather than a 25-year cycle. Key to the success of any such approach, however, is the development of a consistent and effective monitoring protocol for key soil properties and conditions that is current, process-specific, and uniform across agencies and contractors. Hence, research is recommended to develop a standard protocol for ecological measurement and monitoring in the Lake Tahoe basin, which includes variable levels of intensity that can be applied to different types and scale of projects. In its absence, implementers and agencies frequently employ different techniques in attempting to evaluate the performance effectiveness of similar soil conservation activities. Comparative interpretive assessment is then difficult to impossible. Furthermore, evaluating which conservation and/or restoration methods are most effective is recommended in the context of a more comprehensive framework wherein each on-the-ground management strategy could be tested against one another in similar and divergent environments. Therein, lay key opportunities where new and unique soil conservation strategies could be explored. Finally, agency representatives can clearly identify agency-specific areas of concern, and then work with scientists and implementers to articulate the respective critical soil conservation issues. This would greatly assist in the development and design of successful monitoring, opportunistic, and/or experimental research programs that generate data and information directly applicable to agency needs.

English Equivalents:

When you know:	Multiply by:	To get:
Millimeters (mm)	0.0394	Inches
Centimeters (cm)	.394	Inches
Meters (m)	3.28	Feet
Hectares (ha)	2.47	Acres
Square meters (m^2)	10.76	Square feet
Cubic meters (m^3)	35.3	Cubic feet
Degrees Celsius (°C)	1.8 °C + 32	Degrees Fahrenheit

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