

I. Title Page

Title:	Determining sources of highway runoff fine sediment in stormwater, streams, and Lake Tahoe using fingerprinting techniques
Subtheme this proposal is responding to (choose only one)	Theme: Water Quality Subtheme: Roadway Pollutants
Principal Investigator:	James Thomas Desert Research Institute 2215 Raggio Parkway Phone: 775-673-7305 Fax: 775-673-7363 Email: jthomas@dri.edu
Co-Principal Investigators	Alan Heyvaert, Ross Edwards, Markus Berli, Tim Minor Desert Research Institute 2215 Raggio Parkway Phone: 775-673-7300 Fax: 775-673-7363 Email: alan.heyvaert@dri.edu
Co-Principal Investigators	John Reuter Dept. of Environmental Science & Policy University of California, One Shield Ave. Davis, CA, 95616 Phone: 530-304-1473 Fax: 530-753-8407 Email: jereuter@ucdavis.edu
Grants Contact Person	Yvonne Rumbaugh Business Manager 2215 Raggio Parkway Reno, NV 89512-1095 Phone: 775-673-7366 Fax: 775-673-7363 Email: Yvonne.Rumbaugh@dri.edu
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II. Proposal Narrative

a. Justification Statement

Fine sediments (<20 microns) in Lake Tahoe are responsible for >50 % of the average one foot per year decline in Lake Tahoe clarity over the last four decades (Jassby et al. 1999, 2003; Swift et al. 2006). If the sources of these fine sediments can be identified, then steps can be taken to keep these particles from entering the lake. Erosion control projects and best management practices (BMPs) for sediment and nutrient removal from water flowing into Lake Tahoe have been constructed in the Tahoe basin and many more are currently being constructed or planned. Identifying the sources of fine sediment in the lake and in streams and stormwater runoff entering the lake can help land managers, regulators, and other agencies target both the location and types of land use, such as highways and roads, that are major contributors of fine sediment to stormwater runoff, streams, and ultimately the lake. Once specific areas and land uses that are contributing the greatest amount of fine sediment to the lake are identified, then the most cost effective approaches can be used to stabilize these areas and remove fine sediment from the runoff. Identifying the sources of fine particles entering Lake Tahoe will also be very important for obtaining the ~55% reduction in fine particles and nutrients entering the lake that is needed to stabilize the decline in lake clarity and eventually restore it to about 30 meters, as compared to the current lake clarity of about 20 meters (Roberts and Reuter 2007).

Runoff associated with highways and roads has been identified as a major source of fine sediment entering Lake Tahoe (Heyvaert, Thomas, et al., 2006; Roberts and Reuter 2007). Studies in the Tahoe basin have evaluated current treatment practices to remove nutrients and fine sediment from highway runoff (e.g. California Transportation Department (Caltrans) 2003; Mihevc et al., 2004; Jones et al., 2005). These removal methods include sediment traps, hydrodynamic and filtration devices, sediment basins and chemically enhanced adsorption and coagulation. These methods show little (sediment traps) to complete (sediment basins when large enough to retain all runoff) removal of fine sediment. However, despite these efforts highway and roadway sources are still a major contributor of fine sediment to stormwater runoff, to streams, and ultimately into Lake Tahoe. The sources of fine sediment associated with highway and roadway runoff can be diverse and include, anthropogenic sources, such as sand applied for vehicle snow traction and from vehicle generated fine sediment, and natural sources, such as sediments from roadway shoulders, exposed banks along road cuts, and runoff from lands adjacent to highways and roads.

b. Background/Problem Statement

Identifying the main sources of fine sediment entering Lake Tahoe is critical to developing or modifying current and future erosion control projects in the Tahoe basin. The Tahoe TMDL (Total Maximum Daily Load) program has identified roadway runoff as a key source and has considered road discharge implementation projects as significant pollutant reduction opportunities in urban areas of the Tahoe basin (Roberts and Reuter 2007; Lahontan and NDEP, 2007). While primary and secondary roads in the Basin comprise only ~1.5% of the total drainage area, the estimated event mean concentrations for pollutant runoff are high (2.8-3.9 mg/L TN); 0.42-0.72 mg/L for dissolved inorganic-N; 0.5\6-2.0 mg/L TP; 0.10-0.15 mg/L for dissolved P; 150-950 mg/L TSS).

Some historical data area available for fingerprinting sources of fine sediment in Lake Tahoe, streams entering Lake Tahoe, and highway runoff (Caltrans 2001; Rabidoux 2005; J. Thomas and A. Heyvaert, Desert Research Institute, unpublished data). A preliminary analysis of the DRI data, for example, indicates that streams around the Lake Tahoe basin have different chemical fingerprints for fine sediment in streams entering Lake Tahoe (Figure 1). Building on this limited data set, and in particular on land use-based source estimates from the Tahoe TMDL, we can determine specific contributions and sources of highway runoff as part of the overall fine sediment load entering Lake Tahoe. This source information will be important for management decision-making. A similar approach to fingerprinting highway sediment sources, as proposed for this project, was successfully employed in Japan (Adachi and Tainosho, 2005) and similar approaches have been used in other studies (Shi et al., 1997; USGS, 2000; Robertson et al., 2003; Pekey et al., 2004; Polyakov and Nearing, 2004; Kimoto et al., 2006). Buzcu et al. (2003) have used a positive matrix factorization approach with trace element data to apportion fine particulates to various sources in the Houston, Texas area.

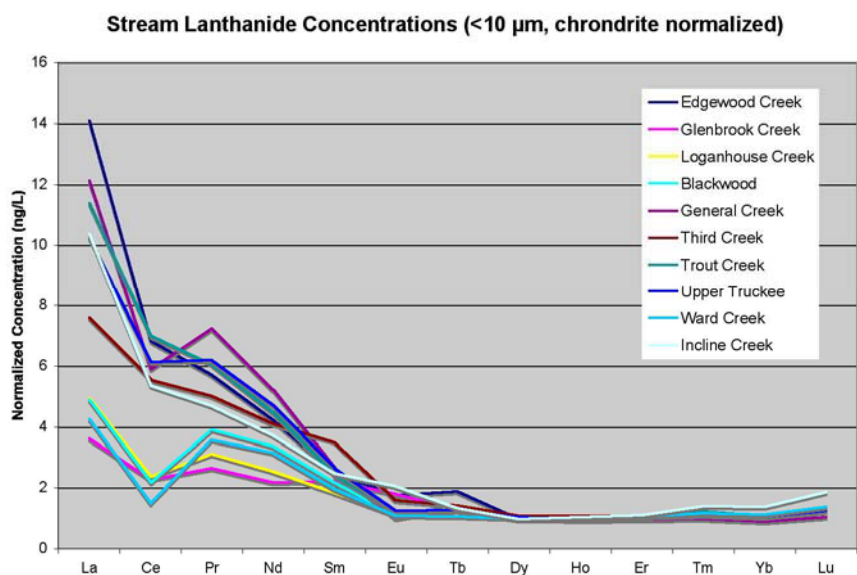


Figure 1. Example of chemical signatures from stream inputs to Lake Tahoe for particle sizes less than 10 microns.

Removal of suspended sediments and nutrients from stormwater runoff associated with highways in the Tahoe basin has been evaluated in preliminary studies for highways along the eastern part of the Lake Tahoe basin (Jones et al. 2005) and in the western portion of the Basin (Caltrans 2001; 2003). Thus, some information is available on cost effective BMPs for fine sediment and nutrient removal from highway and roadway runoff. But, identification of the highway areas and sources from which fine sediment loads are highest is needed for obtaining optimal reductions in fine sediment entering Lake Tahoe.

c. Goals, Objectives and Hypotheses

The primary goal of this proposed project is to determine the sources of fine sediment in highway and roadway runoff. A secondary goal is to distinguish relative contributions from

traction sand, vehicle wear, tire wear, road surface wear, and vehicle emission particulates, as well as from adjacent land surfaces contributing to highways and roadways (for example, road shoulders and slope cuts) in highway and roadway runoff that reaches Lake Tahoe, either directly by stormwater runoff or by entering streams that flow into Lake Tahoe. Another secondary goal is to develop a GIS representation for highways and roadways showing high, medium, and low areas of potential fine sediment yield for highway runoff. The following objectives have been identified to meet these overall goals for the project:

1. Determine source areas of the highway and road corridors where fine sediment is derived from road surfaces, road shoulders, or adjacent land surfaces contributing to highways and roads.
2. Determine anthropogenic source contributions to highway and road runoff of fine sediment, including, for example, traction sand and vehicle sources, such as vehicle and tire wear, vehicle particulate emissions, and road surface wear (e.g. asphalt grinding).
3. Using the source fingerprinting results, develop a GIS representation of potentially high, medium, and low contributing areas for fine sediment along highway and road corridors around the Lake Tahoe basin.
4. Evaluate historical patterns in highway and roadway sediment contributions to Lake Tahoe by examining the fine sediment fingerprint record in lake cores.

This study will identify sources of fine sediment from highways and roads that is entering Lake Tahoe through stormwater runoff and streams. It has been hypothesized that most of the fine sediment from highway runoff is from traction sand applied to highways and from unpaved roads in the basin, but the contributions from different parts of the highway and road corridors, such as the road surface, road shoulders, and from lands adjacent to highways has not been determined. This study will partition fine sediment in highway runoff into anthropogenic materials and basin derived sediment that is present in highway and road runoff using fingerprinting techniques. The GIS analysis will then identify how these features are likely to be distributed around the Tahoe Basin so that resource managers can make better informed decisions about where and how to implement appropriate BMPs.

d. Approach, Methodology, and Geographic Location of Research

The general approach for this project is to sample fine sediment source material and fine sediment in runoff from highways and roadways to fingerprint these sources to determine from where and at what concentrations they are getting into Lake Tahoe. The fine sediment sources and fine sediment in highway and roadway runoff will be fingerprinted using a full suite of major ions and trace elements, with rare earth elements (REEs) and strontium ($^{87}/^{86}$) and lead ($^{206}/^{207}/^{208}$) isotopes. In addition, total phosphorus content in fine sediment samples will be determined, because phosphorus is typically associated with the fine sediment fraction and phosphorus is the limiting nutrient of primary concern in Lake Tahoe. A similar fingerprinting approach to determine sediment sources in highway materials has been used in Japan (Adachi and Tainosho, 2005). Strontium isotopes have been used in the Sierra Nevada (Blum et al., 1993) and in Australia (Douglas et al., 1995; Martin and McCulloch, 1999) to identify sources of suspended sediment in streams and weathering of soil minerals. Lead isotopes, similar to

strontium isotopes, can be used to identify fine sediment sources, particularly fine sediments associated with highways and roads because of the historical use of leaded gasoline.

Volcanic soils typical of the north and west shore areas of the Tahoe basin appear to generate more fine particles from hill slope erosion than granitic soils typical of the south and east shores. These differences in soil types in the Lake Tahoe basin is captured in the new NRCS soils map (SSURGO database for the Tahoe basin), which is available in a GIS coverage at the U.S. Geological Survey Tahoe Basin information clearing house on the web. However, quantitative information on the fine sediment yield of soils in highway corridors is lacking, although some information is available for fine sediment in highway and road runoff (Caltrans, 2003; Mihevc et al., 2004; Jones et al., 2005). This historical data along with data collected for this project will be used to produce a GIS representation of potential erodibility of fine sediment along highways and roadways in the Tahoe basin.

A GIS analysis will be performed to help identify the distribution of highway runoff fine sediment sources around the Tahoe Basin. Preliminary GIS analysis of land surface features along highways (e.g. slope from the 10-meter digital elevation terrain (DEM) maps) and soil types and erodibility from the new NRCS soil map of the basin, will be used to target initial sampling sites for this project to fingerprint fine sediment sources and help determine the distribution of fine sediment particles (<20 microns) in highway runoff sources.

The following are specific tasks that will be performed to meet the goals and objectives of this project:

Task 1. Collect and analyze source material for fine particle (<20 micron) analysis. These source materials include traction sand that is applied to the highways, road shoulder material, road cut material and fine sediment from lands adjacent to highways that is contributing to highway and road runoff. Some of the highway and road shoulder fine sediment will be obtained from the roadway dust SNPLMA Round 7 projects that started in November, 2007 (J. Engelbrecht, Desert Research Institute and H. Kuhns, Desert Research Institute). One hundred and twenty source samples will be analyzed for fingerprinting source materials.

Task 2. Categorize highways in the Lake Tahoe basin as high, medium, or low potential for fine sediment load in highway runoff. GIS analysis will be used to identify erosion potential along highways by using the USGS 10-meter digital elevation model (DEM) for the Tahoe basin to determine slope and the Natural Resource Conservation Service (NRCS) soils SSURGO database for the Tahoe basin for soil erodibility. These data will be integrated with existing USGS road and highway data to develop a derivative metric defining fine sediment load potential as it relates to highway runoff.

Task 3. Collect and analyze water samples from highway and road runoff, including, stormwater flowing directly into Lake Tahoe, streams entering Lake Tahoe, and Lake Tahoe. At each sample site <20 micron samples will be collected for analysis. These samples will be analyzed at the Desert Research Institute ICP-MS Laboratory for REEs and strontium and lead isotopes. The ICP-MS Laboratory is an ultra-clean facility, so very low concentration levels are easily and accurately measured for the proposed fine sediment fingerprinting. Eighty water samples will be

collected at sites throughout the basin during high runoff events that are produced by thunderstorms in the summer and snowmelt and heavy rains from frontal storms in the winter and spring, and for deep and near-shore lake sites.

Task 4. Use historical data and data collected for this study to determine the sources of fine sediment in highway and road runoff that is present in stormwater runoff and streams that flow into Lake Tahoe. From data collected in this study, determine areas of high, medium, and low potential erodibility for highways and roads throughout the Tahoe basin. Additionally, use historical cores collected from Lake Tahoe to evaluate the historical change in fine sediment entering the lake from highway and roadway runoff. Fifty fine sediment samples from lake cores will be analyzed for this effort.

Task 5. Estimate the relative proportions of fine sediment from anthropogenic highway runoff sources and natural sediment sources in highway runoff that are entering the near-shore environment from Lake Tahoe. The sources of the fine sediment entering the near shore are both perennial streams and stormwater runoff, especially from urban areas, flowing directly into the Lake. Anthropogenic highway fine sediment sources include sand applied for traction and roadway contributions of vehicle created fine sediment (brake lining dust, particulates from vehicle exhaust, asphalt dust, etc.) and non-anthropogenic highway runoff sediment sources, including material on shoulders of highways, road cut surfaces, and other non-roadway sources.

Task 6. A final report will present the findings of this study. This report will include a GIS presentation of fine sediment erosion potential along highways and roads throughout the basin.

Standard collection and analytical methods will be used for collecting and analyzing all data subject to the EPA 200.8 (Rev 5,4) method. Prior to analysis filter samples will be prepared by microwave digestion following the method of Kulkarni et al. (2007). Elemental concentrations and isotopic ratio's will be determined using High Resolution Inductively Coupled Plasma Mass Spectrometry (HR-ICPMS) The HR-ICPMS analysis standard operating procedure (SOP) is based on the EPA 200.8 (Rev 5,4) method and determines the concentrations of analytes based on an external linear calibration, which is constructed from a series of standards. To correct for drift in the instruments response during the course of an analysis the analyte responses are normalized to a suitable internal standard (typically indium). In this method, isobaric interferences arising from molecular species and multiply charged cations, are eliminated by either analyzing an interference free isotope (assuming the same isotopic abundance as the standards) or by selecting a medium or high mass resolution. For example the interference of $^{40}\text{Ar}^{16}\text{O}$ on ^{56}Fe is eliminated by performing the analysis at a high enough mass resolution to resolve the species. At the onset of new projects the analytical method is validated using National Institute for Standards and Technology (NIST) standard reference materials. For this project, water and dust SRM's (1640 and 4355 respectively) will be used to evaluate the performance of the analytical procedure. As part of the initial performance evaluation, the method detection limits (MDL, EPA 200.8 definition) will also be estimated from procedural blanks.

Fingerprinting of fine sediment sources and their relative contribution to fine sediment in highway runoff will be developed using the Positive Matrix Factorization (PMF) method

(Paatero and Tapper, 1994). The PMF method will be used instead of Principal Component Analysis (PCA), because Henry (1987) demonstrated that PCA lacks sufficient physical constraints to guarantee a unique, physically valid solution. Previous studies have found that in some scenarios, PMF results are more environmentally realistic than other models like PCA (Huang et al., 1999). PMF has been successfully used to model source attributions of aerosols as part of air sampling studies (which is analogous to determining fine sediment sources), including investigations in polluted industrial locations as well as pristine Arctic regions (Kim et al., 2005; Zhou et al., 2005; Xie et al., 1999; Polissar et al., 1998).

e. Strategy for Engaging with Managers

Project personnel will work closely with NDOT, Caltrans, and federal, state, and local agencies to: (1) obtain available information pertinent to the project; (2) determine the optimal sampling sites, either existing or new, to collect data for this study; (3) obtain samples of traction sand that is being applied to the highways in areas of sample collection; and (4) coordinate with ongoing projects, such as the NDOT BMP effectiveness and Regional Stormwater Monitoring projects. This collaboration will be implemented through face to face meetings with personnel from these organizations. Since we are already meeting with most of these organizations, or their representatives, for the NDOT BMP effectiveness and Regional Stormwater Monitoring projects meetings for this project can be easily included in these efforts. At a minimum a meeting will be held at the start of the project to get information and input from all the agencies that are interested in the project and then after the first year of the project when most of the data have been collected and initial data interpretations are underway, and then before the final report is completed to get agency input, including having interested agencies provide report reviews at the time of colleague review. A presentation of project results will be provided to the Lake Tahoe Interagency Monitoring Program (LTIMP) at the conclusion of this project.

f. Deliverables and Products

Deliverable 1: Quarterly progress reports.

Deliverable 2: Fingerprinting data for source material, water samples, and lake cores.

Deliverable 3: A GIS tool that identifies highway and road sections throughout the Tahoe basin that have high, medium, and low potential to deliver fine sediment in highway runoff.

Deliverable 4: Final project report.

g. Schedule of Milestones/Deliverables

The schedule and milestones for the project will begin when the contract dollars are received. The following timeline was constructed assuming that funding of the project would begin July 1, 2008. Progress reports and invoicing will be submitted quarterly, and the final invoice will be submitted within 90 days after the expiration of the award.

Task	Description	2Q 2008	3Q 2008	4Q 2008	1Q 2009	2Q 2009	3Q 2009	4Q 2009	1Q 2010	2Q 2010
1	Source material sample collection and analysis									
2	Potential fine sediment yields in highway runoff									
3	Water sample collection and analysis									
4	Data analysis									
5	Determine Sources of highway fine sediment									
6	Draft and final reports									

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