

I. Title Page

Title:	Impacts of Vehicle Activity on Airborne Particle Deposition to Lake Tahoe
Subtheme:	3b) Air Quality, Particle Deposition
Principal Investigator:	Dr. Hampden Kuhns Division of Atmospheric Sciences Desert Research Institute 2215 Raggio Parkway Reno NV 89512 Phone: 775 674 7111 Fax: 775 674 7007 Email: hkuhns@dri.edu
Co-Principal Investigator	Dr. John A. Gillies Division of Atmospheric Sciences Desert Research Institute 2215 Raggio Parkway Reno NV 89512 Phone: 775-674-7035 Fax: 775-674-7016 Email: jackg@dri.edu
Co-Principal Investigator	Dr. Alan Gertler Division of Atmospheric Sciences Desert Research Institute 2215 Raggio Parkway Reno NV 89512 Phone: 775-674-7061 Fax: 775-674-7060 Email: alan.gertler@dri.edu
Grants Contact Person	Ms. Lycia Ronchetti Division of Atmospheric Sciences Desert Research Institute 2215 Raggio Parkway Reno NV 89512 Phone: 775-673-7411 Fax: 775-674-7016 Email: lycia@dri.edu
Funding requested:	\$ 165,380
Total cost share	\$ 41,343

II. Proposal Narrative

a. Project abstract

This proposal addresses the need to accurately estimate the impact of vehicle miles traveled (VMT) on particulate matter (PM) loading to the lake as stated in the Air Quality – Particle Deposition Science - Theme. The work will be accomplished via seven objectives: (1) assembling datasets, reports, and journal articles from previous studies, (2) summarizing the location and timing of road dust PM emissions in the basin, (3) summarizing vehicle classes operating on different road types in the basin, (4) summarizing the amount of suspended material that deposits close to the roadway, (5) analyzing the link between road location and the material transported over the lake, (6) assessing the impact of the number and location of trips on lake water clarity, and (7) reconciling estimates of atmospheric deposition fluxes to the lake with prior measurements. The results from the study will enable planners to more accurately estimate the effects of growth as well as VMT reduction strategies on lake water clarity. In addition, the project will provide important information on sediment deposition flux to the lake for use in water quality modeling.

b. Justification statement

Recent studies have demonstrated that pollutants from the transportation system in the Lake Tahoe basin adversely affect air quality (Gertler et al, 2006a). Airborne particles from re-entrained road dust have the potential to deposit to the lake and decrease lake water clarity. A draft Total Maximum Daily Load (TMDL) Technical Report estimates that the atmospheric deposition accounts for 55% of nitrogen and 15% of both phosphorus and fine sediment loading in the lake. In addition, estimates of quantities of atmospheric deposition of fine sediments were rated as having the lowest confidence due to high uncertainty and insufficient data (Roberts and Reuter, 2007). To date, many basin-specific studies have addressed uncertainties related to the individual steps of the vehicle activity-emissions-transport-deposition-water clarity process (Figure 1). These studies have been and will continue to be critical to the understanding and mitigation of elevated PM and increasing concentration of lake sediment. This project will integrate the results of the previous and ongoing studies to quantitatively link changes in vehicle miles traveled (VMT) and road location to lake sediment loading. Establishing this relationship will permit regional planners to develop effective strategies to reduce the negative impact of the transportation system on lake clarity.

c. Concise background and problem statement

Lake Tahoe is a unique environmental asset that has been designated an “Outstanding National Water Resource” by the US Environmental Protection Agency (EPA) to protect its water quality and its scenic characteristics. Of particular concern to resource management agencies in the basin is that optical clarity in Lake Tahoe has been steadily decreasing during the last four decades. This is the result of increased algal growth and particulate light scattering from excess nutrient inputs (Nitrogen [N] and Phosphorous [P]) and from the accumulation of fine sediment particles in the lake due to watershed runoff and atmospheric deposition (Byron and Goldman, 1986; Goldman et al., 1993; Jassby et al., 1999).

Recent work by Swift et al. (2006) has shown that fine inorganic particles are causing about 58% of light attenuation in Secchi disk measurements of water clarity. That study noted that particle sizes from 0.5–10 microns are of particular concern due to their light scattering characteristics and relative abundance. Studies conducted for development of Lake Tahoe’s TMDL have estimated that atmospheric deposition accounts for 15% of suspended fine sediment loading in the lake and that the control of local atmospheric sources could provide significant load reductions (CARB, 2006). Kuhns et al. (2004), Chang et al. (2005), and Zhu et al. (2008) have demonstrated linkages between pollutant emissions generated by motor vehicle traffic in the Lake Tahoe basin and local airborne PM concentrations. This work has aided

in developing an understanding of how different components of the transportation system in the Tahoe basin contribute to elevated airborne PM and deposition of particulate and gaseous species.

Scientists at the Desert Research Institute's Division of Atmospheric Sciences have been actively engaged in characterizing and quantifying the contributions of pollutants from traffic-related (as well as other) sources in the Lake Tahoe Basin beginning in 1997 with planned research extending to 2009. Their research to date has focused on obtaining geographically specific information on the source types, source strengths, composition of the emitted particles from identified sources (for source fingerprinting), seasonality of emissions, and characterization of ambient concentrations.

DRI's approach has been to fill in key knowledge gaps by conducting empirically-based field studies using carefully designed experiments. Descriptions of studies completed or in progress are listed below:

Project 1) DRI Lake Tahoe Source Characterization Study (Kuhns et al., 2004). This study investigated the chemical composition and emission factors of selected particulate matter (PM) sources in the Lake Tahoe basin. Sources sampled included residential wood combustion, motor vehicle exhaust, and entrainment of road dust, traction control material, and road deicing material. In addition, several new emission measurement technologies were applied during this study to investigate residential wood combustion, motor vehicle exhaust, and re-entrained road dust.

Project 2) The Lake Tahoe Atmospheric Deposition Study (LTADS, Chang et al., 2005). This study contributed new information on the contribution of atmospheric deposition to the declining clarity of Lake Tahoe. The Two Week Sampler (TWS) for total suspended particulates (TSP), PM₁₀, and PM_{2.5} were installed at five sites throughout the basin. In addition, MiniVol filter samplers were used to acquire TSP samples at remote/satellite sites with various sampling durations. Collected TSP, PM₁₀, and PM_{2.5} samples were gravimetrically analyzed for total mass concentration, followed by detailed chemical speciation. A total of 127, 129, and 128 sets of TWS samples were collected for TSP, PM₁₀, and PM_{2.5}, respectively; 36 sets of buoy MiniVol TSP samples, and 160 sets of non-buoy MiniVol TSP samples were collected during LTADS.

Project 3) Impact of Winter Road Sand/Salt and Street Sweeping of Road Dust Re-Entrainment (Gertler et al., 2006b). In this study, roadside measurements of PM flux and instrumented vehicle PM measurements were performed to evaluate the effectiveness of street sweeping in reducing dust re-entrainment and assess the impact of abrasives and deicers on ambient PM near the lake. The results indicate use of liquid deicers contributes less to road dust emissions than abrasives. Street sweeping was found to increase the PM₁₀ re-entrainment rate of the remaining road dust. Emission factors for roads in the Tahoe basin tend to decrease significantly from late Spring to early Summer by as much as a factor of four.

Project 4) Measurement and Modeling of Fugitive Dust Emissions from Paved Road Travel in the Lake Tahoe Basin (Kuhns et al., 2007). Based on the results from the Lake Tahoe Source Characterization study that identified re-entrained road dust as a significant contributing source to in-basin particulate matter levels, this project measured road dust emissions from a network of road types in the basin over a one year study period. Field data were collected from August 2006 to August 2007. The final report relates road dust emissions with road type, seasonality, precipitation, and road management practices to better quantify the sources of re-entrained road dust.

Project 5) Development of an Air Pollutant Emissions Inventory for the Lake Tahoe Basin (Gertler et al., 2008). This project constructed a baseline emissions inventory to quantify and evaluate the contribution of various sources to ambient pollutant levels in the Lake Tahoe Basin. In addition to the usual pollutants included in most inventories (i.e., CO, NO_x, VOCs, PM₁₀, PM_{2.5}, and SO₂), estimates of ammonia (NH₃), phosphorous (P), and phosphate (PO₄) were also developed due to their contribution to the declining water clarity of the lake. The inventory spatially allocates emissions based on vehicle miles traveled per link, population density, and land use.

Project 6) Source Characterization of Particulate Matter Depositing to Lake Tahoe (In-progress: January 2007 - February 2009). This project is designed to chemically characterize road dust, road sweepings, traction control material, and soil parent materials and quantitatively relate their chemistry and mineralogy to the composition of particles suspended in the lake water column. These results may be used as an independent measure to bound the influence of road dust on lake water sediment.

Project 7) Receptor Modeling to Determine Sources of Observed Ambient Particulate Matter (PM) in the Lake Tahoe Basin (In-progress: October 2007 – June 2009). This project will analyze the LTADS and DRI data using multivariate statistical procedures, including Principal Components Analysis (PCA) and Positive Matrix Factorization (PMF) to identify factors and groups of chemical species of relevance within the measured data set to distinguish sub-sets of site and seasonal data to assess seasonal trends of sources of the observed particulate matter.

Project 8) Assessing the Impact of Best Management Practices (BMPs) Designed to Reduce the Contribution from Resuspended Road Rust to Lake Tahoe (In Progress: October 2007 – September 2010). The goal of this program is to quantify the cost effectiveness of different road dust control strategies applied in the Lake Tahoe Basin for reducing airborne emissions. A secondary goal is to quantify the effect landscape has on the deposition of particulate matter as it is transported towards the lake.

The data collected as part of these studies as well as complimentary studies by other research groups represent a wealth of information on the location, timing, and amounts of particulate matter and gaseous emission released in the Lake Tahoe basin and their fate through either deposition or transport out of the basin. The information generated from these research projects has been (and will be) examined to answer the research questions for which each project was undertaken. The integration of data collected will be used to assess the link between VMT and deposition of sediment to the lake.

d. Goals, objectives, and hypotheses to be tested

The overall goal of the proposed study is to assemble existing and new data related to mobile source emissions in the Lake Tahoe basin into a single documented database and to subsequently use the assembled information to quantify the impact of location and vehicle class specific VMT levels on air quality, and ultimately lake water clarity due to deposition of airborne particles.

This goal will be realized through meeting the following key research objectives:

- 1) Assemble all relevant data from prior studies
- 2) Summarize the temporal and spatial distribution of mobile source N, P, and particulate emissions in the basin.
- 3) Summarize vehicle class (i.e., car, truck, tractor trailer) distribution based on roadway types.
- 4) Summarize the seasonal near field deposition of sediment near the roadways.
- 5) Assess relationship of trip location and atmospheric deposition to the lake,
- 6) Assess the marginal impacts of a vehicle trip on re-entrained dust,
- 7) Reconcile emissions and deposition rates with measured sediment loading in the lake.

e. Approach, methodology and location of research

We propose to integrate available data from completed and on-going research projects into a unified assessment that addresses the objectives listed above. Many of the data resources that exist are already at DRI from on-going projects. A seasonal and diurnal emissions inventory model linked with GIS land-use data for the basin has been created to supply input into Eulerian air quality models such as CAMx (Gertler

et al., 2008). Specific approaches and methodologies related to the above objectives are described below for each objective:

Objective 1) Assemble All Relevant Data. Data to be assembled are described in Table 1. In addition to the written reports, all relevant data files will be documented and assembled in a structured directory that will be available to this and other studies.

Table 1. Table of data sources and relevant data to be assembled for Objective 1.

Study Reference	Project Number	Relevant Data	Description
Kuhns et al., 2004	1	Vehicle Type Distribution	Based on wheelbase measurements from video records and road tube counters (i.e., Cars, SUVs, Semis, etc.)
Kuhns et al., 2004	1	Road Dust Emission Factors	Based on downwind flux towers and TRAKER measurements
Kuhns et al., 2004	1	Road Dust PM Chemistry	From roadside filter samplers
Chang et al., 2005; CARB, 2006	2	Ambient PM Chemistry and Concentration	LTADS filter samplers
Gertler et al., 2006	3	Road Dust Emission Factors	Based on downwind flux towers and TRAKER measurements
Kuhns et al., 2007	4	Road Dust Emission Factors	TRAKER measurements
Gertler et al., 2008	5	Gridded Emission Inventory	Compiled from (3), TRPA sponsored TRANSCAD, USGS land use, and census data.
Gillies et al., 2009	6	Chemistry of Geologic samples from roads, top soil, traction control material, and lake water	Source samples collected on filters
Englebrecht et al., 2010	7	Source attribution of Atmospheric PM	Principle component analysis applied to LTADS dataset
Gillies et al., 2010	8	Road Dust Emission Factors	Flux tower measurements
Gillies et al., 2010	8	Deposition Rates in Various Landscapes	PM size distributions measured at multiple distances downwind of the road
Gillies et al., 2010	8	Vehicle Type Distribution (i.e. Cars, SUVs, Semis, etc)	Road tube counters
TRPA, 2005	-	VMT by Roadway Link	TRANSCAD Output table showing travel volume and speed on all roads in basin
CARB, 2006	-	PM Deposition Rates	LTADS optical particle counter study at SOLA
UC Davis	-	Meteorological Data	Lake Tahoe REMOTE Sites
Roberts and Reuter, 2007	-	Atmospheric Disposition Fluxes to Lake	Total Maximum Daily Load Report
Bennet et al., 2009		Deposition flux of salt near roadways	Complementary data from parallel study investigating tree health associated with application of road de-icers

Objective 2) Summarize distribution of mobile PM emissions by season and location. Road dust emission factors have been directly measured using flux towers (Kuhns et al., 2004; Gillies et al., 2005, 2007) and additional measurements will be collected as part of *Project 8* listed above. In addition, Kuhns et al. (2007) measured seasonal and spatial variations in road dust emissions using the TRAKER vehicle, a mobile platform that measures dust suspended behind the vehicles tire. Measurements took place on an

80-mile route around the lake on a biweekly basis between August 2006 and September 2007. An example of the measured emission factors is shown in Figure 2 and Figure 3.

These results link road type, vehicle speed, vehicle class, season, and GID maintenance practices to road dust emission factors. The emission factors will be compiled and assembled into a lookup table to extrapolate road dust emissions factors for each road link described in the TRPA's TRANSCAD traffic demand model by season.

The link level table of road dust emissions will be presented using the ARC GIS gridding algorithm used by Gertler et al. (2008) for the seasonal area source emissions. An example emission inventory image for all PM₁₀ sources is shown in Figure 4.

Objective 3) Summarize vehicle class distribution based on roadway types. Road dust emissions are also affected by vehicle type through the process of entrainment by the aerodynamic forces present in vehicle wakes. Moosmüller et al. (1998) and Abu-Allaban et al. (2003) showed that the wakes of high profile trucks entrain dust from road shoulders while wakes from passenger cars could not.

Vehicle class distributions have been determined using video transcription in two locations in Incline Village. Using this technique, motorcycles, passenger cars, pickup trucks, vehicles with trailers, and various classes of trucks were classified (Kuhns et al., 2004). Road tube counters that measure the axle spacing of vehicles have also been used on Highway 28 to obtain a coarse separation of light and heavy duty vehicles based on axle spacing. Road tube measurements will be repeated in *Project 7* described above to better define the distribution of vehicle types on highways in the basin. Since PM emissions factors are related to vehicle type (i.e., tractor trailers suspend more dust than passenger cars), a representative mix of vehicle types will be assigned to the various road types within the TRANSCAD output. With these data we will be able to update and describe the magnitude of vehicle emission factors for the range of vehicles used in the Tahoe Basin.

Objective 4) Summarize the seasonal near field deposition of sediment near the roadways. Trip location is a critical parameter affecting the deposition potential of transportation-produced PM to the lake surface. Winds in the basin are highly variable and depending on the time of day can transport emissions over the lake or out of the basin. Moreover, landscapes (i.e., density of trees and buildings) can play a large role in attenuating concentrations of air pollutants before they reach the lake. Countess et al. (2007) has completed a study to estimate near field deposition from roads in the Tahoe Basin. In addition, an ongoing study is being conducted to investigate tree health associated with the deposition of re-entrained salt from roadways in the Tahoe Basin by Chandalin Bennet of the UNR's Department of Natural Resources and Environmental Science. That project involves over 50 field sites with a wide variety of vegetation and slopes.

Finally, *Project 7* above will quantify the deposition of PM as it is transported downwind by comparing the size distribution of particles at various distances from the roadway. The measurements from project 7 will provide a relative measure of the quantity of particles of various sizes that are transported 10 m to 100 m downwind of the road. The study design expands on the approach used to estimate deposition at the SOLA site during the LTADS study as shown in Figure 5 (CARB, 2006). These variations will be used to assign a PM deposition rates to the landscapes around the basin. For the proposed study, the deposition properties of various landscapes will be summarized. These properties will be linked to land use classifications from GIS layers for the basin.

Objective 5) Assess Link Location and Potential for Atmospheric Deposition to the Lake. Atmospheric PM emissions in the basin have one of three general fates: (1) deposit prior to reaching the lake, (2) deposit in the lake, and (3) transport beyond the lake. The relative magnitude of the first fate depends on particle size, the distance between the road and the lake, the slope, and the type of vegetation. Figure 5 shows an example of the deposition of large particles to the landscape in the first 100 m downwind of a road. The decrease in 0.5 – 1.0 µm particle concentrations is primarily due to the vertical

dispersion of the plume at distance. The largest particles > 10 um decrease due to both vertical dispersion and to deposition. These data can be used to calculate deposition rates for particles of various sizes. Project 8 will provide longer measurements records in a variety of landscapes to improve estimates of near field deposition in the Tahoe Basin.

To achieve this objective, GIS layers of landscapes, road networks, elevation, and lake boundaries will be overlaid. For each link in the TRANSCAD network, a query will determine the direction and shortest distance to the lakeshore, the average slope, and the relative contribution of landscapes en route. Hourly data from meteorological stations around the lake will be assembled to determine the frequency that emissions from each link are transported to the lake. These parameters will be combined to create a deposition efficiency index between 0 and 1 representing the fraction of emissions which deposits prior to reaching the lake. Calculations of indices and emission factors will be performed within the GIS framework. This approach will be used to model the flux of particles to that lake as the remainder of the emissions that do not deposit to landscapes. In addition, source profiles collected from Projects 1, 5, and 6 will be used to estimate particulate phosphorus (an algal nutrient) deposition to the lake.

The mapping of road link indices along with emission factors will help regional planners focus best management practices on the locations that have the greatest potential to emit particles that deposit to the lake.

Objective 6) Marginal Impacts of a Vehicle Trip on Re-entrained Dust. Vehicle trips generated by TRANSCAD translate into vehicle miles traveled on the specific of roadway links. As conveyed by the previously described tasks, the impact of a vehicle trip on lake water clarity depends on seasonality, vehicle type, speed, local BMP, proximity to the lake, and wind direction. With different combinations of factors, the impact of a trip may vary by orders of magnitude. For the purposes of transportation planning, it is useful to categorize trips into groups where policies could have an impact. For example, basin residents make different types of trips than visitors and the temporal/spatial distribution of the trips has a significant influence on emissions. By coupling vehicle trip information with potential VKT reduction strategies such as the implementation of a basin entrance fee, the impacts of re-entrained road dust on regional and local air quality and PM deposition potential can be evaluated.

Objective 7) Reconcile emissions and deposition rates with measured sediment loading in the lake. Project 6 (described above) uses chemical tracers to quantify the sediment loading in the lake associated with road dust, upland runoff, and other geological sources. The expected outcome of that project will be a bounded estimate of the fraction of particles in the lake that may be attributable to dry deposition from roadways. The distribution of sources will be compared with TMDL fine sediment lake flux estimates (Roberts and Reuter, 2007). The estimates of particle deposition to the lake from objective 5 (above) will also be compared with these prior and pending results. Agreement of these independent estimates will provide a weight of evidence and increase confidence in the overall atmospheric deposition flux to the lake. Any discrepancies found will be discussed and recommendations will be made to improve estimation methods.

Study Location: Since this is largely a data analysis study, most of the research will take place at DRI in Reno, NV. Our proximity to Lake Tahoe will enable us to meet with managers and stakeholders at the lake to collect additional information as needed.

f. Relationship of the research to previous relevant research, monitoring, and/or environmental improvement efforts

As shown in Table 1, this study builds upon the measurements and results from previous research studies. These dataset will be integrated to address the link between VMT and PM deposition to the Lake.

g. Strategy for engaging with managers

We will present our results in report form to basin managers, via oral and poster presentations at scientific meetings both in the basin and regionally, as well as reporting findings to the Tahoe Science Consortium (TSC). We will also request to present our results at the Lake Tahoe Interagency Monitoring Program seminar series. Based upon these results, control strategies will be developed and reported to regional planning managers to more effectively reduce PM flux to the lake.

h. Description of deliverables/products

The results of these analyses will be presented to the sponsors, and stakeholders using several methods. General research findings will be presented as talk or posters at meetings hosted at Lake Tahoe for example the Tahoe Basin Science Conference Series and other scientific meetings. More detailed analysis of the results will be conveyed to managers, scientists, and the public in two or more peer reviewed publications. Potential titles of manuscripts relating to the objectives include:

- Impact of Landscape and Roadway Position on Pollutant Deposition in the Lake Tahoe Basin
- Seasonal Quantification of Transportation Source Impacts on Lake Tahoe Water Clarity

III. Schedule of major milestones/deliverables in a table with estimated start and end dates

This project will be completed over the course of one year. Some of the analyses require data that will be produced from concurrent projects. Consequently, completion of objectives from this project may be influenced by scheduling changes that may occur with other projects (Specifically projects 5, 6, and 7 listed above).

Milestone/Deliverables	Start Date	End Date	Description
First Progress Report	2009/07/01	2009/10/01	Assemble available data and summarize results (Objective 1).
Second Progress Report	2009/10/01	2010/01/01	Summarize Road Dust Factors and Vehicle Class Distribution (Objectives 2 and 3)
Third Progress Report	2010/01/01	2010/04/01	Summarize Near Field Deposition and Assess Link Location to Deposition Prior to the Lake (Objectives 4 and 5)
Draft Final Report	2010/04/01	2010/05/30	Assess Impacts of a Marginal Trip and Reconcile Atmospheric Deposition Estimates (Objectives 6 and 7) Deliver draft final report to Tahoe Science Program coordinator Prepare manuscripts for submission to peer reviewed journals
Revise Final Report	2010/06/14	2010/06/30	Incorporate comments and suggestions into final report and deliver hard copies Submit manuscripts for publication

IV. References

- Abu-Allaban, M., J.A. Gillies, and A.W. Gertler (2003). Tailpipe, resuspended road dust, and brake-wear emission factors from on-road vehicles. *Atmospheric Environment* **37**: 5283-5293.
- Byron, E.R. and C.R. Goldman (1986). A technical summary of changing water quality in Lake Tahoe: The first five years of the Lake Tahoe Interagency Monitoring Program. Tahoe Research Group Institute of Ecology. Univ. of Calif. At Davis. 62pp.
- CARB (2006) Lake Tahoe Atmospheric Deposition Study, Report prepared for Lahontan Regional Water Quality Control Board, Nevada Division of Environmental Protection, and Tahoe Regional Planning Agency, September. Downloaded at: <http://www.arb.ca.gov/research/ltads/ltads-report.htm>
- Chang, O., J.C. Chow, S. Kohl, H. Voepel, and J. Watson (2005). Sampling and Analysis for the Lake Tahoe Atmospheric Deposition Study Final Report. Report Prepared by DRI for Research Division, California Air Resources Board 1001 I Street Sacramento, CA 95814
- Countess, R. et al. (2007). Load Reduction Matrix Analysis Report for Atmospheric Deposition Sources of Pollutants into Lake Tahoe. California Regional Water Quality Control Board Lahontan Region 2501 Lake Tahoe Blvd., South Lake Tahoe, CA 96150, July 24, 2007.
- Gertler, A.W., A. Bytnerowicz, T.A. Cahill, M. Arbaugh, S. Cliff, J.K. Koračín, L. Tarnay, R. Alonso, and W. Frączek (2006a). Local Pollutants Threaten Lake Tahoe's Clarity, *California Agriculture*, **60**, 53-58.
- Gertler, A., Kuhns, H., Damm, C., Abu-Allaban, M., Gillies, J., Clayton, R., and Proffitt, D. (2006b). The Impact of Winter Road Sand/Salt and Street Sweeping on Road Dust Re-Entrainment, *Atmospheric Environment*, **40**, 5976-5985.
- Gertler A., E. Weinroth, M. Luria, and J. Koracin (2008) Emissions Inventory for the Lake Tahoe Basin that Incorporates Current and Future Land Use Scenarios, Report prepared for US EPA Region 9, San Francisco, CA, 94105, July 31.
- Gillies, J.A. and A.W. Gertler (2001). Comparison and evaluation of chemically speciated mobile source PM_{2.5} profiles. *International J. of Vehicle Design* **27** Nos. ½/3/4 209-216.
- Gillies, J.A., V. Etyemezian, H. Kuhns, D. Nickolic, and D.A. Gillette (2005). Effect of vehicle characteristics on unpaved road dust emissions. *Atmospheric Environment* **39**: 2341–2347.
- Gillies, J.A., V. Etyemezian, H. Kuhns, J. Engelbrecht, S. Uppapalli, and G. Nickolich (2007). Particulate emissions from U.S. Department of Defense artillery backblast testing. *Journal of the Air & Waste Management Association* **57**: 551-560, doi:103155/1047-3289.57.5.551.
- Goldman, C.R., A.D. Jassby, and S.H. Hackley. 1993. Decadal, interannual, and seasonal variability in enrichment bioassays at Lake Tahoe, California-Nevada, U.S.A. *Can. J. Aquat. Sci.* **50**: 1489-1496.
- Jassby, A.D., C.R. Goldman, J.E. Reuter, and R.C. Richards. 1999. Origins and scale-dependence of temporal variability in the transparency of Lake Tahoe, California-Nevada (USA). *Limnol. Oceanogr.* **44** (2): 282-294.
- Kuhns H., D. Zhu, J. Gillies, A. Gertler, V. Etyemezian, and S. Brown (2007) Measurement and Modeling of Fugitive Dust Emissions from Paved Road Travel in the Lake Tahoe Basin, Report prepared for US EPA Region 9, San Francisco, CA, 94105, December 31.
- Kuhns H., M.-C.O. Chang, J.C. Chow, V. Etyemezian, L.-W.A. Chen, N. Nussbaum, S. K.K. Nathagoundenpalayam, D. Trimble, S. Kohl, M. MacLaren, M. Abu-Allaban, J. Gillies, A. Gertler, C. Damm, C. Denney, C. Gallery, and J. Skotnik (2004). DRI Lake Tahoe Source Characterization Study: Final Report. Prepared for California Air Resources Board by Desert Research Institute, Reno, NV October 22, 2004.

- Moosmüller, H., J.A. Gillies, C.F. Rogers, D.W. DuBois, J.C. Chow, J.G. Watson, and R. Langston (1998). Particulate emission rates for unpaved shoulders along paved roads. *The Journal of the Air & Waste Management Association* **48**: 398-407.
- Roberts D. and J. Reuter (2007) Lake Tahoe Total Maximum Daily Load Technical Report California and Nevada, Draft Report prepared for Lahontan Regional Water Quality Control Board, September. Downloaded at: http://www.swrcb.ca.gov/lahontan/water_issues/programs/tmdl/lake_tahoe/docs/laketahoe_tmdl_tech_rpt.pdf
- Swift, T.J., J. Perez-Losada, S.G. Schladow, J.E. Reuter, A.D. Jassby, and C.R. Goldman (2006). Water clarity modeling in Lake Tahoe: Linking suspended matter characteristics to Secchi depth. *Aquat. Sci.* **68**: 1-15.
- Zhu D, H. Kuhns, S. Brown, J. Gillies, V. Etyemezian, A. Gertler (2008) Fugitive Dust Emissions from Paved Road Travel in the Lake Tahoe Basin, submitted to *The Journal of the Air & Waste Management Association*.

V. Figures

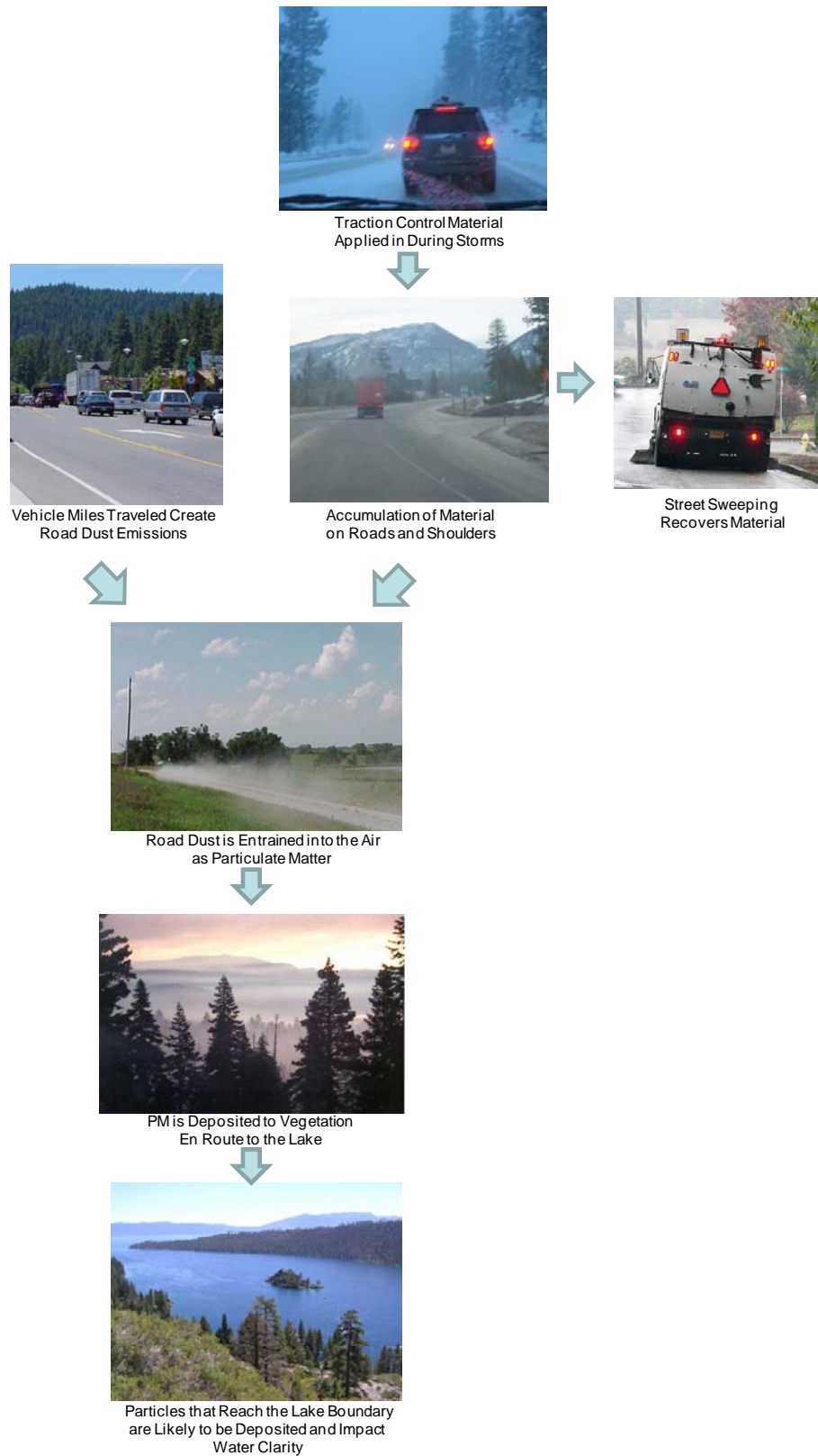


Figure 1. Images of processes linking traction control material and road dust to lake water clarity.

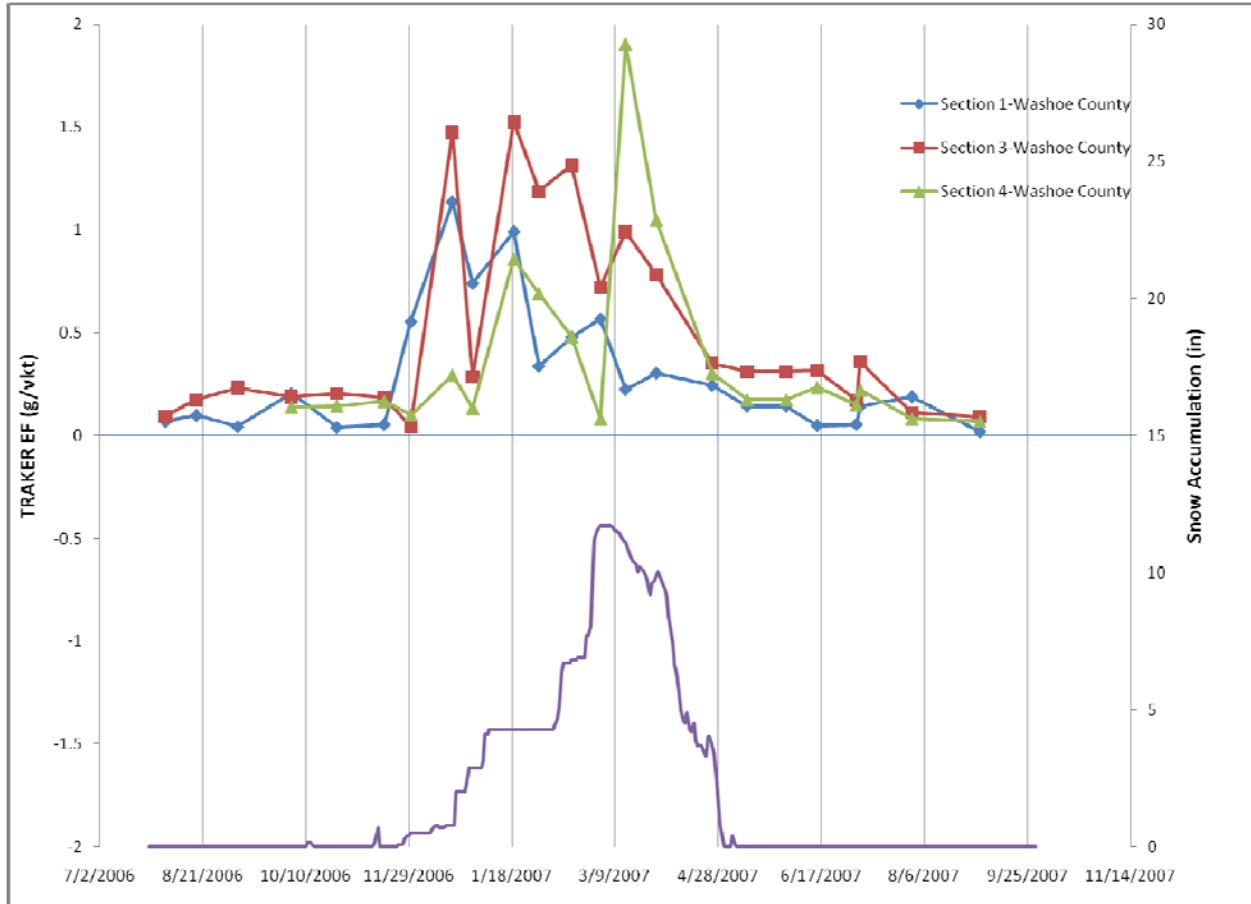


Figure 2. PM_{10} road dust emission factors of Secondary Road Sections near Marlette Lake SNOTEL Station. The numbered sections 1, 3, and 4 correspond to the point labels on the following figure. (Kuhns et al., 2007)

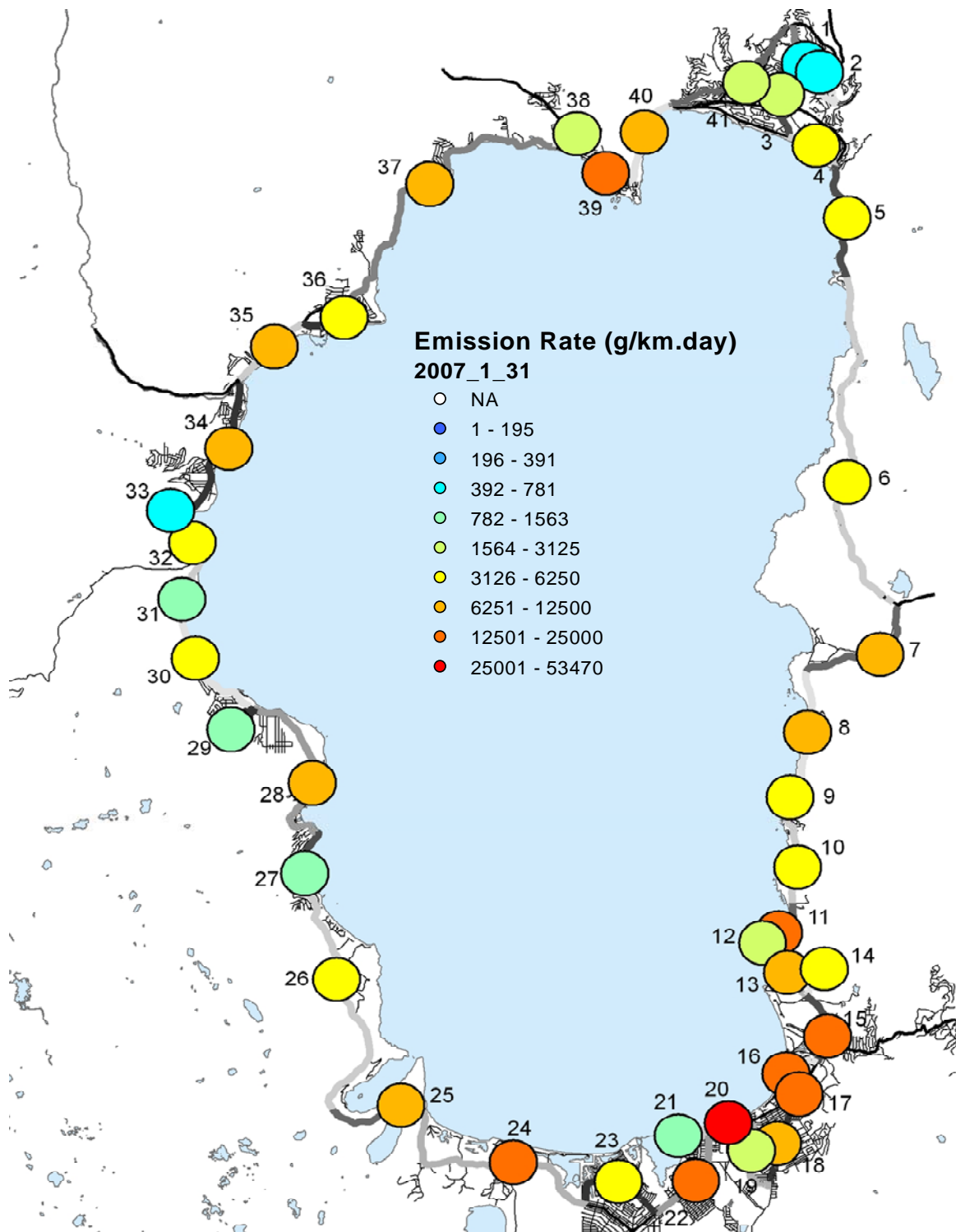


Figure 3. PM₁₀ emission factor map produced from TRAKER measurements around the lake (Kuhns et al., 2007).

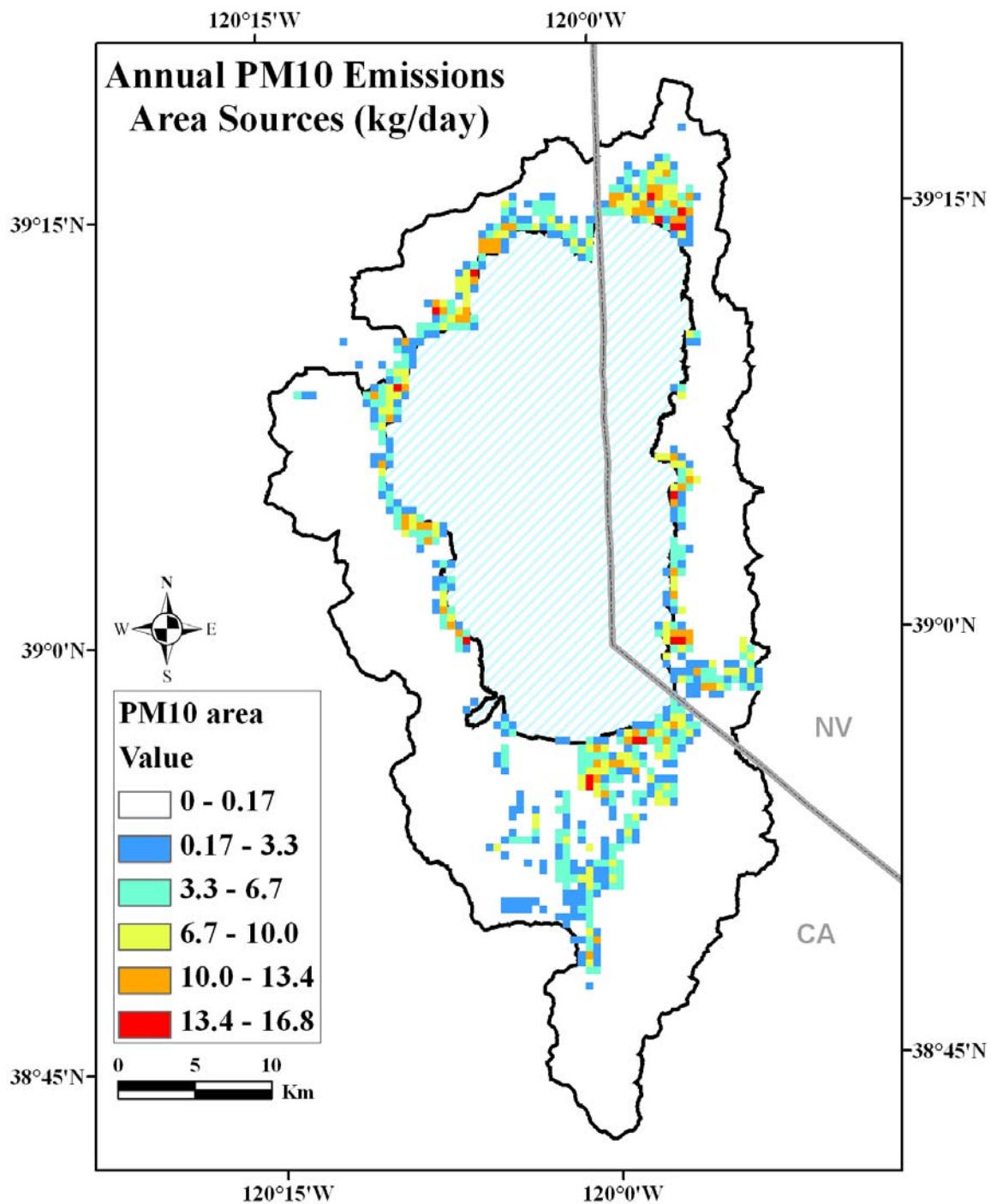


Figure 4. Gridded annual PM₁₀ emissions based on TRAKER data (Kuhns et al., 2007) and GIS based emission model (Gertler et al., 2008).

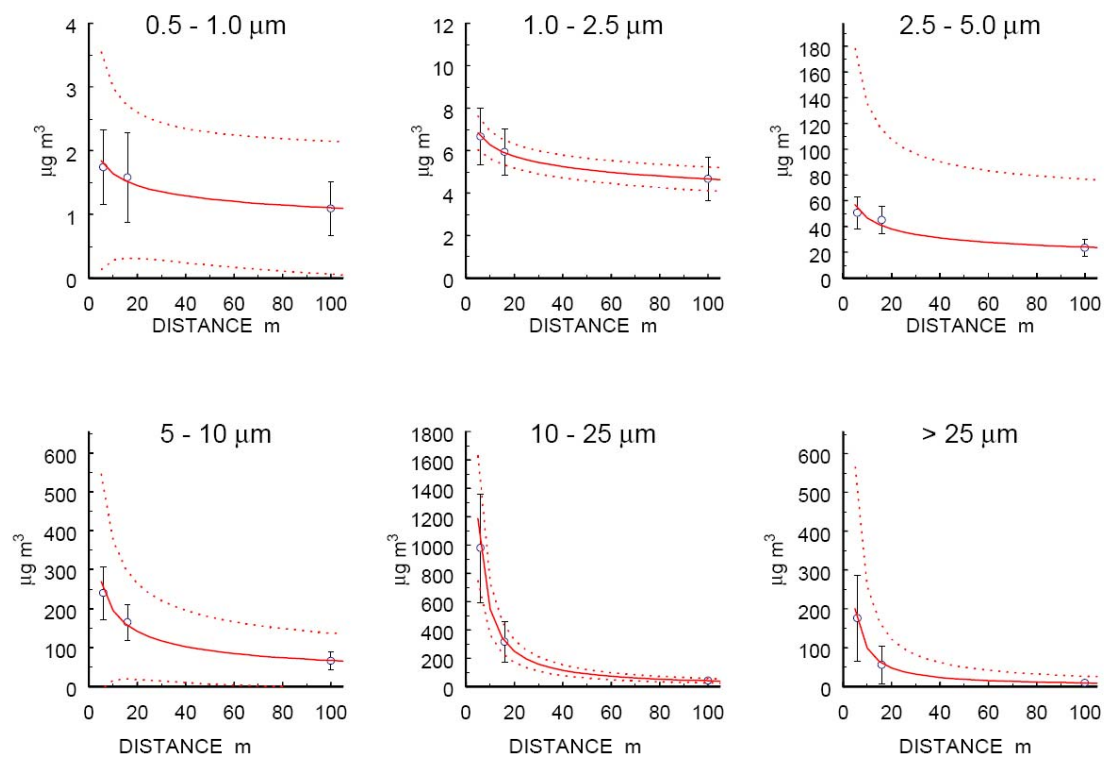


Figure 5. Change in particle concentrations observed at, and fitted power functions for, the area downwind of Highway 50 at SOLA on the evening of March 11, 2004. Dotted lines are 95% confidence bounds for the fits. (CARB, 2006)