Impacts of Vehicle Activity on Airborne Particle Deposition to Lake Tahoe

Dongzi. Zhu[1], H. Kuhns[1], J.A. Gillies[1], A.W. Gertler[1], S. Brown[2]

1. Desert Research Institute
2. Nevada Tahoe Conservation District

Environmental Restoration in a Changing Climate

Tahoe Science Conference

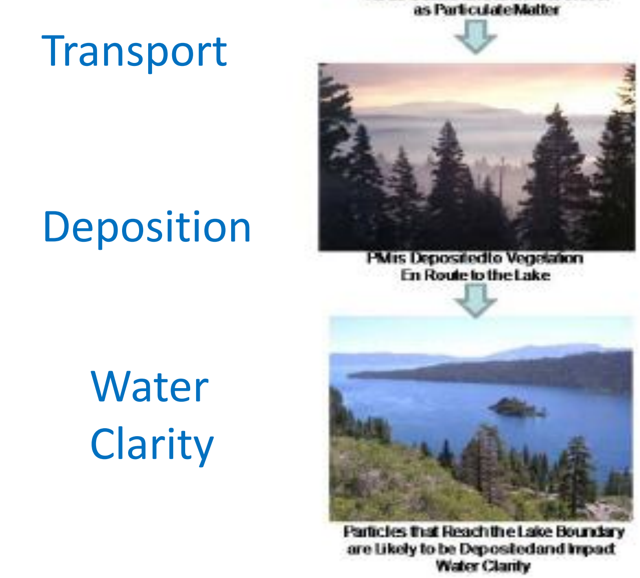
May, 2012

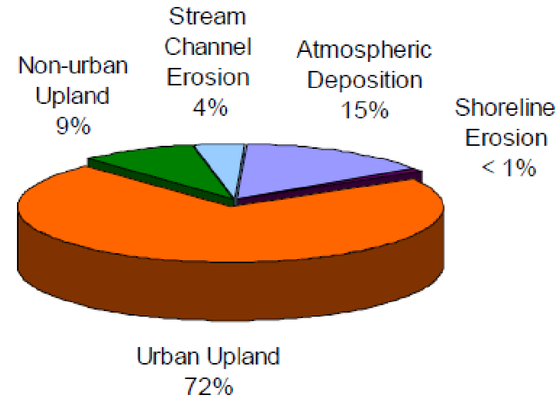
Background

- Atmospheric deposition can be a major source (Dry Atmospheric Deposition 590 ton TSP/yr, 230 ton PM_{10}/yr) of fine sediment in the lake (LTADS, 2006)

- Accumulation of fine sediment particles (FSP, < 16 μm) due to Urban Upland Loading (i.e. watershed runoff ,72%) and atmospheric deposition (15%, TMDL estimates).

- Quantitative estimates of the atmospheric deposition of FSP were rated as “lowest confidence” due to high uncertainty and insufficient data



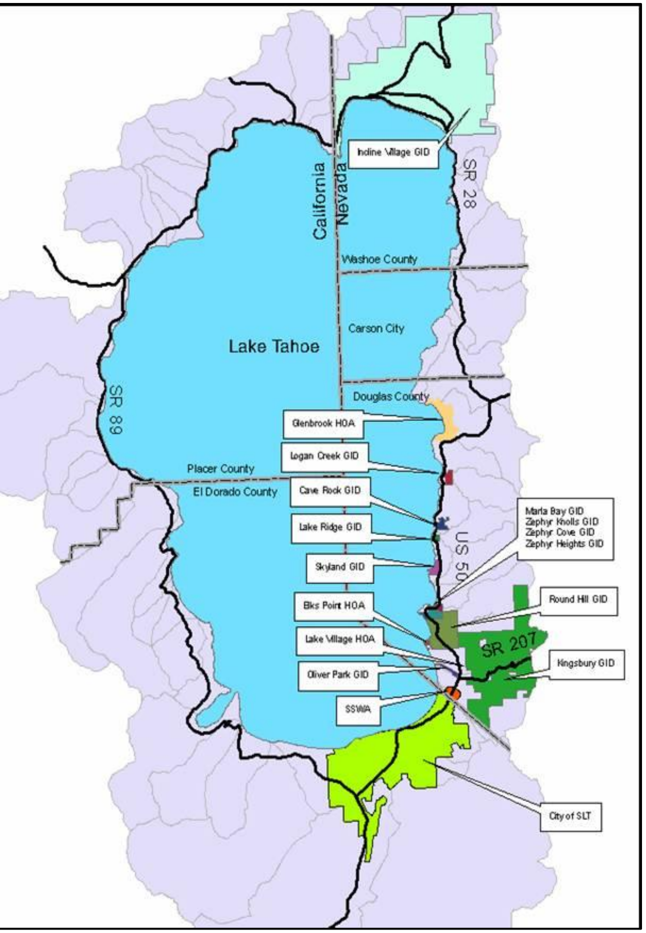


Percent of FSP contributions per source category.

Objective and Literature Review

- ❑ Integrate the results of previous studies, quantitatively link vehicle kilometers traveled (VKT) and road location to lake particulate loading.
- ➢ The Lake Tahoe Atmospheric Deposition Study, LTADS (CARB, 2006)
- ➢ DRI Lake Tahoe Source Characterization Study (Kuhns et al., 2004)
- ➢ Impact of Winter Road Sand/Salt and Street Sweeping of Road Dust Re-Entrainment (Gertler et al.,2006)
- ➢ Measurement and Modeling of Fugitive Dust Emissions from Paved Road Travel in the Lake Tahoe Basin (Kuhns et al., 2007).
- ➢ Development of an Air Pollutant Emissions Inventory for the Lake Tahoe Basin (Gertler et al., 2008)
- ➢ Receptor Modeling to Determine Sources of Observed Ambient Particulate Matter (PM) in the Lake Tahoe Basin (Engelbrecht et al., 2009)
- ➢ Assessing the Impact of Best Management Practices (BMPs) Designed to Reduce the Contribution from Resuspended Road Rust to Lake Tahoe (Kuhns et al., 2010)
- ➢ Tahoe TMDL Pollutant Reduction Opportunity Report (CWB & NDEP, 2008).
- ➢ Road Rapid Assessment Methodology (Road RAM) (2NDNature, 2010).

Seasonal PM_{10} Road Dust Emission Factors from 1 year round On-Road Measurements

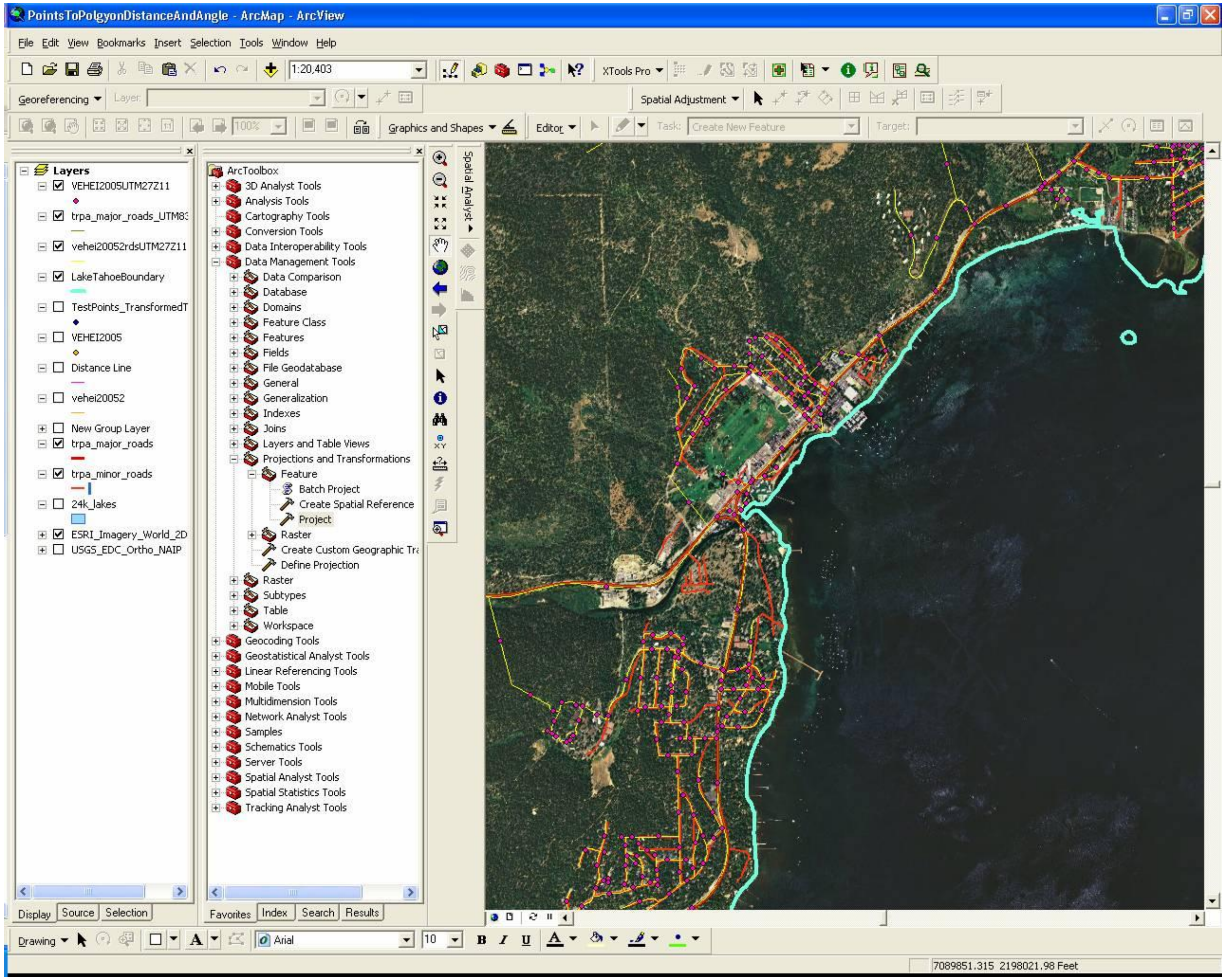


County	Road Type	Winter Daily Average EF (g/VKT)	Winter EF Standard Deviation (g/VKT)	Summer Daily Average EF (g/VKT)	Summer EF Standard Deviation (g/VKT)
Washoe	Primary	0.30	0.09	0.05	0.01
Washoe	Secondary	0.62	0.16	0.15	0.06
Washoe	Tertiary	1.55	0.12	0.59	0.34
Carson	Primary	0.24	0.11	0.04	0.02
Douglas	Primary	0.27	0.07	0.04	0.03
Douglas	Secondary	1.00	0.68	0.27	0.16
Douglas	Tertiary	1.89	1.99	0.50	0.31
El Dorado	Primary	0.74	0.25	0.16	0.14
El Dorado	Secondary	2.02	1.83	0.55	0.57
El Dorado	Tertiary	1.38	0.16	1.17	0.48
Placer	Primary	0.61	0.15	0.15	0.04
Placer	Secondary	1.74	1.53	0.65	0.28
Placer	Tertiary	3.70	3.70	1.65	1.65

The roaddust PM10 EFs were extended to similar roads in the same jurisdiction area

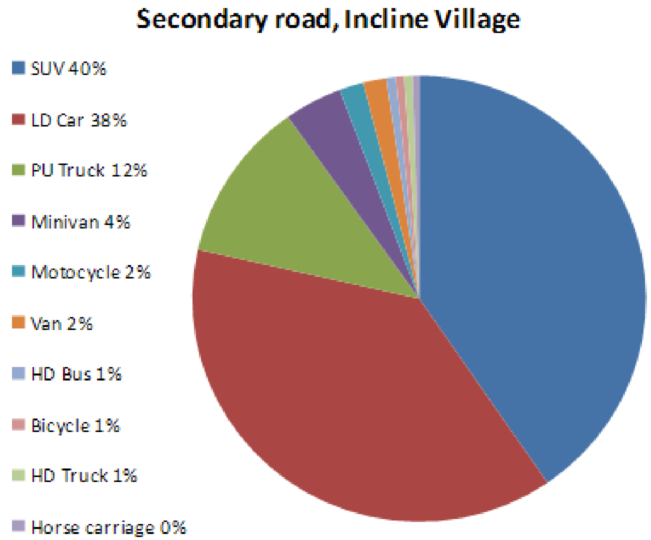
TransCAD VKT modeling (GIS)

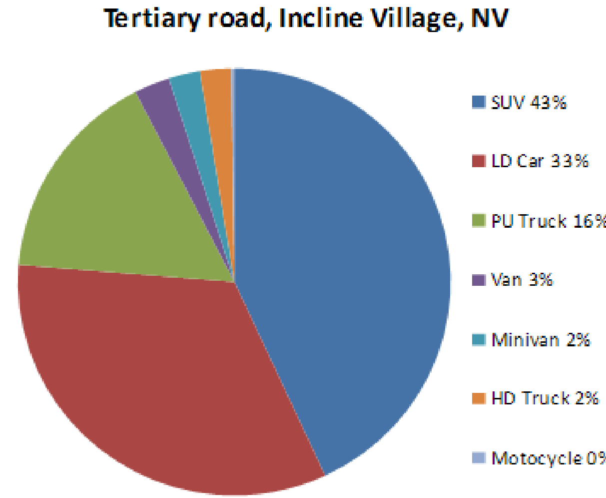
TransCAD modeling produced AADT (Annual Average Daily Traffic) for over 7000 traffic segments in the basin

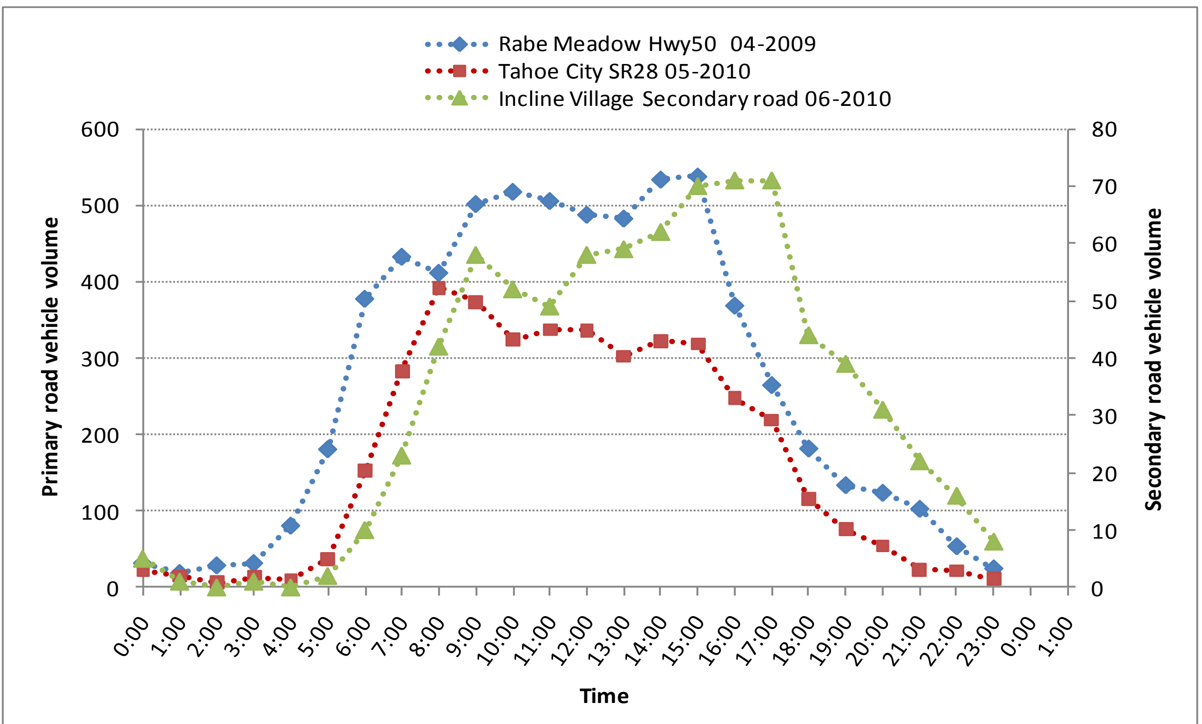


Vehicle class and traffic pattern

Heavy duty trucks (>5 axle) accounted for ~2% of the fleet in Highway 50 (Rabe Meadow) and Incline Village

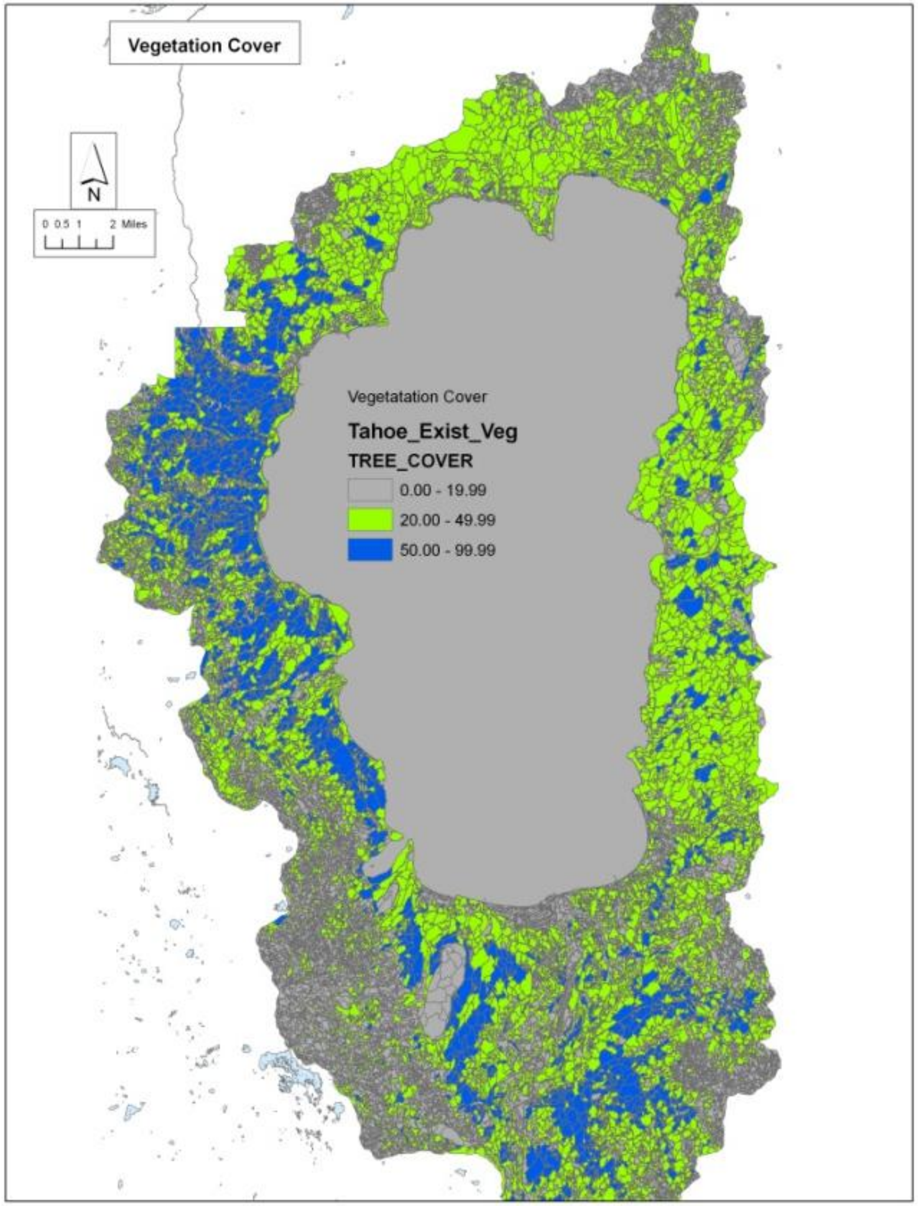






Traffic volume from 7:00 to 15:00 accounted for ~70% of daily total volume. Traffic volume late at night – from 22:00 to 4:00 – only accounted for ~4% of daily traffic volume

Vegetation coverage Enroute of dust transport



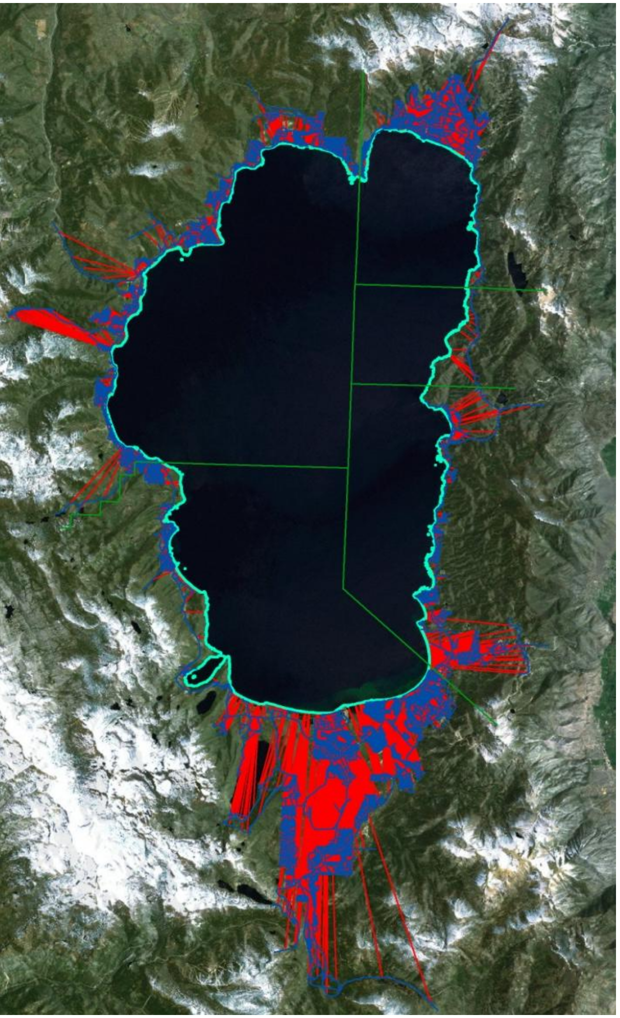
Based on the tree coverage ratio, the vegetation were classified into 3 categories:

Shrubs

Open Trees

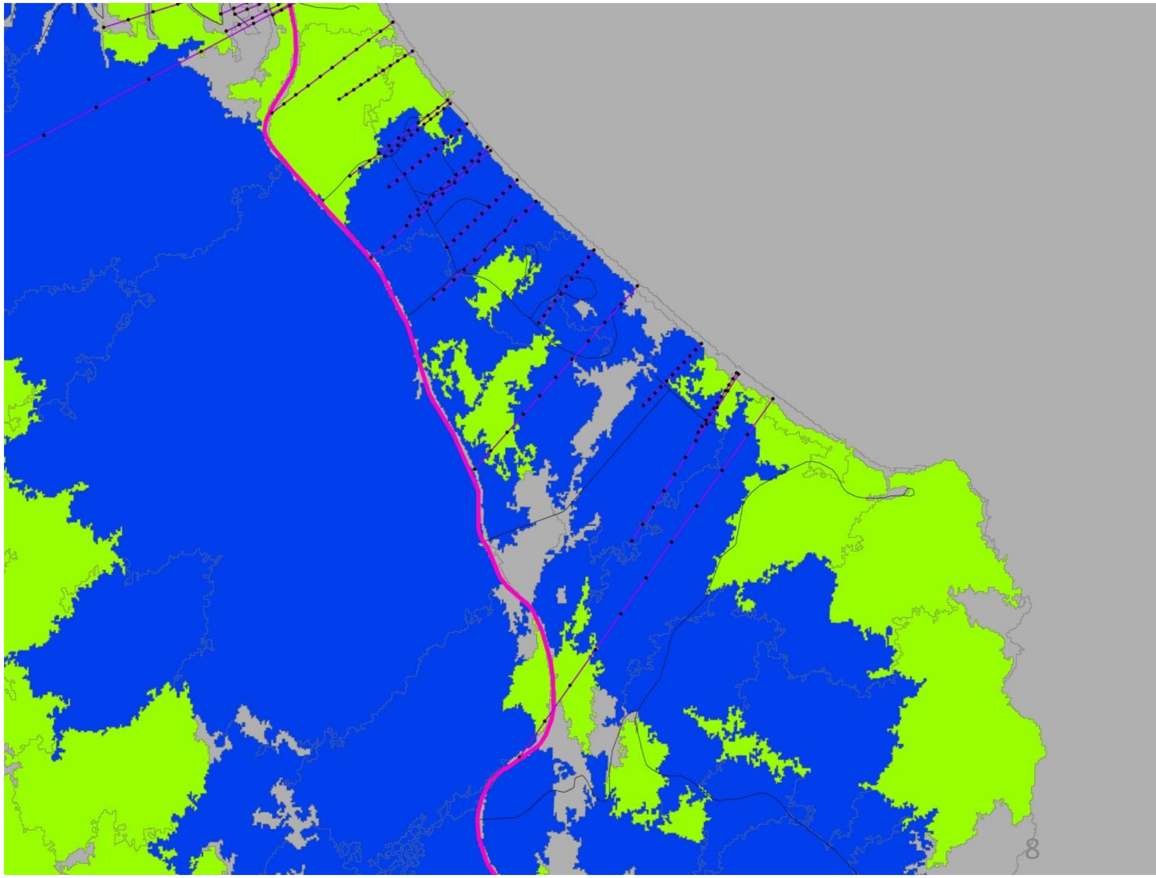
Dense Trees

GIS data processing



ArcGIS queries findings:

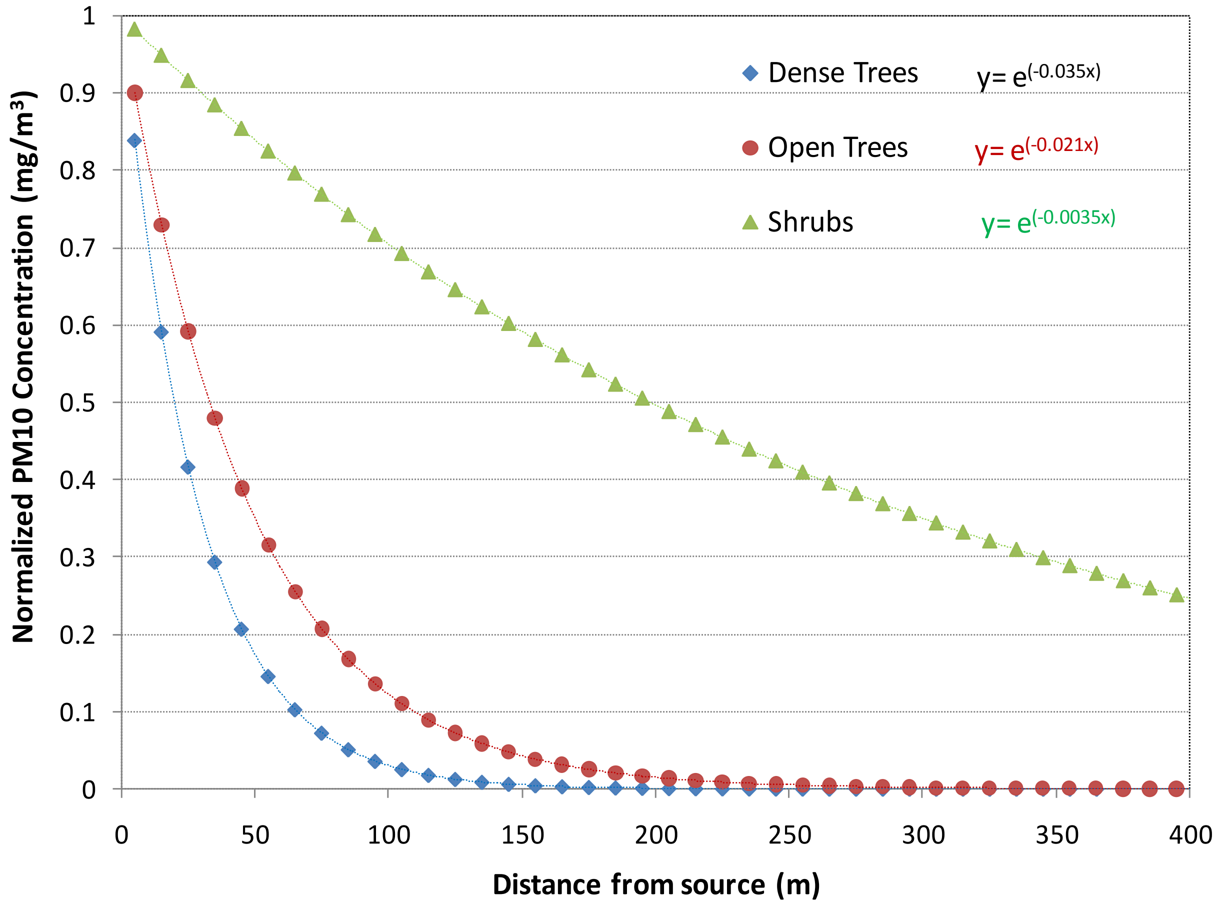
- ➢the shortest distance to the lake for each of the 7235 traffic points
- ➢azimuth angle of each shortest path



First-order near-source deposition model

$$C(x) = C_0 e^{-\frac{V_d X}{UH}}$$

where
C(x) is the particle concentration at *x* meters of horizontal distance from source
C_0 is the particle concentration at source
V_d is the deposition velocity, cm/s
X is the meters of horizontal distance from the source
U is the horizontal wind velocity, m/s
H is the injection height of resuspended particle source and was assumed to be 2 m
Noll and Aluko (2006)

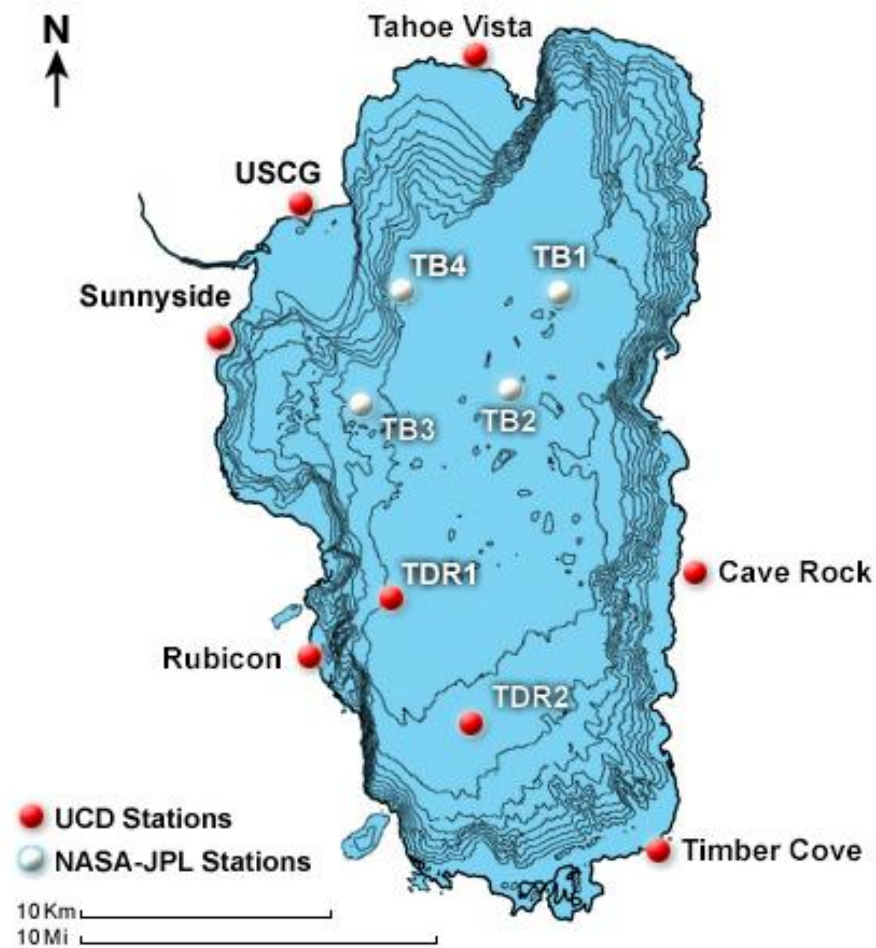


The exponents are from field measurement of Cowherd et al. (2006) and Zhu et al. (2011).

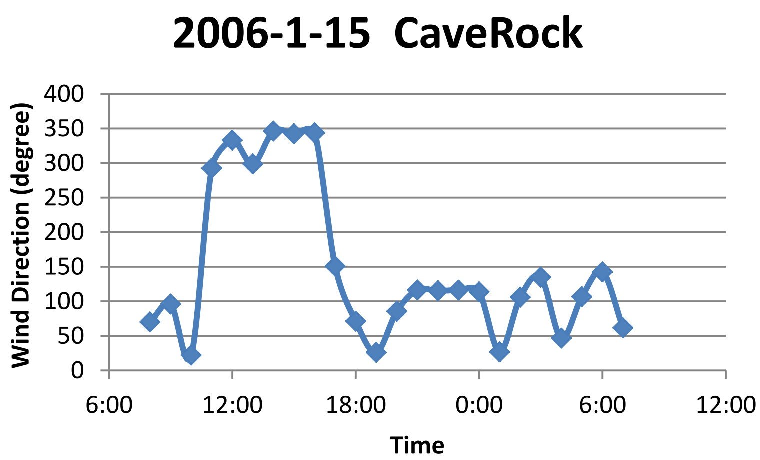
Hourly Meteorological data

Five year (2005-2009) hourly wind speed and wind direction data around Lake Tahoe were obtained from UC Davis's REMOTE project.

The REMOTE project set up 6 meteorological stations around lake: Cave Rock, Timber Cove, Rubicon, Sunnyside, USCG, and Tahoe Vista

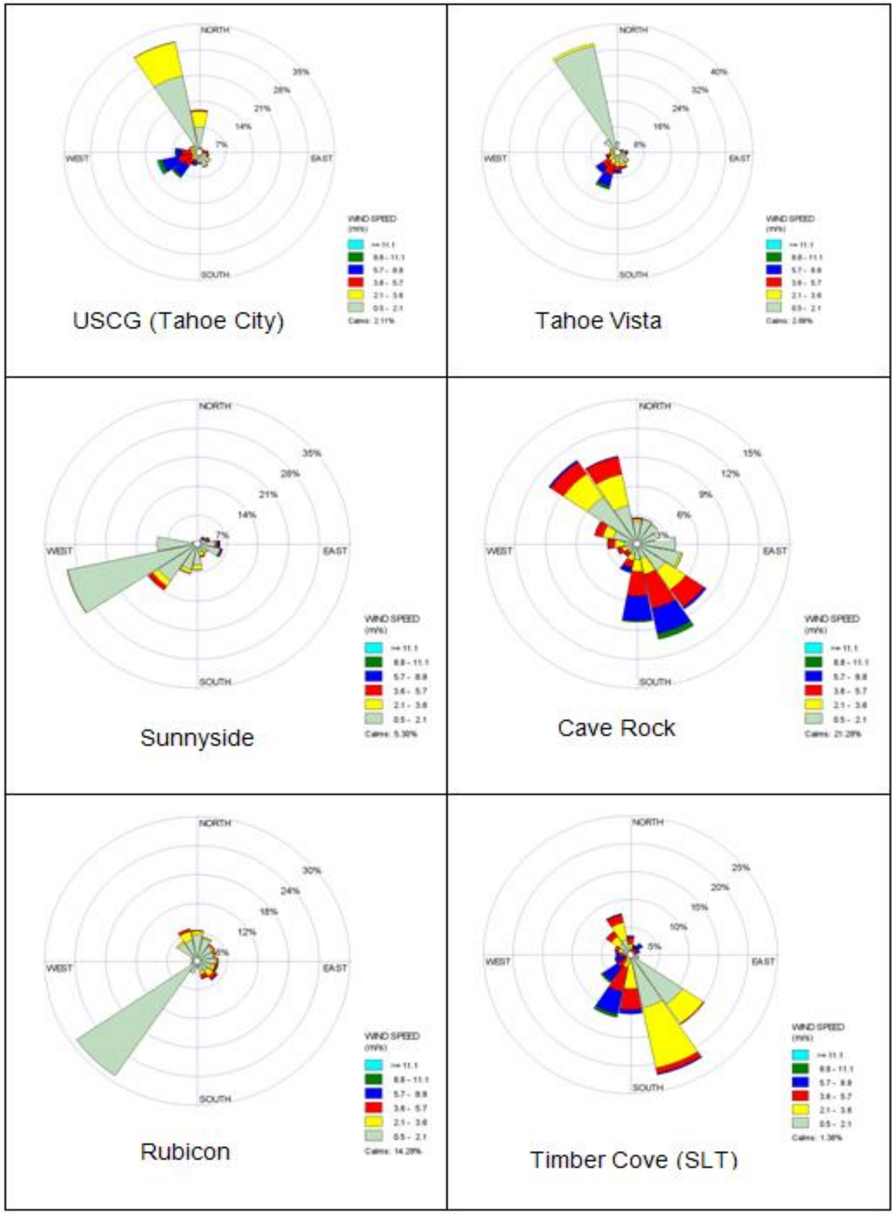


Wind patterns



Winds:

- Onshore during the day
- Offshore at night.



Wind rose map from 1-year (2006) monitoring data for the 6 meteorological stations around Lake Tahoe.

PM mass reaching the lake after vegetation attenuation

$$PM = \sum_{i=1}^{n} EF_i * TrafficVolume * LinkLenth * \exp\left(\frac{-1}{UH\cos\theta}(Vd_1L_1 + Vd_2L_2 + Vd_3L_3)\right)$$

where
n is the number of traffic segments
U is the horizontal wind velocity, m/s
H is the injection height of resuspended particle source and was assumed to be 2 m
V_{d1} is the PM deposition velocity under Shrubs, cm/s
V_{d2} is the PM deposition velocity under Open Trees, cm/s
V_{d3} is the PM deposition velocities under Dense Trees, cm/s
Θ angle of the wind direction relative to the shortest path (perpendicular to the road segment)
X= L cosΘ, where *L* is the shortest distance to the lake for each traffic points
Traffic volume: grouped in 4-periods in a day to reflect the diurnal variation.

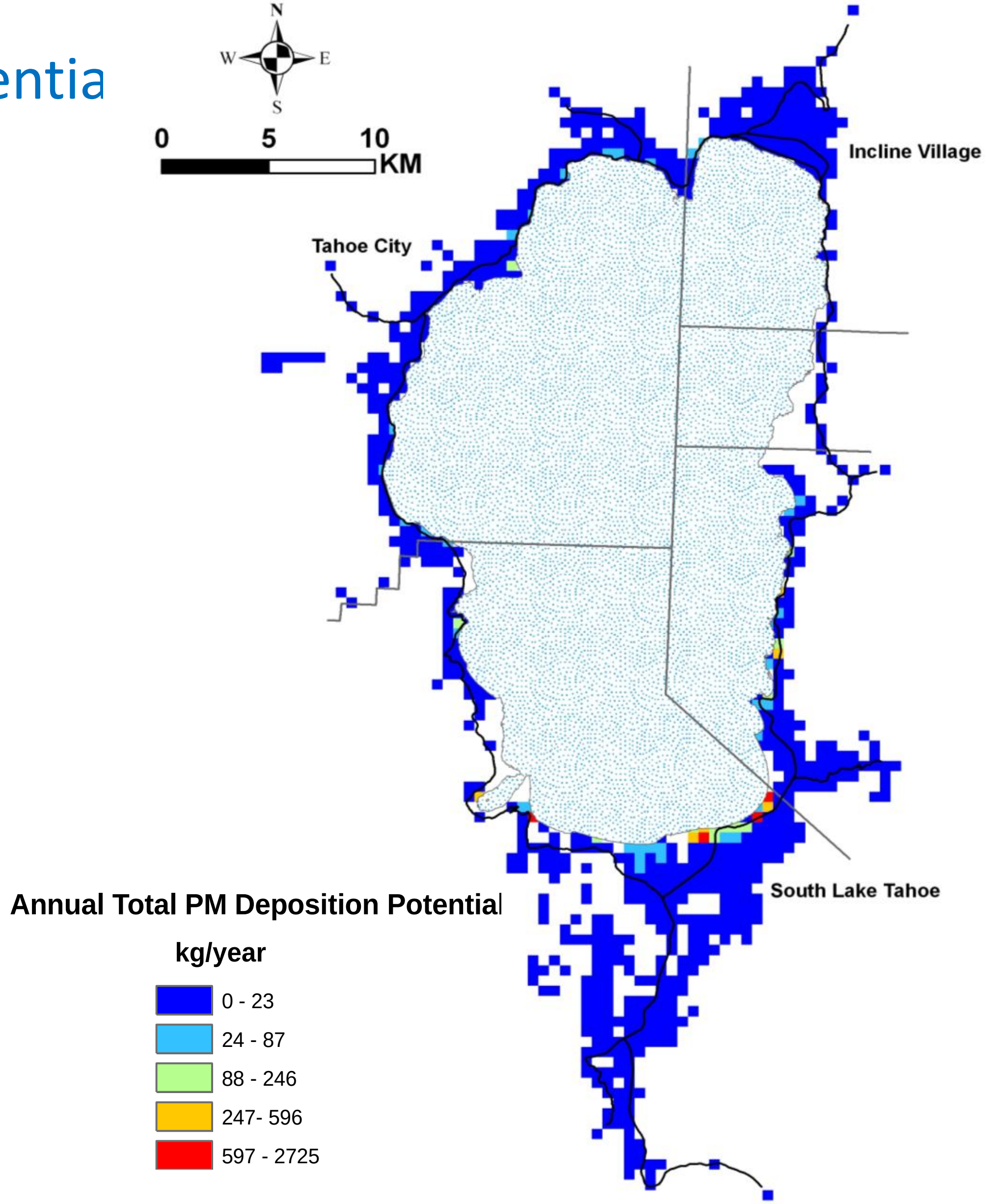
Total PM (or TSP, fine+coarse+large) deposition contributions and VKT from different counties

County	Total PM deposition to lake (Mg/year)			VKT	VKT ratio
	Annual	Winter	Annual Ratio		
El Dorado, CA (incl. SLT)	21	12	61%	1,264,703	57%
Douglas County, NV	7.2	5.9	20%	345,531	16%
Placer County, CA	5.7	4.0	16%	455,463	21%
Washoe County, NV	0.91	0.62	2.6%	141,913	6.4%
Carson City, NV	0.005	0.004	0.0%	11,137	0.5%
Total	36	22		2,218,750	

Findings

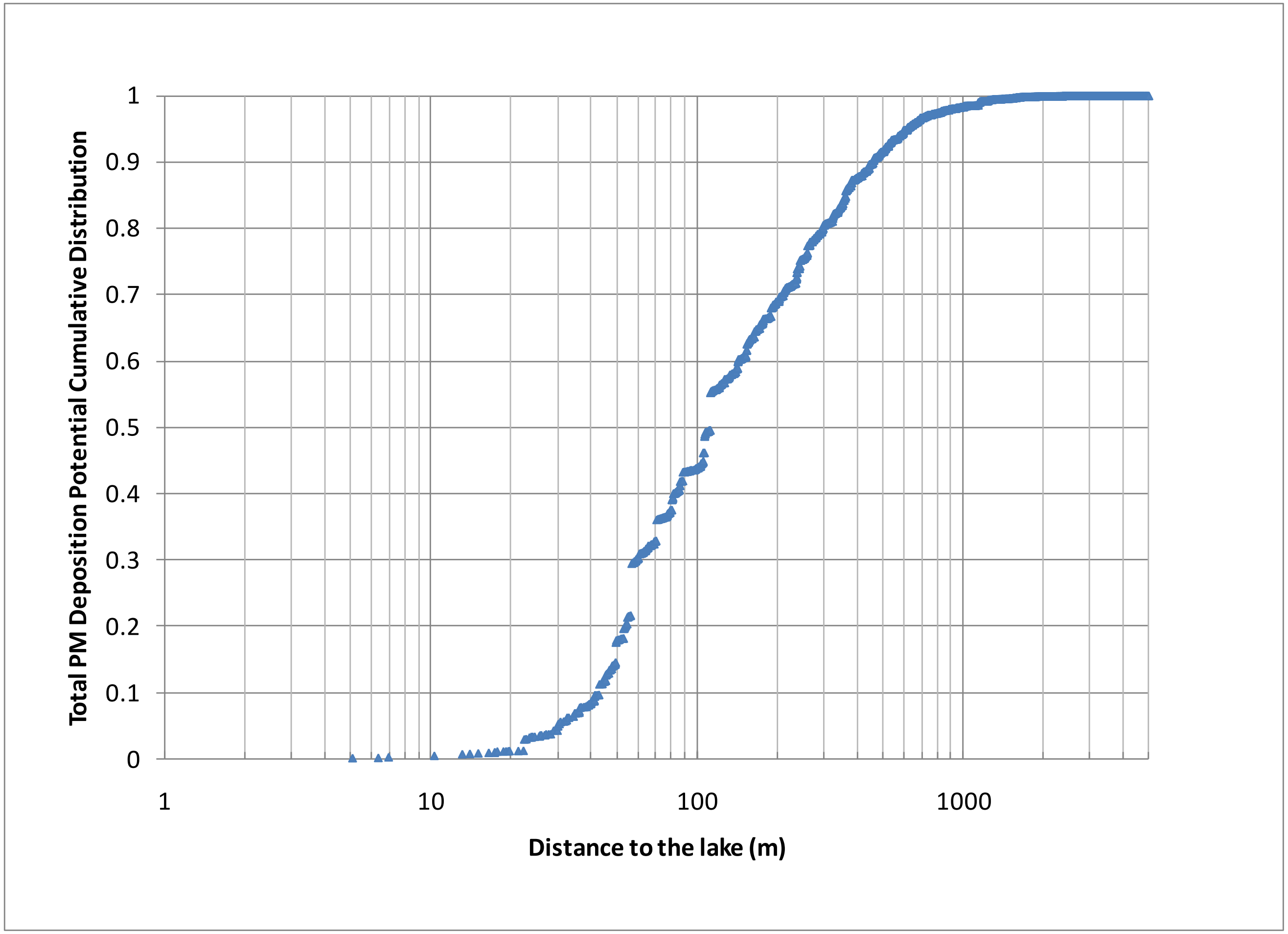
- Annual average PM_{10} deposition to the lake is ~ at 20 ± 10 Mg,
- PM_{large} (particles > 10 μm) deposition to the lake is ~ at 15 ± 7 Mg per year,
- PM_{fine} ($PM_{2.5}$) deposition is estimated to range from 0.23 ± 0.12 to 3.0 ± 1.5Mg per year
- Winter time (Dec-Apr) accounts for 60%-82% of annual dust deposition.
- PM_{10} deposition to the lake is ~2% of the ~1040 Mg PM_{10} emission resuspended by the vehicles
- Annual total PM deposition is ~1.4% of the ~2465 Mg total PM resuspended by the vehicles

Annual total PM deposition potentia



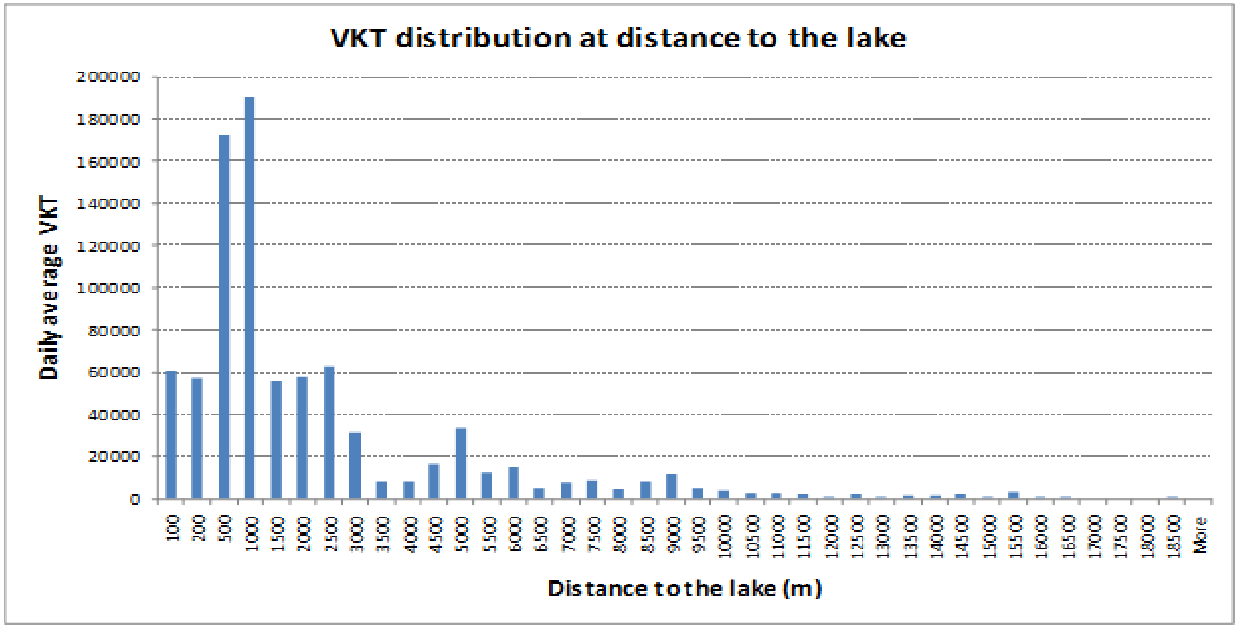
Gridded annual total PM deposition potential for 7235 traffic segments, taking into consideration the vehicle kilometers traveled (VKT), seasonal emission factors (EFs), wind speed and direction, distance to the lake, and vegetation barrier density

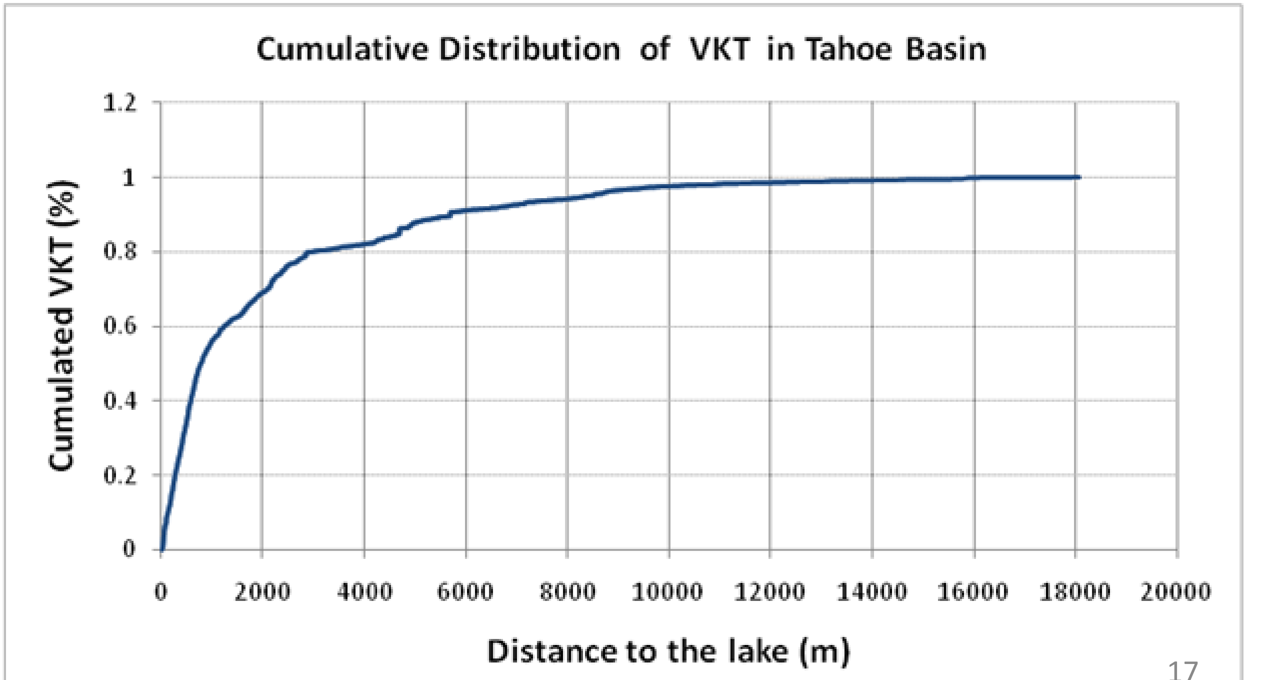
Cumulative Distribution of total PM deposition potential as a function of distance to the lake



90% of total PM deposition potential within 500 m to the lake

80% of cumulative VKT within 3000 m to the lake





Impacts of Vehicle Trips on Re-entrained Dust

- On-shore winds pushing peak emissions away from the lake,
- Nighttime off-shore winds combined with reduced night vehicle volume, the diurnal wind direction and traffic volume fortuitously reduces the direct airborne PM deposition to the lake.
- High-volume vehicle-resuspended road dust from the daytime still deposited onto the road surfaces, curbs, shoulders, and nearby vegetation and soils
- These dust deposits may still enter Lake Tahoe via water runoff or fugitive wind erosion processes, especially if deposited back onto road surfaces where it will be re-entrained again.

Compare to LTADS and TMDL

- LTADS (Dry atmospheric deposition) estimates:
- 60 Mg of $PM_{2.5}$, 230 Mg of PM_{10}, and 590 Mg of TSP were deposited into the lake per year
- PM Deposition/yr = Annual Average PM ($\mu g/m^3$) × V_d × Time × Deposition Area (whole lake)
- The TMDL estimated atmospheric-deposited particles accounted for 15% of the lake loading of 75 x 10^{18} particles (1136 Mg based on 66 * 10^{15} particles per Mg). May represent all sources rather than just paved road dust.
- " did not measure the conc. of particles responsible for majority deposition flux (Holsen et al., 1993)
- This study 36 Mg/yr of TSP deposited into lake from paved road dust. (unpaved emission ≈ paved emission, see PRO report)
- Although large discrepancy, control strategies to reduce the lake sediment load are unlikely to change. The largest sources of sediment: runoff from urban upland areas at 72% of the TMDL.

Conclusions

- Spatial & seasonal patterns observed road dust PM_{10} emission factors (g/vkt) used to create a basin-wide EF database based on road type and jurisdiction.
- Database was linked to the traffic demand model VKT output (TransCAD) from >7000 segments
- GIS quantifies the shortest path and vegetation coverage and attenuation of dust.
- only ~2% of emitted PM_{10} and 1.5% of TSP (Total Suspended Particulate) was estimated to directly reach the lake via atmospheric deposition.

Conclusions (continued)

- Proximity to the lake, prevailing wind directions, and traffic patterns played dominant roles in determining which roads had the greatest potential to deposit fine particles to the lake.
- Overall, roads in El Dorado County (in particular SLT) had the highest potential (67%) to deposit sediment to the lake. Its high VKT causes it to be a major source of airborne-derived PM in the lake.
- Incline Village and Tahoe City made very minor contributions to lake loading.
- Targeted mitigation in areas with high potential to impact the lake (e.g., El Dorado County, CA, and Douglas County, NV) will be more effective than general reduction in basin-wide VKT.
- Shared with storm water management: controlling the largest sources of sediment: runoff from urban upland areas

Acknowledgement

- SNPLMA support
- UC Davis support of met data
- Leon Jiang GIS support

Q & A