Research Needs

- Perform air quality measurements of key species under a range of meteorological conditions. Include measurements for NO_x, NH_3, HNO_3, size-segregated aerosol mass, particle number and particle size distribution, and aerosol chemical composition. Consider the use of advanced monitoring techniques such as differential optical absorption spectroscopy, remote sensing, and the use of airborne platforms to obtain additional data on key atmospheric species.
- Add air quality monitoring stations in the basin, on the ridges leading into the basin, and on the west side of the Sierra Nevada Mountains to assess in-basin vs. out-of-basin sources throughout the year and under different meteorological conditions.
- Monitor plume transport using an aircraft platform to directly assess the pollutant contribution from out-of-basin sources and link these measurements to deposition.
- Develop a Tahoe-specific modeling system that includes appropriate emissions data to evaluate in-basin vs. out-of-basin sources of observed pollutants.
- Complete a meta-analysis of existing work on the conclusions for wet/dry and in-basin versus out-of-basin contributions. A fair amount of data and information exists, but no one has completed a comprehensive synthesis. Additional research questions would then come from this work.

Tahoe Basin Air Quality: The Criteria Pollutants

The Tahoe Regional Planning Agency Compact, amended in 1980, called for TRPA to adopt environmental threshold carrying capacities (“thresholds”) to protect the values of the Tahoe basin. The first set of comprehensive air quality thresholds were adopted by TRPA in August 1982; however, compliance with TRPA’s threshold standards as well as changing federal, state, and local air quality and visibility standards could require amendments to the thresholds. Currently, the TRPA is developing a new regional plan that may include new thresholds, indicators, standards, and regulations for air quality. Table 3.1 presents an overview of the attainment status and trend based on the recent analysis (TRPA 2005) of each criteria air pollutant where attainment of standards has been an issue. For reference, federal and California air quality standards for CO, O_3, respirable particulate matter (PM_{10}), and fine particulate matter ($PM_{2.5}$) are shown in table 3.2. Note that monitoring locations in the basin have been chosen to provide information related to air quality standards, rather than to obtain data for deposition assessment. A discussion of the issues associated with each of these pollutants is presented below.

Table 3.1—Air quality indicator attainment status[a]

Threshold criteria air pollutant	Attainment status				5-year trend
	1991	1996	2001	2006	
Carbon monoxide	Nonattainment	Attainment	Attainment	Nonattainment	Positive
Ozone	Nonattainment	Nonattainment	Nonattainment	Nonattainment	Unknown[b]
Particulate matter (PM_{10})	Nonattainment	Nonattainment	Attainment	Nonattainment	Unknown

[a] Results for 1991 to 2001 were obtained from Tahoe Regional Planning Agency (2005).
[b] More stringent ozone standards became effective in May 2006. This may result in additional ozone violations in the future.

Table 3.2—California and federal air quality standards

Air quality constituent	Averaging time	California standard	Federal primary standard
Carbon monoxide	8 hr	9 ppm	9 ppm
	1 hr	20 ppm	35 ppm
	8 hr (Tahoe)	6 ppm	N/A
Ozone	8 hr	70 ppb	75 ppb
	1 hr	90 ppb	None
Particles less than 10 µm in diameter	24 hr	50 µg/m^3	150 µg/m^3
	Annual arithmetic mean	20 µg/m^3	None
Particles less than 2.5 µm in diameter	24 hr	Same as federal	35 µg/m^3
	Annual mean	12 µg/m^3	15 µg/m^3

Note: The Nevada standards are the same as the federal standards.

Carbon monoxide—

Carbon monoxide is a tasteless, odorless, and colorless gas that is slightly lighter than air and is associated with substantial health risks especially at high altitudes. It affects humans by reducing the supply of oxygen to body tissues. The primary source of CO emissions is combustion of hydrocarbon fuels by motor vehicles; home heating devices such as fireplaces, stoves, and furnaces; and industrial processes. In the Tahoe basin, the primary source of CO emissions is from mobile sources such as motor vehicles and boats. For this reason, it is important to concentrate on transportation improvements within the basin as a control method for reducing CO levels. Owing to the substantial health risks posed by CO, the TRPA, California, Nevada, and the federal government have all adopted standards for this pollutant.

Carbon monoxide is considered a "hotspot" pollutant, meaning elevated levels are very localized. Thus, it is necessary to use data from multiple monitoring stations within the basin to report on this pollutant. Currently, CO is only measured at one location (South Lake Tahoe), which does not provide the necessary data to either evaluate ambient conditions or make recommendations for improvements.

Ozone—

Ozone is a secondary pollutant that is formed in the atmosphere by a photochemical process involving HC, NO_x, and sunlight. This pollutant poses a substantial health risk especially to the young and elderly in the form of lung and other respiratory illnesses. Ozone also damages trees and plants, particularly ponderosa pines (*Pinus ponderosa* Dougl. ex Laws.), Jeffrey pines (*Pinus jeffreyi* Grev. & Balf.), and quaking aspen (*Populus tremuloides* Michx.) (Davis and Gerhold 1976, Miller et al. 1996). Ozone precursors are produced from human activities such as the combustion of fossil fuel, chemical processing, fuel storage and handling, and solvent usage. As with CO, the primary source of O_3 precursor emissions in the basin is vehicle exhaust. Currently, O_3 is measured at two locations (South Lake Tahoe Airport and Incline Village). However, as is the case for CO, this does not provide the necessary data to either evaluate ambient conditions or make recommendations for improvements.

Particulate matter—

Particulate matter (PM) pollution consists of very small liquid and solid particles in the air. Two fractions of PM are generally measured: (1) PM_{10} (particulate matter with aerodynamic diameter less than 10 μm) and (2) $PM_{2.5}$. The primary sources of PM_{10} in the basin include motor vehicles, sand, salt and road dust, smoke from both natural and human-set fires, and fugitive dust from construction and the landscape. PM_{10} can increase the number and severity of asthma attacks, cause or aggravate bronchitis and other lung diseases, and reduce the body's ability to fight infections. These effects are particularly harmful to children, exercising adults, and the elderly. PM_{10} was only measured at the South Lake Tahoe site from 2001 to 2005 by CARB. As with the other pollutants, PM_{10} measurements are inadequate.

Fine particulate matter, $PM_{2.5}$, also is of concern. These particles have been linked to increases in human mortality and morbidity (Pope and Dockery 2006). $PM_{2.5}$ is primarily generated from combustion processes and can contain significant amounts of carcinogens. California and the federal government have adopted standards and have increased efforts to study and control this pollutant. $PM_{2.5}$ is measured at the two IMPROVE sites located at South Lake Tahoe and D.L. Bliss State Park. Coverage throughout the basin is inadequate to evaluate ambient conditions or offer recommendations for improvement.

There are a number of issues associated with the implementation of new air pollution standards and thresholds. These include:

- Not all agencies are in agreement that a single standard for the criteria pollutants is appropriate basinwide. Currently, there are different pollution standards and measurement protocols for each state, local, and federal agency with jurisdiction in the basin. This leads to confusion and the expenditure of substantial amounts of resources to keep track of each of the multiple standards.

- A permanent criteria pollutant monitoring program is lacking. The basin's air quality monitoring program has suffered greatly in the last few years owing to reductions, relocation, or removal of various monitoring stations and the lack of adequate resources to implement this program.
- An improved modeling system for criteria pollutants is needed. Although commonly available in other air basins, critical tools necessary to relate pollutant emissions to ambient and local air quality are lacking for the Lake Tahoe air basin. Specifically, these include updated activity data for each emissions source and an emissions model. Without these tools, the ability to assess the effectiveness of past or future emission reduction strategies is substantially limited.
- There is a lack of information on ecosystem health effects of the criteria pollutants. Although numerous air quality standards have been established by the U.S. Environmental Protection Agency (U.S. EPA), California, Nevada, and TRPA, these standards were primarily implemented for human health concerns. Although it is understood that these standards provide some protection for the ecosystem, additional information is needed to ensure these standards adequately protect the ecosystem health of the basin.

Knowledge Gaps

- What is the mechanism to adopt uniform standards for the criteria pollutant in the basin?
- How many air quality monitoring sites are necessary and where they should be located to adequately monitor the basin for criteria pollutants and their sources and what species should be measured? What air quality monitoring is necessary to evaluate programmatic changes? Should monitoring capabilities be added to obtain deposition data?
- To improve and update the emissions inventory, what are the activity, population, and emission factors that control emissions from the various sources of criteria air pollutants in the basin?
- For the cases where standards are exceeded, what are the appropriate emission reduction strategies to use in the basin? What are the costs, effectiveness, and constraints of each strategy?

- To develop thresholds that protect ecosystem health in the basin, what are the appropriate ecosystem health standards for criteria pollutants that need to be considered?

Research Needs

- Conduct studies to determine the number, distribution, and sampling frequency and protocol of a monitoring network that is adequate to obtain information related to air quality standards or other pollutants of interest (e.g., polycyclic aromatic hydrocarbon (PAHs), size-segregated and chemically speciated PM, and HNO_3). As part of this study, consider alternative monitoring techniques such as remote sensing or biomarkers (i.e., lichens).
- Develop basin-specific activity rates, emissions inventory, and emission models necessary to evaluate the present and future conditions and programs in the basin. Develop emission estimates for transportation and other large-scale programs included in the various planning and programmatic documents produced by basin agencies.
- Complete studies to inform implementation of the programs aimed at reducing the criteria pollutants emission levels in the basin. It is recommended that these studies also could provide information on cost, effectiveness, implementation issues, and constraints.
- Complete studies to determine the appropriate standards for criteria pollutants that protect ecosystem health in the basin. Primary concerns would focus on water quality and the clarity of lakes, as well as vegetation and wildlife health.
- Implement studies to assess the impact of pollutant levels (e.g., $PM_{2.5}$ and PAHs) on the health of humans living at altitudes similar to that of the Lake Tahoe basin.

Visibility in Lake Tahoe Basin

Visibility is an indicator of air quality, and good visibility is a desired condition in and of itself. The original visibility thresholds for the Lake Tahoe basin were first developed by the TRPA in the early 1980s after analyzing data collected in a short-term (June 1981 to May 1982) visibility monitoring program (Pitchford and Allison 1984). Both regional (basinwide) and subregional thresholds were developed from this study. Regional visibility is defined as the overall prevailing visibility in the Lake Tahoe basin. The primary impact of regional visibility degradation is a general reduction in clarity, contrast, and color of vistas seen through the regional haze. Subregional visibility in the Lake Tahoe basin is characterized by a layer of perceptible haze that spreads over the urbanized areas, especially the south shore of the lake.

When the regional visibility thresholds were defined, it was thought that optical measurement techniques of the period (long-path horizon/sky contrast) would be unduly influenced by meteorological conditions, thus indicating below-standard conditions, when in fact the air in the basin was quite clean (low aerosol concentrations). Because the South Lake Tahoe aerosol consists of a large fraction of absorbing aerosols (e.g., aerosols composed of elemental carbon), it also was realized that basing the subregional standard on nephelometers that only measure the scattering coefficient, would significantly underestimate the true subregional visibility. As a result, an interesting hybrid was developed for both the regional and subregional thresholds. The standards were defined in terms of an optical property—visual range—but the results were calculated from high-quality speciated aerosol data. At the time these standards were developed, no guidelines existed for using the calculations. It was thought that proper algorithms would be developed as visibility research matured.

In 1989, TRPA instituted a visibility monitoring program to gather the data necessary to address its visual air quality standards. The program was fully operational and funded by 1991. Details of the program are discussed elsewhere (ARS 1989, 2000). The monitoring program consisted of two major, fully instrumented sites—Bliss State Park and South Lake Tahoe—and one additional site that has had some periodic measurements: Thunderbird Lodge. The TRPA operated the Bliss State Park site from 1990 to November 1999. In December 1999, the Bliss State Park site was added to the national IMPROVE monitoring network, with funding provided by the US EPA. Both sites were operated by Air Resource Specialists, Inc. In June 2004, TRPA permanently shut down the South Lake Tahoe site.

Results from detailed analyses of the limited 1981–82 measurements and monitoring data collected between 1989 and 1991, indicated that within the experimental uncertainty of the 1981–82 measurements, there was no statistically observable change in the visual air quality levels in the Lake Tahoe basin between 1981 and 1991. Thus, in 1999 after further monitoring, TRPA restated visibility standards in terms of the current monitoring and data analysis techniques and set the baseline period as 1991–93 (table 3.3).

Table 3.3—1999 Tahoe Regional Planning Agency visual air quality environment threshold carrying capacities, 1991–93 baseline

Area	Visibility threshold
Regional visibility (Bliss to Round Hill)	Achieve a visual range of 156 km (b_{ext} = 25.1 Mm^{-1}) at least 50 percent of the year as measured by particulate concentrations
	Achieve a visual range of 115 km (b_{ext} = 34.0 Mm^{-1}) at least 90 percent of the year as measured by particulate concentrations
Subregional visibility (South Lake Tahoe)	Achieve a visual range of 78 km (b_{ext} = 50.2 Mm^{-1}) at least 50 percent of the year as measured by particulate concentrations
	Achieve a visual range of 31 km (b_{ext} = 126.2 Mm^{-1}) at least 90 percent of the year as measured by particulate concentrations

Two additional TRPA standards were adopted in the early 1980s:

- Regional visibility: Reduce wood smoke emissions by 15 percent from the 1981 base values.
- Subregional visibility: Reduce wood smoke emissions by 15 percent and suspended soil particles by 30 percent from the 1981 base values.

These stated reduction goals in wood smoke emissions and soil particulate concentrations appear to have been added as qualitative guidelines even though they are stated as specific reduction percentages. There are no existing valid estimates of wood smoke emissions for 1981, thus deciding if a 15 percent reduction has occurred is impossible. The reference to "soil" in the subregional visibility standard is not well understood. There is no existing record of what "soil" means, i.e., PM_{10} mass, reconstructed $PM_{2.5}$ fine soil, or more probably coarse mass (the resultant PM_{10} to $PM_{2.5}$ gravimetric mass). Thus, these additional standards have not been addressed in any meaningful fashion. However, given the new-found importance of the effects fine soil particle deposition on lake water clarity, the TRPA standard to reduce suspended soil particles by 30 percent from 1981 base values takes on increased importance.

Figure 3.5 shows the TRPA visibility standard cumulative frequency plots for the baseline period 1991–93 and 2001–03. As can be seen, subregional visibility has improved dramatically since the 1991–93 baseline. Regional visibility has improved on the cleanest and average (50 percent frequency) days, but has not improved much on the haziest (90 percent frequency) days. The TRPA is recommending through the Pathway process to replace the 1991–03 baseline with the 2001–03 period (table 3.4). This is an attempt to prevent the loss of any visibility improvements that have occurred in the basin.

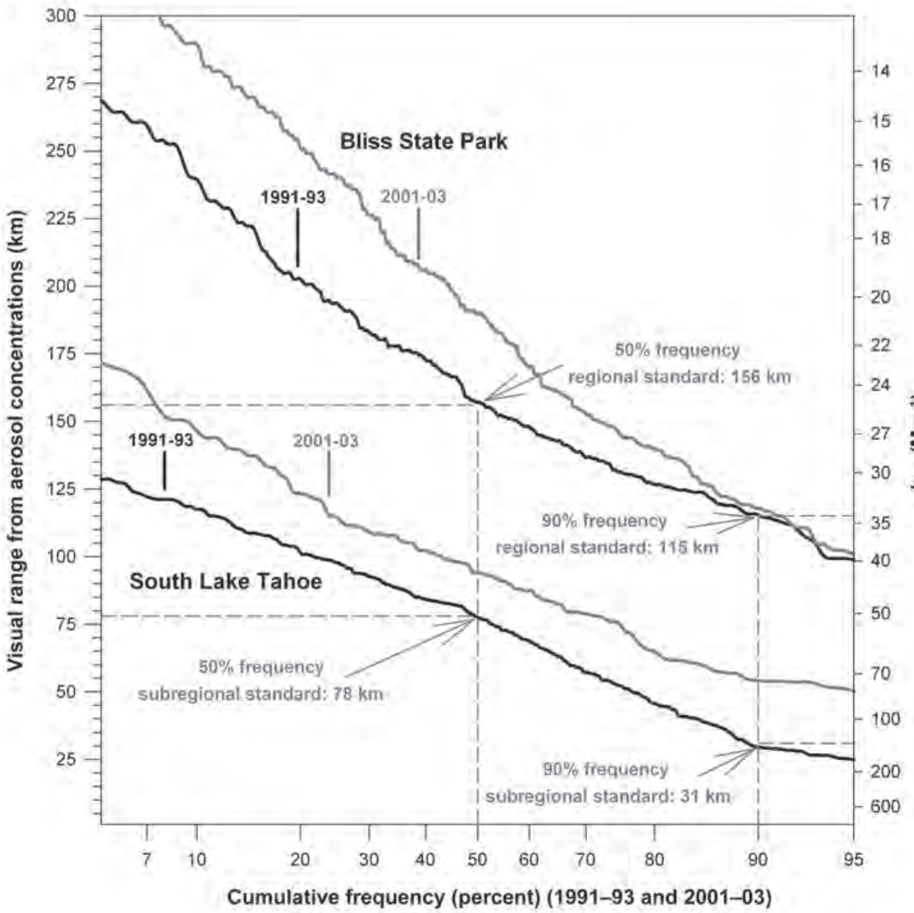

Figure 3.5—Tahoe Regional Planning Agency visibility standards: cumulative frequency plots of reconstructed extinction for 1991–93 (baseline year) and 2001–03 (from TRPA 2005).

Table 3.4—2006 proposed Tahoe Regional Planning Agency visual air quality environment threshold carrying capacities, 2001–03 baseline

Area	Visibility threshold
Regional visibility	Achieve a visual range of 188 km (b_{ext} = 20.8 Mm^{-1}) at least 50 percent of the year as measured by particulate concentrations
	Achieve a visual range of 116 km (b_{ext} = 33.7 Mm^{-1}) at least 90 percent of the year as measured by articulate concentrations
Subregional visibility	Achieve a visual range of 93 km (b_{ext} = 42.1 Mm^{-1}) at least 50 percent of the year as measured by particulate concentrations
	Achieve a visual range of 55 km (b_{ext} = 71.1 Mm^{-1}) at least 90 percent of the year as measured by particulate concentrations

Scott Hinton

Exhaust plume from a diesel truck located on a side road off of Highway 89, near Meyers, California.

Currently there are a number of concerns regarding visibility monitoring in the Lake Tahoe basin. The Bliss State Park site has been in continuous operation since 1990. Its operation and maintenance are currently funded by the US EPA as part of the IMPROVE monitoring network; however, funding and continued operation are uncertain. The South Lake Tahoe visual air quality monitoring station is now permanently shut down owing to loss of the property lease. This site was only 100 m west of the earlier South Lake Tahoe location; thus data from the site are deemed appropriate for use in the TRPA Subregional Visual Air Quality standard calculations. There was no available location near the two past monitoring sites that would allow direct continuation of the subregional speciated aerosol monitoring record. A new monitoring site has been installed in South Lake Tahoe. However, it is quite a distance from Highway 50 and the old monitoring sites. No overlapping time series exists, so comparisons among the sites are not possible.

Knowledge Gaps

- Visibility measurement locations are limited in the Lake Tahoe basin compromising the ability to accurately estimate regional and subregional visibility.
- Standards have been adopted requiring percentage reductions in emissions, but the link between changes in these sources and the effects on visibility are unclear.

Research Needs

- Expand the spatial distribution of the visibility monitoring network to include locations in addition to Bliss and South Lake Tahoe is recommended.
- Address the current lack of measurements related to the subregional standard.
- Quantify the contribution of wood smoke and other sources in the basin.

Air Pollutant Emission Inventories

Optimally, emission inventories (EIs) describe the magnitude, along with when and where various pollutants are emitted in a regional domain. Because emissions are generated from numerous intermittent sources (e.g., fireplaces, disturbed land, vehicles, and commercial businesses), assembling a comprehensive emission inventory would include the use of careful assumptions, which result in a product that will achieve the necessary objectives. Uses of EIs include:

- **Planning**—As populations and activities change within a region, it is useful to know how this will affect emissions and ultimately atmospheric concentrations.
- **Mitigation**—Knowing the sources and magnitudes of pollutants allows for the design of cost-effective control measures that will reduce atmospheric concentrations.
- **Simulation**—EIs are used as inputs to air pollution dispersion models to simulate the impacts of sources on atmospheric concentrations within the modeling domain.
- **Monitoring**—Tracking changes in emissions is useful for interpreting other long-term time series such as lake sediments and atmospheric concentration records. Correlations between emission records and these time series provide strong empirical evidence to relate sources to the observed levels of pollutants in the air and lake sediments.

Because ambient concentrations of aerosols within the Lake Tahoe basin are below the National Ambient Air Quality standards, the primary objective of a Tahoe-specific EI is to focus mitigating efforts to protect human health and improve lake water clarity.

A preliminary EI was assembled for Lake Tahoe as part of the CARB LTADS (Kuhns et al. 2004). In this study, local emission factors for road dust, vehicle exhaust, and residential wood combustion were measured in the basin. Wood-burning activity data were collected via a survey of local residents (Fitz and Lents 2003). Vehicle exhaust emissions were derived from an estimate of the number of gallons of gasoline and diesel sold in the basin. Road dust was estimated from Department of Transportation published data of vehicle miles traveled. These data were supplemented with CARB county-level emission inventories and extrapolated to the portions of the Nevada counties that fell within the Tahoe basin. Emissions from wild and prescribed fires were not included in the EI owing to a lack of information on the quantity of fuel burned throughout the year. Table 3.5 shows the estimates of a variety of air pollutants that culminated from that study.

Note that many of these sources are estimated with the goal of building a comprehensive California EI. As a result, some sources such as farming operations and unpaved road dust were estimated by scaling measurements collected in other counties to the Tahoe basin based on population or land area. These assumptions are unlikely to introduce a large error on the total statewide emissions; however, they are likely to be inappropriate for the specific needs of the Tahoe basin.

Courtesy of Tahoe Regional Planning Agency

Airborne dust created during bike trail sweeping near Tahoe Pines, California.

Table 3.5—Emission inventory results for the Tahoe basin[a]

Source	TOG	ROG	CO	NO_x	PM	PM_{10}	$PM_{2.5}$
				Megagrams per year			
Natural (nonanthropogenic) sources	0	0	30	0	5	5	5
On-road mobile sources[b]	1,019	935	2,489	148	7	7	4
Aircraft	112	99	998	73	34	30	30
Recreational boats	344	318	2,500	103	22	17	13
Off-road recreational vehicles	547	503	1,751	34	0	0	0
Off-road equipment	241	219	1,777	602	43	43	39
Fuel storage and handling	56	56					
Residential wood combustion and campfires[b]	570	251	6,400	187	726	680	653
Farming operations	392	30			60	26	4
Construction and demolition				366	176	39	
Paved road dust[b]				628	287	48	
Unpaved road dust				1,138	679	145	
Fugitive windblown dust				17	9	4	
Waste burning and disposal	202	90	1,162	30	133	129	120
Cooking	4	4			17	13	9
Solvent evaporation	422	387					
Stationary sources	413	254	43	82	9	4	4
Total	4,321	3,148	17,151	1,260	3,206	2,105	1,118

Definitions of emissions are as follows:

TOG = total organic gases, ROG = reactive organic grasses, CO = carbon monoxide, NO_x = nitrogen oxide, PM = particulate matter, PM_{10} = particles less than 10 micrometers in diameter, $PM_{2.5}$ = particles less than 2.5 micrometers in diameter.

[a] Emissions were estimated by scaling the California Air Resources Board Tahoe Air basin emissions with a multiplier based on land area, population, or vehicle kilometers traveled.

[b] Sources measured as part of the Lake Tahoe Atmospheric Deposition Study.

The Desert Research Institute recently completed a year-round monitoring program in the Lake Tahoe basin to measure the emissions of PM from roadways. The results of this study were integrated into a model to estimate emission factors based on the existence of emissions controls as well as meteorological and seasonal data for all road types in the Lake Tahoe basin. In addition, the study examined the effectiveness of emissions controls (i.e., sweeping, stormwater diversion systems, paved shoulders, and track-out prevention) for reducing particulate emissions (Kuhns et al. 2007).

A new project to improve these estimates and allocate them spatially within the basin has been approved for funding via the US EPA Region IX with funding from the Southern Nevada Public Lands Management Act. This study has recently been completed and will provide a detailed emissions inventory for the criteria pollutants and other key species (e.g., NH_3). Based on this inventory, the major contributors to ambient pollutants are as follows:

- CO: Mobile sources and residential fuel combustion. There is a strong seasonal dependence in the residential fuel combustion source.
- PM_{10}, $PM_{2.5}$, P, and phosphate (PO_4): Areawide sources, particularly residential fuel combustion and road dust resuspension. Emissions are significantly higher during the winter. Use of the road sediment data obtained with the DRI TRAKER (an instrumented vehicle developed to quantify silt loading on roads) significantly reduced the estimated resuspended road dust contribution when compared with the previous inventory.
- NO_x and NH_3: Mobile sources are the dominant contributor.
- VOCs: Mobile sources, biogenic sources, and areawide sources all contribute to VOC emission. There is a strong seasonal dependence in the biogenic and areawide source contributions

Knowledge Gaps

Linking air pollutant emissions to endpoints of interest (e.g., lake water clarity, or impacts to human or ecosystem health), creates some unique requirements for a Tahoe-specific EI. To develop cost-effective mitigating strategies that will improve water clarity, the following topics not generally included in EIs are recommended:

- The EI should account for the major species that are impacting the lake, specifically crustal particulates, N and P.
- Evaluation of the uncertainty and measurement of the size and composition of the particulates emitted from different sources.
- Accounting for emissions from events such as wildfires and prescribed burns, which can contribute to pollutant emissions.
- Addressing the lack of knowledge regarding the impact of wet deposition and scavenging by vegetation that may ultimately contribute to pollutant runoff into the lake.
- Knowing what N and organic species are emitted locally and what are transported into the basin in order to accurately simulate the fate and transport of N in the basin.

Research Needs

- It is recommended that emissions be geo-referenced to their specific sources (i.e., roads, erodible hillsides, beaches, residences, and fire sites). Additional work on the emissions inventory may be necessary to evaluate the contributions from out-of-basin sources.