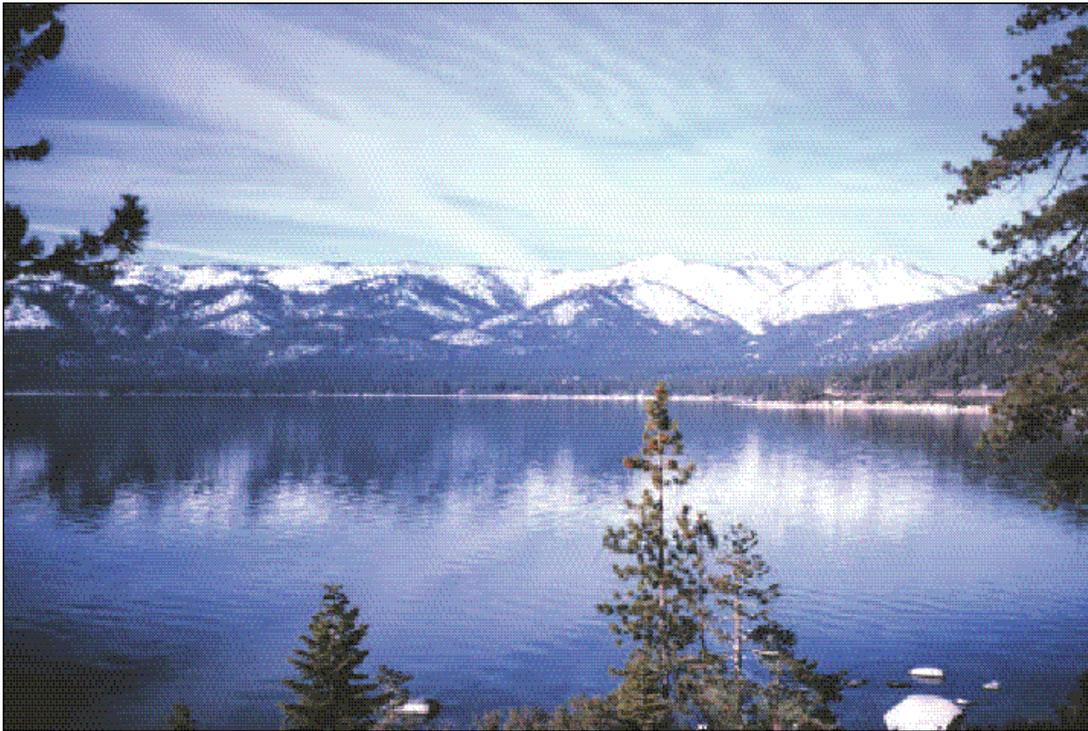


# **THE LAKE TAHOE AIR QUALITY RESEARCH SCOPING DOCUMENT:**

## ***DETERMINING THE LINK BETWEEN WATER QUALITY, AIR QUALITY AND TRANSPORTATION***



Photograph by Timothy G. Rowe, U.S. Geological Survey.

**A COOPERATIVE RESEARCH PROPOSAL BY THE TAHOE REGIONAL PLANNING AGENCY AND THE  
UNIVERSITY OF CALIFORNIA, DAVIS  
JULY, 2000**

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*DETERMINING THE LINK BETWEEN WATER QUALITY, AIR QUALITY  
AND TRANSPORTATION***

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**TABLE OF CONTENTS**

**EXECUTIVE SUMMARY ..... 7**

**1.0 INTRODUCTION ..... 8**

**1.1 The Lake Tahoe Area ..... 8**

**1.2 The Tahoe Regional Planning Agency Air Quality Scoping Document ..... 8**

**2.0 BACKGROUND ..... 11**

**2.1 The Lake Tahoe Basin Planning Area ..... 11**

Public and Private Lands ..... 11

The Tahoe Basin ..... 12

Humans and Lake Tahoe ..... 12

Terrestrial and Aquatic Impacts ..... 12

Airborne Lake Contaminants ..... 13

**2.2 Historical Development of Efforts to Protect Lake Tahoe ..... 14**

Lake Tahoe Basin Management Unit ..... 15

The Tahoe Regional Planning Agency (TRPA) ..... 16

Threshold Evaluations ..... 16

The 1987 Regional Plan ..... 17

Tahoe Environmental Improvement Program (EIP) ..... 18

1997 Presidential Forum ..... 18

Forest Health Consensus Group ..... 19

Transportation Measures ..... 20

**2.3 The 2007 Regional Plan and Beyond ..... 21**

**2.4 Physical Setting ..... 22**

Air Quality at Lake Tahoe ..... 23

Water Quality at Lake Tahoe ..... 24

Visibility at Lake Tahoe ..... 25

**2.5 Pollutant Transport and Deposition ..... 26**

**2.6 Current Understanding of Atmospheric Parameters at Lake Tahoe ..... 29**

**2.7 Nutrient Deposition to Lake Tahoe ..... 29**

Contribution of nitrogenous compounds to Lake Tahoe eutrophication ..... 30

Contribution of phosphorus compounds to Lake Tahoe eutrophication ..... 32

Contribution of fine insoluble particles to Lake Tahoe eutrophication ..... 32

Summary of atmospheric processes at Lake Tahoe ..... 33

**3.0 DEVELOPING AIR QUALITY PROCESS LINKAGES FOR MANAGEMENT**

**USE 34**

[The Need for Models](#)..... 34  
[Models and Adaptive Management](#)..... 34  
[Models for Adaptive Air Quality Management](#) ..... 35

**3.1 The Framework Model**..... 36

**3.2 Mechanistic Air Quality Modeling**..... 38

[Emission Modeling](#)..... 38  
     [Transportation](#)..... 38  
     [Residential Wood Combustion](#)..... 39  
     [Wild and Prescribed Fire](#)..... 39  
[Meteorological Modeling](#)..... 39  
[Air Quality Modeling](#)..... 40  
[Advantages of Mechanistic Air Quality Models](#)..... 41

**4.0 GENERALIZED AIR QUALITY WORK PLAN** ..... 44

**4.1 Research and Monitoring Needs** ..... 44

[Spatial and Temporal Identification of Ambient Atmospheric Constituents](#)..... 46  
     [Nitrogen \(N\)](#)..... 47  
     [Fine particles](#)..... 47  
     [Other atmospheric species needed for quality assurance](#) ..... 48  
[Sampling Locations](#)..... 50  
[Atmospheric Experiments](#)..... 53  
[Enhanced Basin and Upwind Meteorology](#)..... 55  
[Temperature and Pressure Effects on Atmospheric Processes](#)..... 55  
[Transportation Needs With Respect to Air Quality](#) ..... 56  
     [Socio-economic and demographic characteristics](#)..... 57  
     [Traffic composition data](#)..... 57  
     [Road surface conditions](#)..... 57  
     [Specific Transportation Needs for Linkage to Air and Water Quality](#)..... 57  
[Institutional Coordination](#)..... 58  
     [Sampling sites](#)..... 59  
     [Wildfire and prescribed fire monitoring](#)..... 59  
     [Transportation data](#)..... 59

**4.2 Summary and Cost Estimate**..... 59

**5.0 TRANSPORTATION**..... 61

**5.1 Transportation System Trends**..... 62

[Exhaust Emissions From Vehicle Tailpipes](#)..... 68

<a href="#">Nitrogen Compounds</a> .....	68
<a href="#">Ozone</a> .....	69
<a href="#">Carbon Monoxide</a> .....	69
<b>5.2    <a href="#">Transportation Modeling</a>.....</b>	<b>70</b>
<a href="#">Transportation Conformity</a> .....	70
<a href="#">TRPA Transportation Modeling History</a> .....	71
<a href="#">Issues of Current Transportation Modeling at Lake Tahoe</a> .....	72
<a href="#">Road Dust From Traffic</a> .....	74
<a href="#">Transportation-Related Pollutant Control Measures</a> .....	74
<a href="#">Transportation Model: Long-term Efforts</a> .....	80
<a href="#">Coordination of Transportation and Air Quality Models</a> .....	81
<a href="#">Transportation Model: Long-term Efforts</a> .....	84
<a href="#">Resident Trip Chaining Model</a> .....	85
<a href="#">Visitor/Recreational Tour Model</a> .....	87
<b><a href="#">REFERENCES</a>.....</b>	<b>89</b>

**Tables**

[Table 1. Generalized work plan summary for Lake Tahoe air quality research.](#)..... 10

[Table 2. 1996 Estimated Annual Average Emissions for the Lake Tahoe Basin \(Tons/day\)](#)  
..... 24

[Table 3. Understanding of Atmospheric Parameters at Lake Tahoe.](#) ..... 29

[Table 4. Atmospheric Nitrates at Lake Tahoe.](#)..... 31

[Table 5. Atmospheric Sources with and Transport to the Lake Tahoe Basin.](#)..... 33

[Table 6. Important atmospheric species in the Lake Tahoe Basin.](#) ..... 50

[Table 7. Proposed research sites and sampler configuration.](#)..... 53

[Table 8. Estimated annualized cost breakdown for air quality research for the Tahoe Basin.](#)  
..... 60

[Table 9. Base Year Trip Purpose VMT, Trips, and Miles](#)..... 65

[Table 10. Trip Purposes in the TRPA Transportation Model](#)..... 71

[Table 11. 1995 Socio-Economic Data Sources\\*](#)..... 72

**Figures**

[Figure 1. Milestone timeline for implementation of 2007 Regional Plan for the Lake Tahoe Basin.](#) ..... 21

[Figure 2. Schematic Air Model \(including processes and pollutants\) for the Lake Tahoe Air Basin.](#) ..... 28

[Figure 3. Subregional Framework: Model Linkages](#) ..... 37

[Figure 4. Area Covered by the Lake Tahoe Airshed Model \(LTAM\).](#)..... 42

[Figure 5. Current and proposed atmospheric sampling and monitoring sites in the Lake Tahoe Basin.](#) ..... 52

[Figure 6. Total predicted residential growth for 2001,2006, and 2016](#) ..... 63

[Figure 7. Number of trips of 1995 and 2016](#) ..... 64

[Figure 8. Traffic Volumes \(ground counts\)](#) ..... 64

[Figure 9. Year1995/2016 VMT](#) ..... 65

[Figure 10. VMT Threshold Performance Measurement Model](#) ..... 67

[Figure 11. Transportation System Performance Model](#) ..... 79

[Figure 12. Integrated Transportation and Air Quality Model](#)..... 83

[Figure 13. Resident Tour Model: \(A\) Activity Model, \(B\) WRT Model, \(C\) NWRT Model](#)  
..... 86

[Figure 14. Recreational Tour Model: \(A\) Activity Model, \(B\) Tour Model.](#)..... 88

## **Executive Summary**

The federally chartered Bi-state Compact mandates that Tahoe Regional Planning Agency (TRPA) protect Lake Tahoe's environment, especially the lake's famed water clarity, by adopting planning standards and setting environmental carrying capacity thresholds. The current standards and thresholds as adopted in the 1987 Regional Plan, have reduced environmental degradation in the Lake Tahoe Basin, but have not fully halted the progressive loss of lake clarity. If current lake water quality trends are not reversed in the near future permanent degradation of water quality will result. TRPA is required to adopt a new 20-year Regional Plan in 2007. This report outlines research needed to provide a sound scientific basis for developing new policies for inclusion in the 2007 plan to reverse the unacceptable loss of lake clarity.

Data collected in recent years suggest that deposition of bio-available airborne nitrogen, phosphorous, and insoluble fine particles contribute much of the clarity degradation, with the remainder being due to pollutants transported to the lake via surface and ground water. The proposed research is needed to progress from the present qualitative understanding of the effects of air pollutants on Lake Tahoe to a quantitative assessment of the contributions of individual sources and calculations of the potential benefits of various regulatory alternatives. Air pollutant sources that need to be studied include fires, road dust, vehicle exhaust, and residential heating emissions originating in the Basin, and the whole spectrum of emissions from upwind population centers. Effective and cost efficient control programs cannot be developed until this quantitative assessment is completed.

This Scoping Document, prepared in consultation with experts in water quality, air quality, and transportation analysis, proposes a plan to quantify the linkages between traffic, air pollutants and lake water clarity. The plan builds on the foundation of past research with a focused program of water and air quality measurement leading to development of predictive tools suitable to evaluate potential strategies to reverse the air deposition effects on lake clarity.

Loss of lake clarity is driven by complex interactions of human activity with natural processes in air, water, and soil. This problem cannot be addressed piecemeal; research on this problem needs to address the effects of both local and distant pollution sources, and to integrate atmospheric and aquatic processes. Completion of all elements in the recommended study is necessary to provide a sound scientific basis to select cost-effective measures to protect lake clarity. Without this integrated research, there exists a significant risk of both ineffective controls and unnecessary negative social and fiscal impacts through misdirected policies. With the 2007 planning cycle in mind, a scientific structure for new Basin threshold recommendations will be in place by 2003 as a preliminary result of the proposed work. The recommended program of research is designed to be fully completed in five years.

Estimated Annual Cost = \$800,000

## **1.0 Introduction**

### **1.1 The Lake Tahoe Area**

The Tahoe Region is defined by the area within the Lake Tahoe Basin and a portion of the Truckee River corridor between Tahoe City and Alpine Meadows. The Region lies between two mountain ranges, the Carson Range on the east, and the Sierra Nevada on the west and the California-Nevada state line bisects the Region. Approximately one-third of this Region is located within Nevada and two-thirds within California. On the California side, the Region includes portions of El Dorado, and Placer Counties. On the Nevada side, portions of Carson City, Douglas and Washoe Counties are within the Region's boundaries. The total land area within the Region is approximately 207,430 acres with more than 85 percent publicly owned.

Lake Tahoe is the predominant feature of the Basin and contains about 40 percent of the Region's total surface area. Lake Tahoe is approximately 12 miles wide and 22 miles long, with a shoreline of about 71 miles. The Lake's elevation varies with a maximum elevation of approximately 6,229 feet above sea level. A dam at Tahoe City, California, at the Lake's only outlet, the Truckee River, controls the level of the Lake. The Lake's maximum depth is 1,645 feet with an average depth of 1,027 feet.

The topography of the Region consists chiefly of steeply sloping mountains with a few flat or moderately sloping landforms where most development has occurred. Peaks surrounding the Region range from a low of 8,000 feet above sea level to 10,881 feet at Freel Peak. The mountains around the Region form a bowl shape with Lake Tahoe occupying the bottom in the center of the bowl.

The unique combination of topography and scenic recreational opportunities presents a challenge for planners in the Lake Tahoe Basin. A number of potential management strategies must be evaluated with adequate knowledge of ecological processes and process linkages. Development of research and monitoring protocols is essential to gain understanding about the interactions among the various Basin processes. An outline of the protocols to be developed for air quality and transportation follows.

### **1.2 The Tahoe Regional Planning Agency Air Quality Scoping Document**

This document, the Tahoe Regional Planning Agency (TRPA) Air Quality Scoping Document, was commissioned to outline the research necessary to provide sound scientific basis for future air quality thresholds in the Lake Tahoe Basin. A new Regional Plan will be established in 2007, and air quality thresholds will feature prominently among those monitored for this new plan.

Recent limnological studies of the Lake Tahoe Region indicate a significant air quality related impact to the continued ecological decline of the Lake and surrounding watershed. However, gaps in understanding of atmospheric parameters necessary to establish linkages between air quality and Basin impacts exist. Inadequate knowledge of these linkages hampers the ability to effectively manage the Lake Tahoe Basin. Therefore, a focused air quality research program is

necessary to provide adequate understanding of Basin linkages for management decisions. Table 1 is an outline of the research proposed in this document.

The incorporated study completed as a result of this document must include all aspects of this proposed work in conjunction with ongoing water quality related research. No longer effective is a single medium research program that neglects any aspect of the system in the Tahoe Basin. Lake water quality/clarity, atmospheric visibility, human health, forest health, and socioeconomic impacts must all be addressed for restorative management of the Basin to be successful. Following this introduction a background including historical perspective, physical setting, and known processes is given in Chapter 2. Chapter 3 outlines the conceptual model framework that will be developed as part of the proposed work. Chapter 4 is a generalized work plan describing the air quality research necessary to increase our understanding of atmospheric parameters for the development of the conceptual model, and Chapter 5 is a description of transportation related issues in the Tahoe Basin including methods for evaluation of current thresholds and future work necessary to establish an extensive transportation model for Lake Tahoe.

**Table 1. Generalized work plan summary for Lake Tahoe air quality research.**

Suggested work is broken down into 6 components:

- 1) Spatial and temporal identification of ambient atmospheric constituents (size segregated aerosols, continuous sampling with no longer than 4-hour integration, Basin-wide representation).
  - a. Constituents for lake clarity
    - i. Particulate P (bio-available phosphate, etc.), particulate N (bio-available nitrate, ammonium, etc.),  $\text{HNO}_3$  (nitric acid),  $\text{HN}_3$  (ammonia),  $\text{NO}_x$  (nitrogen oxides), fine particles.
  - b. Constituents for forest and human health
    - i. CO (carbon monoxide),  $\text{O}_3$  (ozone),  $\text{NO}_x$ ,  $\text{PM}_{10}$  mass,  $\text{PM}_{2.5}$  mass.
  - c. Constituents for database (flux calculation, measurement QA, and mass closure).
    - i. Aerosols: Organic (total carbon, speciation, biogenic/combustion sources), hydrogen content (organic surrogate), All soil elements (Fe, Al, Si, Ca, K, etc.), Urban/industrial tracer elements (Se, Pb, As, etc.), ions ( $\text{Cl}^-$ ,  $\text{Na}^+$ , sulfate, etc.), halocarbons, isotopic tracers.
    - ii. Gases:  $\text{SO}_x$  and  $\text{NO}_x$  oxidation mechanisms (isotopic tracers for source characterization).
- 2) Establishment of new and upgrading of existing air quality measurement sites.
  - a. Co-located deposition and air samplers.
  - b. Portable sample sites for event characterization (prescribed/wild fires, etc.).
  - c. Additional sites for intensive studies from #1 (lake surface, urban footprint, aloft, etc.).
  - d. Supplemental measurements at existing monitoring sites (ARB, TRPA, NDEP, etc.) for intensive studies from #1.
- 3) Research experiments to address specific atmospheric processes at Tahoe.
  - a. Determine the relative contribution of in-Basin versus out-of Basin pollutant sources at Lake Tahoe.
  - b. Intra-Basin pollutant transport and deposition (spatial and temporal patterns).
  - c. Urban pollutant concentration area of influence.
  - d. Vertical pollutant distribution and timing of lake contact.
  - e. Deposition of pollutants to the lake and forest (and subsequently forest to lake).
- 4) Enhanced meteorological measurements to characterize Basin and upwind met.
  - a. Surface met (wind speed/direction, solar radiance, precipitation, temperature, pressure) at each site.
  - b. Enhance Basin met (acoustic sounder for inversion height).
  - c. Upwind radar profiling (characterize upwind airflow).
  - d. Link to regional meteorological measurements/weather models.
- 5) Temperature and pressure-related source and transformation research.
  - a. Gasoline and diesel emissions (altitude, winter driving cycles).
  - b. Urban emissions (domestic appliances especially wood heaters, food prep., etc.).
  - c. Atmospheric reactions ( $\text{O}_3$  chemistry, nitric acid formation, hydrocarbon oxidation, nitrate formation, etc.).
- 6) Transportation research with respect to air and water quality.
  - a. Vehicle fleet data (type, size, age, emissions category)
  - b. Roadside dust re-entrainment (particulate size, transport to lake, bio-available P and N dust composition,
  - c. Socio-economic and demographic characteristics (transportation demand, economics, under-served populations).
  - d. Traffic composition data (location, time of day, trip length, idle time, speed, vehicle mix)
  - e. Road surface conditions (paved/unpaved, sanded, surface condition, wet/dry).

## **2.0 Background**

### **2.1 The Lake Tahoe Basin Planning Area**

The Lake Tahoe planning Region includes the area within the Lake Tahoe Basin and the portion of the Truckee River corridor from Tahoe City northwest to Alpine Meadows. It lies between two mountain ranges, the Carson Range on the east, and the Sierra Nevada on the west and is bisected by the California-Nevada state line. Approximately one-third of the Region is located within Nevada, including portions of Carson City, Douglas and Washoe Counties, and the remainder is in California, including portions of El Dorado and Placer Counties. The planning area covers about 325 square miles, of which Lake Tahoe itself represents about 40 percent (192 square miles). Lake Tahoe is approximately 12 miles wide and 22 miles long, with a shoreline of about 71 miles. The Lake's surface elevation varies between 6,223 and 6,229 feet above sea level, under control of a dam on the Truckee River at Tahoe City, California. The Lake's maximum depth is 1,645 feet with an average depth of 1,027 feet.

#### ***Public and Private Lands***

The land use patterns in the Tahoe Basin are firmly established, and under current restrictions, there is little likelihood of major change. About 84 percent of the Basin land is in public ownership; 77 percent in National Forest and 7 is state lands. The remaining 16 percent is in private ownership. Development is predominantly in the areas adjacent to Lake Tahoe and in the wide, gently sloping valleys in the south end of the Basin. There are roughly 25 developed towns and communities in the Tahoe Region, including major population centers in Incline Village, Kings Beach, Tahoe City, Tahoma, and the South Lake Tahoe/Meyers area. The gaming areas are located at the north and south Stateline areas, along with a casino in the Incline Village commercial area. These areas provide tourist accommodations, commercial facilities, and indoor entertainment and recreational facilities (USGS, 1998).

The undeveloped areas of the Tahoe Region are predominantly publicly owned. The United States Forest Service (USFS) manages the bulk of the public land in the Basin, but not all. Scattered along the west shore, California State Park units in the Basin include Emerald Bay, D.L. Bliss, Sugar Pine Point, Ward Creek, and Burton Creek State Parks as well as Lake Tahoe State Recreation Area. Nevada State Parks holdings are concentrated on the northeast shore where Lake Tahoe State Park stretches from Sand Harbor, near Incline Village to Spooner Lake just north of U.S. Highway 50. California and Nevada counties, the City of South Lake Tahoe, and the Basin's public utility and improvement districts also manage and own park facilities. Public ownership of land is slowly increasing due to USFS purchases the Burton-Santini Act, while both California and Nevada have State acquisition programs as well.

The renowned clarity of Lake Tahoe is a result of the climate, topography, and geochemistry of the Tahoe drainage Basin. Unfortunately, the same characteristics that make the Basin attractive to residents and visitors also make it very sensitive to the pollutants generated by human activity. The following sections provides a brief review of the elements of the Tahoe Basin environment that influence lake clarity and mediate the potential for anthropogenic impacts on lake water quality.

## ***The Tahoe Basin***

The Tahoe Basin was formed as the Sierra crest on the west and the Carson crest on the east were pulled apart during the regional uplift of the Sierra, dropping a vee-shaped block of land between. Subsequent eruption of the Mt Pluto volcano dammed the valley on the north end of the depression, forming Lake Tahoe. The Truckee River runs from its headwaters near Carson Pass, about 15 miles south of Lake Tahoe, northward through the Tahoe Basin, then drains through a canyon west and north from Tahoe City, between the Sierra crest and Mt. Pluto. Lake level has dropped about 800 feet as the modern Truckee River has cut its present canyon. Glacial moraines and ancient delta deposits form terraces on the basin walls that mark the ancestral high-stands of the lake. The structural origin of Tahoe Basin makes the lake very deep compared to its surface area and the drainage area around it, so that lake water replacement at present inflow would take about 700 years. For this reason, changes in water quality induced by relatively short-term events, of either natural or human causes, are essentially permanent alterations.

During the past million years or so, cycles of glaciation followed by warming periods created the Basin's spectacular landforms (Sierra crest, Fallen Leaf Lake, Emerald Bay, etc.). This glaciation stripped the Sierra crest of overlying volcanic rocks, leaving the bare granite features visible today. As the glacial epoch waned, stream flow in the Basin was much higher than at present, depositing large volumes of sediment as deltas where streams meet the lake. Under modern conditions, these deltas, especially that of the Upper Truckee, became wetlands (meadows) with slow-moving braided drainage channels and dense vegetation of grasses and willows.

The clarity of Lake Tahoe is in part a consequence of the Basin's glacial history (the most recent glacial epoch ended only about 20,000 years ago). Much of the Sierra crest is now bare granite, and at lower elevations only thin, poorly developed soils have formed since the end of glaciation. The minimal weathering of the recently glaciated surfaces and young moraine deposits yields only a small output of nutrients into the Basin's ground and surface waters, and these nutrients are dissolved in the enormous water volume of the Sierra snow pack. Coupled with the filtering effects of the wetlands, which removed sediment and nutrients before they could enter the lake, these conditions kept Lake Tahoe's natural particle and nutrient levels very low, suppressing growth of algae and plankton that cause turbidity. This results in the lake's unusual clarity, but it also makes the lake very sensitive to increased inputs of sediment and nutrients.

## ***Humans and Lake Tahoe***

The human presence in the Tahoe Basin both alters natural processes and introduces new sources of sediment and nutrients that can threaten lake clarity.

### **Terrestrial and Aquatic Impacts**

Prior to 1950, activities in the Basin primarily acted to accelerate natural sediment and nutrient transport. Logging, road building, clearing for summer homes, etc. accelerated natural transport of nutrients to the lake by disturbing soil and disrupting natural nutrient storage in soil and

vegetation. Downslope from disturbed areas, enhanced runoff can strip soil or erode streambeds, further accelerating transport to the lake.

The rapid settlement of the Basin over the last four decades has added two new dimensions to the problem of accelerated nutrient release. The first is intentional alteration of natural drainages: “reclamation” of wetlands and meadows or channelization of streams disrupts the natural filtering and nutrient capture processes, allowing these materials to flow directly to the lake. The second is the enhanced runoff created by permanent clearings, paved surfaces, and buildings.

New sources of sediment and nutrients have also accompanied the post-World War II boom. Most obvious are new terrestrial and aquatic nutrient and sediment sources, including sewage, fertilizers and imported soil materials (e.g. sand applied to roads in winter). An additional poorly quantified source of sediment is accelerated lake shoreline erosion due to sustained high lake levels impounded by the dam at Tahoe City.

### Airborne Lake Contaminants

Less obvious, but no less significant, are the “modern” sources of airborne fine particles and nutrients that can be deposited directly to the lake, or that can fall on land and be carried by surface waters to the lake. These “modern” sources include both pollutants from sources within the Basin and those carried by wind from upwind urban and agricultural areas. These airborne sources are the focus of the research plan developed in this document.

Airborne inputs to Lake Tahoe come from three groups of sources. Populated areas in the Basin generate airborne anthropogenic materials such as road dust, vehicle exhaust, chimney smoke, etc. Undeveloped areas in the Basin may also produce airborne dust and smoke, some of which is “natural”, and some which is due to the direct and indirect effects of land management practices (prescribed fires, road work, etc.). Finally, airborne materials generated in upwind areas, including the San Francisco Bay area and the Central Valley are carried into the Sierra by the Region’s prevailing winds.

Airborne materials are unusually important in the Tahoe Basin because the topography is well suited to trapping air near the lake surface. In summer, the cold lake, coupled with downslope air drainage, causes a nighttime accumulation of a shallow, stable layer of air over the lake; this layer usually dissipates by midday due to solar heating. In winter, the longer nights make the downslope air drainage much stronger, so that even though the lake may be warmer than the overlying air, the inversion is still very persistent. This nocturnal lake inversion is present most days of the year, often made visible by the smoke that accumulates in it near populated areas. The effect of the combination of downslope drainage winds and the lake inversion is to hold air pollutants in close contact with the lake surface much of the time, thus the potential for airborne impacts on lake water quality are amplified by the effects of terrain.

The impact of the atmosphere on water quality is one of the least understood aspects of air quality in the Basin. Establishing the magnitude of the nutrient impacts (actual contribution of bio-available phosphorus (P) and nitrogen (N) to lake water) of each of the major source groups (urban, wildland, and out-of-Basin) is the first order of business in resolving the airborne impacts to Lake Tahoe. Within each group, the source-specific unraveling of effects is needed in order to

predict future impact levels. Finally, for sources subject to TRPA regulations or thresholds, impact levels need to be predicted under various potential policy frameworks.

## **2.2 Historical Development of Efforts to Protect Lake Tahoe**

Archeological evidence indicates that humans have lived in and around the Tahoe Basin for at least the last 8000 years. The Washoe Indians first occupied the Region approximately 1300 years ago. It is generally accepted that these peoples set fires and otherwise altered the Basin's ecosystems, but there is no evidence that humans had any significant impact on lake clarity until the latter part of the 19<sup>th</sup> century.

The discovery of the Comstock Lode and the resulting silver boom around Virginia City, just a few miles east of Lake Tahoe, led to the first large human impacts on Lake Tahoe. From 1870 to the mid 1890s, the demand for shoring timbers and fuel drove intensive logging in the Tahoe Basin. Virtually all accessible stands of large trees were logged during this period (D.L. Bliss' Carson and Tahoe Lumber and Fluming Co. is reputed to have cut 750 million board feet of lumber and 500,000 cords of wood in a period of 28 years). While there are no records of lake clarity during the Comstock period, it seems likely that logging had a large impact on surface water quality, both as a source of sediment and through release of nutrients. Likewise, cessation of logging and onset of new forest growth probably progressively reduced the effects on water quality over ensuing decades.

After the wane of the Comstock boom, most logging ceased, and activity at the lake focused on tourism, primarily in summer. Tourism grew slowly during the first half of the 20<sup>th</sup> century, accompanied by the development of a modest permanent population, and expansion of summer home developments.

From the Comstock period on, fire was viewed as a threat to the forest resources of the Tahoe Basin. Population growth through the 20<sup>th</sup> century was paralleled by increasing fire protection, reaching a very high degree by the 1980s. This protection served not only to promote forest growth, but also to unintentionally modify the structure of Tahoe's forests. Two major effects of fire suppression are the elimination of small groundfires that would otherwise consume needle litter and suppress understory growth (including ferns, broadleaf shrubs, and certain tree seedlings), and general accumulation of excess ground fuels that provide the fuel ladder needed for a ground fire to progress to a tree-killing crown fire. Among the consequences of these changes were changes in relative populations of conifer species, development of a denser tree cover, which reduced forest resistance to drought and promoted spread of pests (such as pine bark beetles), and increased risk of stand-clearing fires. The role of fire in the transport of nutrients to the lake is unclear, but there is anecdotal evidence to suggest that fire management strategies may influence lake nutrient inputs, as well.

In 1913, the U.S. Bureau of Reclamation completed Tahoe Dam. The dam was built as part of the Newlands Project (irrigating the Lahontan Basin near Fallon, Nevada.). Tahoe dam allows storage of up to 732,000 acre-ft. of water in Lake Tahoe by raising the lake 6 feet. It has historically been operated by Truckee-Carson Irrigation District under direction of a Federal water master responsible for allocating water for irrigation, power production, municipal, and domestic use among various downstream users along the Truckee River in both California and

Nevada. The 1990 Truckee-Carson Settlement Act mandated resolution of conflicts among these users, resulting in the Truckee River Operating Agreement (TROA). The Bureau of Reclamation took over operation of Tahoe Dam on February 1, 2000, in order to implement these agreements.

Although not fully evaluated, there is evidence that shoreline erosion due to elevated lake levels may be introducing both sediment and nutrients into Lake Tahoe. The Tahoe Dam cannot be operated solely for the benefit of lake water quality. Rather, these concerns must be balanced against TROA's other goals. The TROA mandate encompasses drought protection for the Reno metropolitan area, municipal and industrial water storage for Fernley, improved in-stream flows in the Truckee River, improved recreational levels in California reservoirs, Federal storage dedicated to wetlands restoration and fish recovery, and water allocation among California, Nevada, and the Pyramid Lake Tribe. Although Tahoe interests were considered in the TROA, the long-term effects of revised dam operations on Lake Tahoe are not fully known.

The roots of the modern development patterns at Lake Tahoe were sown in the decades after World War II, with the construction of better highways and large scale land subdivision. The publicity provided by the 1960 Winter Olympics at Squaw Valley, coupled with the population boom in the West that has characterized the last half century drove growth of resort use at a phenomenal rate. Between 1960 and 1980 the number of residential dwellings in the Basin expanded from 500 to 19,000 units and the number of subdivided lots approached 50,000. By 1997, visitation had grown to 3.5 million persons per year (USGS, 1998).

By the late 1950s it had become evident that lake clarity was decreasing. Sewage effluent and septic tank leakage were suspected causes. In response, a local agency, the Lake Tahoe Area Council (LTAC) was formed to find a solution. The LTAC initiated efforts to develop a Basin-wide sewage collection system; and in 1968 a sewage export system was put in place. While this effectively controlled sewage impacts on water quality, it simultaneously created capacity for significant population growth as well. This new capacity came on line during the period of skiing's great growth as a popular recreation activity. Rapid expansion of ski areas in the Basin added enormously to winter visitation, while California and Nevada's population growth fueled a growing demand for second homes and recreational resort facilities.

During this period, there was little sensitivity to the effects of development on water quality. The best example of this is the subdivision of Tahoe Keys, which was built by filling in most of the meadow formed by the delta of the Truckee River where it entered Lake Tahoe, and replacing it with homes, and a marina.

### ***Lake Tahoe Basin Management Unit.***

The United States Forest Service (USFS), recognizing the need for unified management in the Tahoe Basin established the Lake Tahoe Basin Management Unit (LTBMU) in 1973. This combined management of Tahoe Basin lands formerly distributed among the Tahoe, Eldorado, and Toiyabe National Forests. LTBMU focuses on recreational and ecological management. It currently operates 945 campsites and is host to seven tenant resort facilities.

### **The Tahoe Regional Planning Agency (TRPA)**

By the late 1960s, the esthetic and environmental impacts of uncontrolled growth could no longer be ignored. After a period of inter-state friction and much local rancor, the foundation of the current unified Basin management structure was created in 1969, when California and Nevada signed the Tahoe Bi-State Compact, creating the Tahoe Regional Planning Agency (TRPA). In 1980 with the re-ratification of the bi-state compact, TRPA was charged with setting development standards and environmental carrying capacity thresholds to "...lead the cooperative effort to preserve, protect and enhance the unique natural and human environment of the Lake Tahoe Region."

The specific threshold areas addressed are:

Water Quality

Air Quality

Soil Conservation

Vegetation

Fish Habitat

Wildlife Habitat

Noise

Scenic Resources

Recreation

As an initial effort to gain control of land use in the Basin, TRPA imposed a limited building ban from 1981 to 1984 to provide "breathing room" for TRPA to adopt environmental thresholds and amend its regional plan to achieve those thresholds. The thresholds were established in 1982 and the amended plan was adopted in 1984, thus permitting TRPA to end its building moratorium.

TRPA's authority and competency was immediately challenged by both development interests asserting an "unlawful taking" and the State of California asserting that the plans were inadequate to fulfill the terms of the Compact. As a result, TRPA's first unified Basin plan was not adopted until 1987, but out of those confrontations has come a realization by all parties that the preservation of the Basin's environment, especially the lake, is key to preserving the recreational demand that drives the Basin's economy.

### **Threshold Evaluations**

TRPA's procedures call for periodic review of the Environmental Threshold Carrying Capacities (ETCC) to determine whether or not they are being met and to reassess the threshold levels in light of emerging scientific information. Since 1982, the Noise and Scenic Resources thresholds

have had minor revisions, and TRPA revised the visibility thresholds in 2000. The rest of the thresholds are essentially unchanged from 1982.

Most of the original 1982 ETCCs were based on sparse data or abstract goals, so that evaluating threshold status is not an easy task. The difficulty of retroactively establishing baselines for most thresholds and/or measuring their current status, and thus of readily determining how much progress has been made, makes an integrated scientific study in support of full reassessment a high priority.

For thresholds based on environmental conditions for which there are routine monitoring programs with long records, (e.g. California and Nevada monitoring for, CO, NO<sub>x</sub>, Ozone, and PM<sub>10</sub> for Air Quality, or the Tahoe Interagency Monitoring Program (TIMP) for surface Water Quality) it is possible to determine progress toward the ETCC's with considerable precision. Other thresholds, such as visibility, rely on monitoring installed subsequent to 1982, so that current conditions are known, but the baseline is unclear. For these, a reasoned review is necessary to determine whether or not conditions today are better or worse than in 1982. (For visibility, a new report (Molenar, 2000) has just been completed which evaluates the instrumental record, discusses problems in data interpretation, and concludes that there has been no significant trend in visibility in recent years.) Some ETCCs are based on presumed linkages to environmental problems. For example, the Vehicle Miles Traveled (VMT) threshold is based on the need to reduce the air quality impact on water quality. However, the VMT threshold has also been used by some as a means to control gridlock in the Basin. Increased knowledge about the transportation related impact on water quality has raised questions about the usefulness of the VMT threshold as it now exists. Unfortunately, only the air quality component has an instrumental monitoring record available; traffic and transportation status are not amenable to continuous monitoring, so evaluating this threshold must await a new Basin-wide transportation study (proposed in this report). Still other ETCCs cannot practically be directly measured. The threshold for wood smoke from residential heating was set to limit adverse health effects and visibility degradation from airborne particles (PM<sub>10</sub>). While TRPA, the California Air Resources Board (CARB), and the Nevada Department of Environmental Protection (NDEP) operate air quality monitoring stations which can measure visibility and PM air quality, there are no baseline data on actual wood use in 1982, and no direct means to determine how much wood is burned or exactly how much smoke is generated today. This threshold will continue to rely on indirect evidence (air quality data) to determine attainment status.

The need to evaluate all the ETCCs before the next planning cycle is a major motivating factor for the comprehensive research plan presented in this report, since the complex linkages among some of the thresholds requires a broad scope to accomplish the review.

### ***The 1987 Regional Plan***

Growth is limited according to the Lake Tahoe Basin 1987 Regional Plan, as amended. At this time, TRPA authorizes construction of a maximum of 300 new residential units per year (although not all the allocations are fully utilized in some jurisdictions every year). Generally, this level of development has been fixed since 1987. Between development and the purchase of sensitive parcels by public agencies, the current pool of remaining residential lots may be depleted in some jurisdictions as early as 2007, with 2020 being the latest that vacant lots will

likely remain. For commercial and tourist development, controlled growth is planned in some locations and redevelopment in others. Specific community plan target areas were identified for new allocations of commercial floor area commensurate with community improvements. In other areas, redevelopment of existing commercial and tourist capacities was determined to be a prudent environmental and economic course of action. No concomitant extensive expansion of public service facilities is expected. In some locations, expansion of recreation capacity or services has been identified in the plan. All growth has been linked to infrastructure capacity, such as water rights and sewer capacity, so that when or if the limits of the Regional Plan are reached no additional residential subdivision or influx of commercial activity is envisioned. The TRPA will complete the next 20-year Regional Plan in 2007. This plan can be expected to look towards redevelopment and rehabilitation as major themes, since the availability of new “bedroom” capacity is limited to the development of vacant parcels. The work outlined in this document specifically addresses the needs of the 2007 Regional Plan.

### ***Tahoe Environmental Improvement Program (EIP)***

The TRPA Environmental Improvement Program (EIP), begun in 1997, is an integrated interagency effort to accelerate achievement of environmental threshold carrying capacities (ETCC) established for the Lake Tahoe Region. The EIP is designed to accomplish, maintain, or exceed multiple environmental goals through a partnership among all the agencies having regulatory authority or research interests in the environment at Lake Tahoe.

The EIP structure is intended to bring the efforts and expenditures of all the participants together in a single plan so that high priority tasks are accomplished first and linked tasks can be coordinated. The Plan has three levels of integration: 1. Projects – discrete resource management or research tasks that are “one-time” funded (such as creating a GIS-based resource inventory and management information system). 2. Operation and Maintenance – ongoing baseline funding needed to maintain facilities and support ongoing resource management activities (e.g. use and updating for the resource information system established under level 1). 3. Programs – multi-year funded ongoing and evolving efforts in research and monitoring needed to fill knowledge gaps, assess progress toward ETCCs, and develop new management approaches. Present EIP efforts are focused on developing a long-term plan and budget. Budget elements identified through 2007 total approximately \$908 million. EIP activities through 2017, although less well-defined, are projected to add another roughly \$500 million.

### ***1997 Presidential Forum***

Establishing environmental thresholds and developing policies are only part of the process needed to preserve Lake Tahoe. Additional needs, ranging from capital projects to basic research, must be met to support the ongoing planning process. In July of 1997, President William Jefferson Clinton and Vice-President Al Gore visited Tahoe to meet with local and state leaders to identify how federal agencies could fulfill their obligations, both as land managers in the Tahoe Basin and through support of local and regional programs. These meetings resulted in both new Federal policy commitments and a Federal financial commitment of \$50 million toward local investment and expenditures. While some of those funds were earmarked for ongoing activities and capital investments (e.g. repair of the sewage export pipeline), this federal commitment also covers support for research needed to develop a sound scientific basis for

managing the Basin's physical and biological resources. The following list of subject areas were identified at the forum as crucial to protection of lake water quality (numbers are for reference, NOT rankings) (USGS, 1998).

1. Restoration of Wastewater Pipeline
2. Develop Basin Water Quality Model
3. Implement Threshold Monitoring to Evaluate Progress and Attainment Status
4. Establish a Water Quality Research Team
5. Pursue the Tahoe-Baikal Partnership
6. Establish an Environmental Hotline
7. Analysis of LTIMP Data
8. Digital Mapping of Basin
9. Identify Sources of Gasoline Pollution
10. Restore Populations of Lahontan Cutthroat Trout
11. Implement Road Erosion Control
12. Construct Stormwater Settling Basin
13. Establish Road Weather Info System
14. Implement Forest Road Decommissioning
15. Implement Watershed Restoration on National Forest Service Lands
16. Wetlands Restoration
17. Identify Environmental Restoration Opportunities (Upper Truckee and Trout Creek)
18. Public Education in Support of "Backyard Conservation"
19. Source Water Protection Study
20. Integrated Tahoe Watershed Assessment
21. Develop a Basin-Wide Fire History to Support Ecological Burn Planning

The research plan suggested in this report constitutes the scientific community's view of what needs to be done to clarify the sources and identify controls for excess lake nutrients. This directly relates to task areas 2, 3, 19, 20, and 21.

### ***Forest Health Consensus Group***

One of the critical issues identified in the Presidential Forum is the management of wildland fuels and the restoration of forest health. In 1998, TRPA convened the Forest Health Consensus Group, composed of residents, forestry professionals, public safety officials, environmental regulatory agencies, and others who have overlapping interests in vegetation and fire management in the Basin. The Group's goal is to coordinate programs of forest health and fire

protection in the Basin. The restoration of forest health will include a wide array of activities, including wildlife habitat improvement, the reintroduction of fire as a management tool, a reduction of the impacts of undesired fires, and fire hazard reduction in the urban - wildland interface. The FHCG has identified map and database updates, development of a potential natural vegetation model, and a late successional forests enhancement program as priority elements to support developing a Lake Tahoe Basin forest management strategy.

USFS is committed to support the FHCG's efforts to shape, monitor, and update a comprehensive forest management strategy integrated with other ecosystem restoration efforts. The USFS has already begun work on fuel management with adoption of a goal of treating 3000 acres per year. Their program includes the reintroduction of fire to the Tahoe Basin ecosystem, using fire on 1000 acres, and manual fuel reduction on another 2000. As a land manager, USFS has committed to fuel reduction on 3500 government-owned small parcels over a 5-year period (1998-2003) (USGS 1998).

### ***Transportation Measures***

Transportation problems at Lake Tahoe are important both for ecological impacts and for “quality of life” for both residents and visitors. TRPA is the designated Metropolitan Planning Organization (MPO) for the Tahoe Basin under the Federal Transportation Enhancement Act (TEA-21). Since overall development policy precludes major new road construction in the Basin, TRPA has focused transportation planning on better utilization of existing assets and reducing emissions from vehicles in the Basin. Trip reduction programs have focused on implementation through fleet operators – one example is the shift from post boxes to mail delivery in the Basin, which eliminates daily trips from each residence or business to the Post Office. Emission reduction programs include recent regulations on exhaust emissions from boats, and efforts to get fleet vehicles in the Basin converted to compressed natural gas (e.g. U.S. Postal Service). Alternative transportation in the Basin includes bicycle, shuttle (including the South Lake Tahoe Coordinated Transit System [CTS]), and bus systems. Bicycle path development is approaching 60 percent completion of the planned network. Transit efforts are focusing on expanding small-scale services (demand-responsive transit), and coordination of corridor services (e.g. scheduled buses) with both public and private local services (Dial-a-Ride, ski shuttles, etc.). Some progress in reducing emissions is expected due to Federal initiatives arising from the Presidential Forum, including efforts to expand support for transit and reducing emission from federal vehicles in the Basin.

Future efforts will include assessment of parking, traffic flow management, identification of under-served populations, etc., but these projects are dependent on having current demand and activity data. Comprehensive transportation origin/destination information was last gathered in 1974; socioeconomic data were updated in 1995 based on the 1990 census. An updated database, consisting of 2000 census data and results of the new transportation study proposed in this document, is essential to effective transportation planning in the Basin.

### 2.3 The 2007 Regional Plan and Beyond

In order to assure that TRPA’s plans remain tied to actual conditions in the Basin, the plans, and the ETCCs on which they are based, are slated for revision every 20 years. The 20-year review is a two-step process, beginning with evaluation of the appropriate levels and attainment status of each of the nine threshold areas, then consideration of the plan to attain the thresholds.

**Figure 1. Milestone timeline for implementation of 2007 Regional Plan for the Lake Tahoe Basin.**

YEAR	2000	2001	2002	2003	2004	2005	2006	2007
Process								
							Regional Plan Development/Adoption	
					Threshold Report			
	Threshold Research/Analysis							

As indicated in this and other assessments of Lake Tahoe’s environmental health, the scientific understanding of Lake Tahoe’s complex systems has advanced, to varying degree, across all threshold categories. In the case of some of the air quality thresholds, however, there remain significant gaps in understanding of the processes that control pollutant movement in the Lake Tahoe air Basin. The research plan described in later chapters of this report was developed with the goal of providing TRPA sufficient scientific information to effectively meet its management responsibilities. Implementing the research, monitoring, and analysis activities identified in this document will provide all the components for a conceptual multi-media nutrient transport model suitable for guiding sound policy decisions, but TRPA cannot hold off plan development activities until all this work has been completed.

The 2007 Regional Plan formulation and adoption will take approximately two years, including the environmental documentation. Prior to that, any revisions to ETCCs must be considered. Therefore, information needed for inclusion in the 2007 Regional Plan must become available during the 2003 - 2005 period.

New policy initiatives must be based on legally defensible interpretation of established scientific data. Therefore, the research program proposed here is structured around two time-sensitive goals. The first is to fully develop the conceptual models that describe the linkages that tie the factors that govern air pollutant emissions (residential and commercial land use, traffic, road maintenance, vegetation management, etc.) to the processes that govern air pollutant deposition to the Basin’s waters. This conceptual, quasi-quantitative, framework must be available to TRPA in 2003 to allow TRPA to begin evaluating the appropriateness of the ETCCs and developing policy responses to deal with preserving lake clarity. The details of how these linkages operate, which are the final outputs of the proposed research program, can then be developed in parallel with the evolving policies, with the goal of having quantitative findings suitable for establishing planning goals available in 2005. This tiered strategy provides TRPA with the necessary scientific support for its regulatory program without holding TRPA planning and policy development hostage until the completion of the entire research program in 2005.

## 2.4 Physical Setting

Lake Tahoe lies in a depression between the crests of the Sierra Nevada and Carson ranges on the California-Nevada border at a surface elevation of 1898 m (6260 ft.) above sea level. The Tahoe Basin is operationally defined by the 7000-foot (2050 m) contour, which is continuous around the lake, except for a narrow opening near Tahoe City at the where the Truckee River exits the Basin. The mountains surrounding the lake are generally 8000 to 9000 feet (~2500 m) high, with some reaching elevations of 10000 ft. (~3000 m.). The Lake Tahoe Basin drainage area is 812 km<sup>2</sup> with a lake surface of 501 km<sup>2</sup>. With the lower ridges to the east, this terrain forms a bowl-shaped basin that defines atmospheric processes almost as much as it defines hydrological processes. The presence of the cold lake at the bottom of this Basin further defines an atmospheric regime that, in the absence of synoptic weather systems, develops very strong (up to 10° C), shallow (30 m) subsidence and radiation inversions throughout the year. In addition, the rapid radiation cooling at night regularly generates gentle (1 m/s) down-slope nocturnal winds draining from the ridge tops down across the lakeshore and fanning out over the lake itself.

Local pollutant sources within this bowl are trapped by the Basin's frequent inversions, greatly limiting the volume of air into which they can be mixed, which in turn allows them to accumulate to elevated concentrations. Further, each night the down slope winds move local pollutants from developed areas around the periphery of the lake out over the lake, increasing the opportunity for these pollutants to deposit into the lake. This meteorological regime, characterized by weak or calm winds and a strong inversion, is the most common pattern at all times of the year (Cahill *et al*, 1989; and Cahill *et al*, 1997).

The second most common meteorological regime is transport from the Sacramento Valley and Bay Area into the Lake Tahoe Basin. The location of Lake Tahoe directly to the east of the Sierra Nevada crest allows the prevailing westerly winds combined with local mountain upslope winds to bring air from the populated regions west of the Sierra into the Tahoe Basin. This pattern develops when the western slopes of the Sierra Nevada, heated by the sun, cause the air to rise in a chimney effect and move up and over the Sierra crest and into the Tahoe Basin. The strength of this pattern depends on the amount of heat, and is usually strongest in summer, beginning in April and essentially ceasing in late October (Cahill *et al*, 1987; Myrup *et al*, 1989; Cahill *et al*, 1997). This summer pattern is responsible for most of the transport of non-local pollutants into the Tahoe Basin.

Other regimes at Lake Tahoe are defined by strong synoptic patterns able to overcome the dominant terrain-defined meteorology. The most important of these is the winter storm regime that brings almost all the Basin's precipitation, received mostly in the form of snow. Less frequent is the pattern driven by Great Basin thermal lows that circulate moisture in from the east during the summer, a situation usually characterized by thunderstorms along the Sierra's eastern slope. Finally, strong high pressure patterns north and north west of Lake Tahoe can bring strong, dry winds across the Basin at almost any time of the year.

Each of these meteorological regimes has the potential for influencing anthropogenic pollutant concentrations within the Basin. Two have the greatest potential for high concentrations: The most frequent episodes of high pollution occur under the local Basin inversion, when local

emissions from sources such as motor vehicles, chimney smoke, and forest burning, are trapped in the Basin. The other significant pollution potential regime involves transport of pollutants from lowland California to the west. This brings concentrations of both ozone and fine particles (including sulfates, nitrates, and smoke from industrial, urban, vehicular, agricultural, and forest sources) from the western slopes of the Sierra Nevada, the Sacramento Valley, and the San Francisco Bay area. The lowest pollution regimes are associated with winter storms and high winds. Winter storms have strong vertical mixing that dilutes local and upwind pollutants to low concentrations while bringing in air from the very clean North Pacific. This is evidenced by the fact that snowfall within the Basin has a relatively low concentration of anthropogenic pollutants such as nitrates and sulfates (Laird *et al*, 1982; Cahill *et al*, 1987). In between winter storms, the Basin is generally de-coupled from the sources in the Bay Area and Sacramento Valley by local inversions in those source areas. In these periods, the dominant airflow comes along clean transport trajectories; thus the accompanying air quality is solely dependent on local conditions within the Basin. Less frequently, winter low-pressure systems come from the east, again from a very clean sector of the country (Malm *et al*, 1994). Fall and winter high pressure is usually associated with winds from the northwest, and generally brings very good regional air quality. When these winds are strong enough to break up the Basin's local inversion the air quality is very good, but when it is weak, this regime is associated with persistent Basin inversions and associated build-up of local pollutants. Late summer thermal lows developing in the Great Basin bring occasional transport from the southeast. Southeastern flow is usually accompanied by strong convection, very deep mixing, and occasional thundershowers in the Basin, a situation that keeps both imported and locally generated pollutant concentrations low.

### ***Air Quality at Lake Tahoe***

Air quality at Lake Tahoe, when compared to that of most urban areas is very good to excellent. Few, if any violations of state and federal air quality standards for gases and particles have occurred in recent years. In 1969, California and Nevada designated Lake Tahoe as its own Air Basin, and stringent Basin-specific air quality standards were adopted. The revised standards include, for example, lowering the California CO standard from 9 ppm to 6 ppm to compensate for the effects of increased respiration at high altitude, and adoption of a stringent visual range standard of 30 miles in dry air by both states (In 1989, California revised its visibility standard from "visual range" to an equivalent 8-hour average of measured light extinction). Additional Basin-specific air quality goals were adopted as local and regional visibility thresholds defined in the 1981 TRPA ETCC, and specific emission reduction goals were adopted for CO, dust, and smoke.

The CARB (1996) estimates for annually averaged daily emissions (Table 2) in the California portion of the Lake Tahoe Air Basin are given in the following table. In this inventory, area-wide sources dominate particulate matter emissions, of which dust from both paved road and unpaved road contributes almost half of total estimated PM and PM<sub>10</sub> emissions.

**Table 2. 1996 Estimated Annual Average Emissions for the Lake Tahoe Basin (Tons/day)**

Source	HC	CO	NO <sub>x</sub>	SO <sub>x</sub>	PM	PM <sub>10</sub>
<b>Stationary</b>	2	0	0	0	0	0
<b>Area-wide*</b>	7	16	0	0	7	5
<b>Mobile (On-road)</b>	9	67	2	0	0	0
<b>Mobile (Other)**</b>	13	77	3	0	0	0
<b>Natural (Non-anthropogenic) Sources</b>	0	0	0	0	0	0
<b>Paved road dust*</b>	-	-	-	-	2	1
<b>Unpaved road dust*</b>	-	-	-	-	2	1

\* *Area-wide sources* include agriculture, construction, and open burning, and emissions from numerous a multitude of small sources, such as residential fuel combustion and utility equipment (lawn mowers, generators, etc.). Note: dust from paved and unpaved roads was included in area-wide sources; they are separated here for the purposes of discussion in this report.

\*\* *Other mobile sources* include all off-highway vehicles (construction equipment, boats, snowmobiles, etc.)

Source: California Air Resources Board (CARB)

Vegetation injury can occur at ozone concentrations below the human health standards. The 1988 Pedersen ozone damage survey found that 75% of all sampled sites showed evidence of some ozone damage. Basin-wide, 22.9% of yellow pines had some foliar damage due to ozone exposure. Although the Lake Tahoe air Basin is not an ozone non-attainment area under either CA (0.09 ppm/hr) or Federal (0.12 ppm/hr) air quality standards, the slightly more stringent TRPA ozone standard of 0.08 ppm/ is regularly violated. South Lake Tahoe is unique in California for seeing ozone increase from 1973 to 1993. Recent years' data suggest some improvement.

Air pollutant data are available from a number of sources. Aerosol concentration and composition data are available, although dated, from CARB/UCD studies conducted in 1977 and 1979. There is also an ongoing Tahoe Regional Planning Agency (TRPA)/Air Resource Specialists (ARS)/UCD collaboration extending from 1989 to the present in which aerosol data are being collected to track visibility. Gaseous data are available from a 1973 CARB study, from NDEP monitoring at Incline (limited data only), and continuous sampling since 1989 by the ARB at two sites in South Lake Tahoe. A more complete Basin-wide monitoring network is needed to fully assess air quality and track changes.

### **Water Quality at Lake Tahoe**

Surface water quality in the Lake Tahoe Basin is generally good by human use criteria, however, Lake Tahoe water clarity has been decreasing for decades due to rapidly increasing nutrient loading in the lake. Since 1959, numerous studies have documented exponentially increasing algal productivity, presumably driven by external nutrient inputs to the lake (e.g., Goldman, 1974; 1981; 1985 and 1986). Goldman, *et al.* (1993) reported on a review of 25 years of bioassays that showed a changeover from nitrogen (N) and phosphorus (P) co-limitation to strong P limitation occurred about 1980. Jassby *et al* (1994) reported a persistent phosphorus limitation in the lake as opposed to co-limitation by nitrogen (N) and phosphorus (P). Experimental results indicate that the elevated nitrogen level is a result of the atmospheric

deposition of dissolved inorganic nitrogen (DIN) and total nitrogen onto the lake surface. The sources of P to the lake are not fully accounted at this time; limited data indicate both surface and aerial sources need to be assessed.

Increased land coverage, disturbance of watersheds, and sustained artificially high lake levels are thought to contribute to decreased water quality (Byron and Goldman, 1989). Stream water sampling showed that concentrations of  $\text{NO}_3\text{-N}$ , total P, and suspended sediment in the streams increased significantly with the disturbance of high hazard lands (erodible soils, steep slopes, etc.). Increased disturbance of lower hazard lands (more stable soils) only resulted in increases in the concentrations of soluble (immediately bio-available) and total P. These findings link human disturbance in these fragile mountain watersheds, such as various types of land development and vehicle travel on unpaved roads, with nutrient loading in the lake, particularly when disturbance affects the most erodible areas of the watersheds.

### **Visibility at Lake Tahoe**

Fine particles ( $\text{PM}_{2.5}$ ) are a major factor in visibility degradation in the Tahoe Basin. The numerical ECC thresholds set by TRPA define minimum frequency goals. For regional visibility (visual range) the goals are 171 kilometers (103 miles,  $b_{\text{ext}}=22.9 \text{ Mm}^{-1}$ ) for at least 50% of the year and 97 kilometers (58 miles,  $b_{\text{ext}}=40.3 \text{ Mm}^{-1}$ ) at least 90% of the year, as calculated from measured particulate matter concentrations. The subregional visibility threshold is 87 kilometers (54 miles,  $b_{\text{ext}}=45.0 \text{ Mm}^{-1}$ ) for at least 50% of the year and 26 kilometers (16 miles,  $b_{\text{ext}}=150.5 \text{ Mm}^{-1}$ ) for at least 90% of the year. To assess the causes of visibility degradation and to determine compliance with these thresholds, TRPA maintains two visibility-monitoring sites, a regional site at D. L. Bliss State Park on the western side of the Basin, and a subregional site in the city of South Lake Tahoe.

The main contributors to visibility degradation (Cahill *et al*, 1974, Molenaar, 2000), are fine sulfur aerosols, fine soils (some from roadway dust), ammonium nitrate, and smoke. During the winter, fine soil particles are generated by traffic activity along major thoroughfares, especially where sand has been applied for traction on snow and ice. During the summer, most localized PM is generated by traffic activity on secondary unpaved roadways. Recent observations by Molenaar *et al* (1994) and the CARB (Table 2), show that more than 50% of total PM emissions are generated from paved and unpaved road traffic, as a combination of road dust and tailpipe emissions. Some progress has been made on reducing the paved road contribution to fine soil dust emissions, especially in spring, by controlling slushing and other efforts to minimize suspended dust from winter road sanding operations. The success of these efforts is visible in reduced fine soil in  $\text{PM}_{2.5}$  samples from TRPA's South Lake Tahoe site.

Other significant aerosols impacting summer time regional visibility include smoke, nitrates, fine soil, and sulfates. This latter group have major contributions from out-of-Basin upwind sources – including the San Francisco Bay Area, the Sacramento Valley, and the western slopes of the Sierra Nevada (Cahill *et al*, 1997). Sub-regional aerosols reach their maximum in winter, when emissions from strong local sources (smoke from residential wood heating, diesel and gasoline vehicle exhaust, etc.), combined with secondary nitrates, are trapped in the bottom of the Basin under persistent temperature inversions.

In addition to daily residential and transportation emissions, occasional events, such as wild or prescribed fires, can have significant effects on air quality in the Lake Tahoe Basin. Estimates of smoke impacts generated by the Lake Tahoe Airshed Model (LTAM) were reported in the recent USFS Watershed Assessment Project (Cliff and Cahill, 2000). They found that, for historical fire regimes (pre-fire suppression) frequent fires resulted in persistent morning smoke over the lake in the summer, with clearing and regional dispersion around noon. The calculated smoke concentrations are sufficient to violate TRPA regional visibility standards. These findings amplify the importance of full evaluation of potential air quality impacts as part of any planning to re-introduce fire into the Tahoe Basin ecosystems.

## **2.5 Pollutant Transport and Deposition**

A conceptual model showing the sources, transport pathways, and sinks of air pollutants in the Tahoe Basin and linking them to their effects on visibility and lake clarity is presented in Figure 2. The complexity of the problem is evident with many sources and pathways influencing pollution in the Basin.

Source characteristics (emission rates, emission chemistry) for most upwind sources are fairly well understood (with the notable exceptions of wildland fires and road dust). Within the Basin, chimney smoke must be added to open fires and dust as significant information gaps. Additional studies are needed to flesh out understanding of the source dynamics in the Basin. Particular effort is needed to fully characterize roadway emissions, especially during transient events such as melting/drying after snow. Fire dynamics need to be better characterized, not only for total emissions, but to determine how smoke disperses from different types of fires, and what fraction of smoke deposits to vegetation, soil, and water, both near a fire and far downwind.

Quantitative data is relatively scarce on the meteorological processes that transport these pollutants, both locally and regionally, controlling their concentration or dispersion and their potential for terrestrial or aquatic deposition. For pollutants originating outside the Basin, the timing and frequency of transport and relative dilution upon arrival over the Lake Tahoe Basin need to be determined. Once over the Basin, the potential for them to reach the Basin floor needs to be known. When local inversions are strong, transported pollutants may pass over the Basin with little impact, simply because they cannot be mixed down into the Basin. During periods when transported pollutants are mixed to the surface, their deposition dynamics need to be known to determine what fraction deposits to land or vegetation, what deposits to water, and what remains suspended to impair visibility.

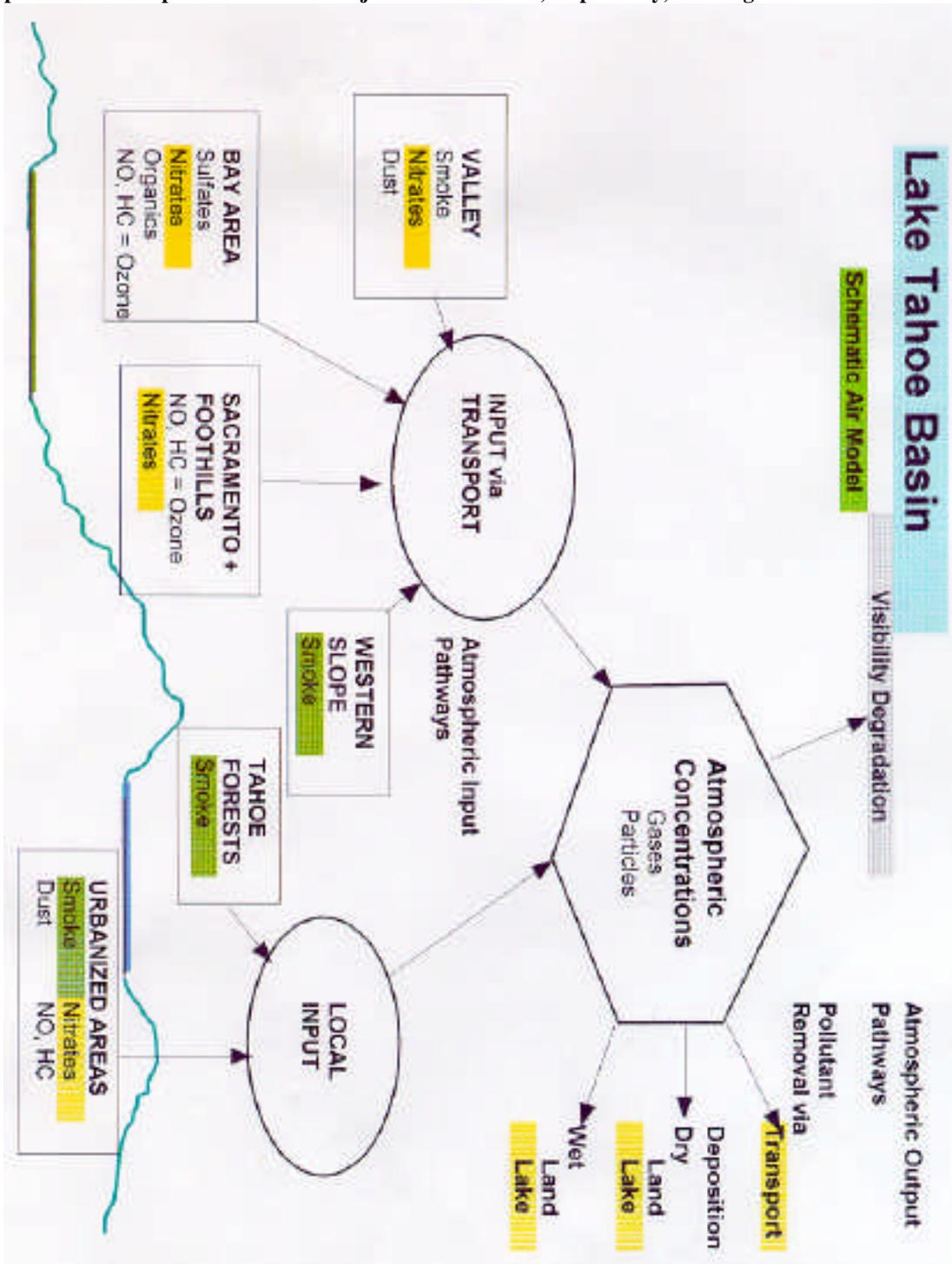
For pollutants originating within the Basin, their local spatial distribution and temporal persistence need to be known. Once these factors have been determined, specific terrestrial and aquatic deposition rates will be needed to calculate their impact on lake and stream water quality (and the suspended fraction's effects on visibility).

Transformation rates must be known to quantify the formation of secondary pollutants, especially the conversion of nitric acid vapor to nitrate aerosol in both long-range transport and beneath the lake inversion.

Finally, micrometeorological data are needed to properly characterize the lake-air interface, so that direct lake deposition can be calculated.

Some of these data can be obtained by monitoring local atmospheric conditions (measuring pollutants and meteorological parameters), either in the Basin or upwind. Other information must be estimated through models. A single monitoring site provides information about its immediate vicinity. In order to understand impacts upon the Tahoe ecosystem, however, monitoring data need to be overlain onto the spatial pattern of pollutant receptors. Since neither the atmosphere nor the Basin's resources are homogeneously distributed, full evaluation of air pollution effects requires implementing monitoring at several sites throughout the Basin, thereby obtaining the link between resources and pollutant exposure. In addition, the network must be temporally sufficient. This means that it must take measurements very often (if not continuously) in order to not miss transient events, and it must remain in operation long enough to observe the long-term variability of both local and regional processes.

Figure 2. Schematic Air Model (including processes and pollutants) for the Lake Tahoe Air Basin. Note: Arrows represent transfer of pollutant or effect of pollutant between “boxes”. For example, atmospheric concentration of pollutant is the metric for visibility degradation and deposition potential (i.e. the source of the effect), which is derived from transport and local input (the source of the pollutant). The highlighted pollutant or receptor indicates the major source or effect, from a given “box”.



## 2.6 Current Understanding of Atmospheric Parameters at Lake Tahoe

As noted earlier, air quality is partially implicated in the reduction of lake clarity, damage to forests and in visibility concerns. As explained above, the complexity of these problems and limitations in data and theory result in limitations in the ability of researchers and managers to predict present conditions at unmeasured sites and extrapolate the impacts of future regulatory actions. Therefore, it is important to accurately gauge the level of confidence we have in both measurements and theory as applied to Lake Tahoe (Table 3). The five parameters are broken down by scientific knowledge as high, limited or seriously deficient.

**Table 3. Understanding of Atmospheric Parameters at Lake Tahoe.**

<b>LEVEL OF UNDERSTANDING</b>				
<b>Parameter</b>		<b>High</b>	<b>Limited</b>	<b>Seriously Deficient</b>
<b>Meteorology</b>		South Lake Tahoe	West, NW shores, upwind derived	East, NE shores
<b>Sources</b>		Upwind (Central Valley, Bay Area)	Transportation	Local urban, Area sources, fires (wild/prescribed)
<b>Concentrations and Composition</b>	Gases	South Lake Tahoe	Rest of Lake Tahoe area	
	Particles	South Lake Tahoe	West shore	NW, NE, East
<b>Processes</b>	Transport	South Lake Tahoe	Rest of Lake Tahoe area	
	Deposition		Coarse particles	Fine particles
			Gases	
<b>Effects</b>		Visibility loss	Human health	
		Ozone tree damage	Lake nutrient effects	

A conceptual framework that thoroughly incorporates important aspects of air quality and resulting effects is shown in Figure 2. While there remain significant gaps in our understanding of visibility in the Basin, especially regarding conditions at the north end of the lake, and additional work is also needed to address vegetation damage, by far the largest uncertainty lies in tracking the generation and deposition of the phytonutrients that are degrading lake clarity. In the following discussion, we focus primarily on declining water clarity and the atmospheric contribution to this degradation.

## 2.7 Nutrient Deposition to Lake Tahoe

Based on algal growth studies (Goldman, 1988), there are three major contributors to the eutrophication of Lake Tahoe – nitrogen, phosphorus, and fine particles. Nitrogen (N) and phosphorus (P) are necessary nutrients, while insoluble fine particles provide a growth surface

for algae. Algal growth is not linear with total nutrient supply; rather, algae use nutrients in specific proportions. If one nutrient is available in abundance, but another is scarce, adding more of the abundant nutrient will not stimulate algal growth, while addition of the scarce nutrient alone will stimulate growth. This process is termed nutrient limitation. Historically, Lake Tahoe has been N-limited, and addition of nitrogenous compounds dominated eutrophication until the early 1980s. Since that time, the balance has shifted to P-limitation (Goldman, *et al.* 1993). Managing algal growth will depend on determining the N and P contributions from various sources, and reducing inputs in appropriate amounts to limit algal biomass in the lake. Atmospheric nutrient sources include sources, such as motor vehicles, that provide N, and others, such as soil particles, that provide P and inert particles. A few sources (notably wildfire smoke, for example) may contribute all three components.

The most recent nutrient budget given by the University of California, Davis' Tahoe Research Group (TRG) indicates significant lake input derived from the atmosphere. This budget indicates that more than 50% of nutrient nitrogen and 27% of nutrient phosphorous in Lake Tahoe originates in the atmosphere (Reuter *et al.*, 2000).

### ***Contribution of nitrogenous compounds to Lake Tahoe eutrophication***

Nitrate has long been identified by TRG as a major factor in lake eutrophication, leading to loss of clarity and extensive shoreline algae growth, however, complete Basin-wide data on nitrogenous compounds is sorely lacking. The last complete survey of gaseous nitrogenous pollutants around Lake Tahoe was the pioneering ARB study in the summer of 1973. While it is reasonable to assume that the general pattern observed in 1973 still persists, no comparable survey has been undertaken in the past quarter century, and there are no Basin-wide data at all for fall, winter, or spring. Although nitric acid is an important source of N deposition, there are no data on nitric acid concentrations in the Tahoe Basin. The TRPA/UC Davis monitoring program uses the robust IMPROVE-equivalent nitrate measurement method, but it is limited to just two sites (D. L. Bliss State Park and South Lake Tahoe) and data are only available since 1989. ARB monitoring of NO<sub>x</sub> gases occurs only in South Lake Tahoe and has recently been started at Echo Summit along Highway 50.

In the 1980's TRG began an extensive series of nitrate measurements for both wet and dry deposition in the northern portion of the Lake Tahoe Basin, focusing on the Ward Valley site. From these measurements, TRG concluded that dry deposition of nitrate was a dominant source of nitrogen in Lake Tahoe waters (Jassby *et al.*, 1994). The TRPA/UCD data on nitrate particles indicate that most nitrate is transported into the Basin in summer months, and substantial transported nitrogen is present year round (Molenaar *et al.*, 1994).

Together these two results have led some to suggest that the eutrophication of Lake Tahoe is dominated by out-of-Basin sources, thus making in-Basin control measures less effective. The confirmation of this hypothesis would have profound legal implications to TRPA's efforts to control in-Basin pollutants. This supposition was challenged, however, in the Sierra Nevada Ecosystem Project (SNEP), an exhaustive study of the range in general (Air Quality, Cahill *et al.*, Chapter 48, Vol. II) and Lake Tahoe in particular (A Case Study of Lake Tahoe, Elliott-Fisk *et al.*, Vol. III). This report examined the disagreement between the predicted dry deposition from the South Lake Tahoe measured nitrate particle mass and the Ward Valley measured dry

deposition reported by TRG. Since measured particulate nitrate could not account for the high deposition values observed in the TRG deposition buckets, this report offered a calculation suggesting that gaseous  $\text{NO}_x$  was likely responsible for the total N reported in Jassby et al. (1994). However, Elliott-Fisk *et al.* (1997) concluded that, since levels have remained essentially constant for 20 years,  $\text{NO}_x$  is not responsible for the increasing turbidity of the lake.

**Table 4. Atmospheric Nitrates at Lake Tahoe. (Deposition values are for dry deposition only).**

	<b>Species</b>	<b>Source</b>	<b>Amount</b>	<b>Area of Influence</b>	<b>Deposition velocity</b>
<b>Gases</b>	$\text{NO}_x$	Local	73 $\mu\text{g}/\text{m}^3$ (44 $\mu\text{g}/\text{m}^3$ )* (22 $\mu\text{g}/\text{m}^3$ )**	Urban fringe $\pm$ 4 km	$\sim$ 1 cm/sec
<b>Particles</b>	$\text{NO}_3$	Summer: Sacramento	0.36 $\mu\text{g}/\text{m}^3$	Basin wide	$\sim$ 0.03 cm/sec
		Winter: Local	0.9 $\mu\text{g}/\text{m}^3$	Urban fringe $\pm$ 4 km	$\sim$ 0.1 cm/sec

\*Corrected from 1974 data by 1976-1996 trend.

\*\*Estimated area of impact, over lake.

Source: Tom Cahill, UC Davis AQG, July, 1997

Thus, the presence of massive amounts of gaseous nitrogen species, all locally generated, could easily dominate transport from out-of-Basin particulate sources; but, lack of contemporaneous gas monitoring to fit to the TRG measurements prevents conclusive resolution of this question. The presence of the water layer in the bottom of the TRG dry deposition collector, a configuration unique to TRG, and the sudden three-fold increase of recorded dry deposition when the water was added to the protocol in 1987, lead to questions regarding exactly what chemical transformation processes are responsible for the high N in the samples. Yet, TRG's nitrate measurements themselves have been shown to be sound. Further insight into the problem can be gained by comparing the TRG results to other deposition data in California. While the wet deposition data is rather comparable to other data in the range, the dry deposition values are far higher than those measured at far more polluted sites.

One hypothesis is that the roadway  $\text{NO}_x$  is pushed out over the lake with the weak nighttime winds, and is not cleared until the inversion breaks, typically around 11 AM. During this time,  $\text{NO}_x$  is held close to the lake surface in a layer that is often less than 50 m thick. It is conceivable that the combination of high gaseous concentrations, rapid deposition velocities, and long residence times could raise the levels seen in the TRG deposition buckets, since they have a layer of water in the bottom. If this is in fact occurring, then the TRG deposition measurements may well turn out to be the correct ones to mimic the lake surface, and the atmospheric N sources include both gaseous (almost entirely local) and particulate (almost entirely transported) nitrogen compounds. Resolution of this discrepancy will require co-located sampling for aerosols, dry deposition, and gaseous N-species.

### **Contribution of phosphorus compounds to Lake Tahoe eutrophication**

The problems regarding the process of phosphorus contribution to reduced water clarity are radically different from that of nitrogen. With nitrogen, there are many potential sources, gaseous and particulate and the critical unknowns are their relative concentrations and the rates at which these species enter the lake. For phosphorus, there is a sharp discrepancy between the deposition and aerosol data. Measurements by TRG supply two facts: 1) phosphorus compounds, when added to lake water, accelerate algal growth more than any other compound, and 2) consistent levels of phosphorus are seen in the TRG deposition buckets. Aerosol measurements from the TRPA/UC Davis monitoring sites show negligible (typically less than 5 ng/m<sup>3</sup>) levels of PM<sub>10</sub> and PM<sub>2.5</sub> particles. No known phosphorus containing gases are suspected at Lake Tahoe, although there are no measurements; large particles not collected by the TRPA/UCD samplers may supply the “missing” P, but without measurements there remains a profound mystery.

Two potential bio-available P sources have been suggested: coarse soil dust and wood ash. Soil dust was suggested by Jassby (1994), based on the strong gradient in P concentrations between the shoreline and on-lake dry deposition measurements. Confirming this would require extensive localized monitoring. Since wood ash is a known source of phosphorus, smoke is also a prime suspect. This is supported by the observations of algal blooms after wildfires (Goldman, *et al.*, 1990) and observations of phosphorus in total suspended particles (TSP) from smoke (Cahill *et al.*, ARB 1977). A potential mechanism for wildfires to drive atmospheric P deposition involves the fires’ high temperatures, which both thoroughly ash wood and provide the energy to loft ash particles high in the air. More problematic are prescribed fires, especially ground fires, in which lower temperatures, less complete combustion, and weak lofting suggest a low potential for ash transport, but such fires are more frequent and may still be a significant source of airborne phosphorus. Wood burning fireplaces, which have highly variable combustion conditions, are another potential source. Since residences surround the lake, even weak P production from fireplaces or woodstoves could have significant effects. Even when the sources have been fully identified, quantifying the emissions and determining the spatial distribution of airborne P (including total and the soluble fraction) will require monitoring at multiple sites around the lake.

### **Contribution of fine insoluble particles to Lake Tahoe eutrophication**

The contribution of fine particles to the decreasing lake clarity at Lake Tahoe differs from nutrient input in two important ways. The size, concentration, and source of fine particles in the atmosphere are known, but the exact impact of PM on lake eutrophication and declining lake transparency is unclear. For example, there are abundant sources of fine particles in the spring runoff of the Upper Truckee River and other streams, leaving highly visible plumes as these streams join the lake. However, few measurements have been made in deposition studies or in the water column of atmospherically contributed fine particles. The examination of the transport of fine particles, including phosphorus, from roadways and in the water column itself should be conducted. Microscopic examination of the size and morphology of these particles is necessary, since in many cases the insoluble grains act as surfaces for algae and bacteria.

### **Summary of atmospheric processes at Lake Tahoe**

The following table summarizes what is known about atmospheric sources within and transport to the Lake Tahoe Basin.

**Table 5. Atmospheric Sources with and Transport to the Lake Tahoe Basin**

<b>Sources</b>	<b>Description</b>
<b>Gases</b>	<ul style="list-style-type: none"> <li>▪ All primary gases (CO, NO, NO<sub>2</sub>, NO<sub>x</sub>, NMHC, SO<sub>2</sub>, etc) are thought to be primarily local.</li> <li>▪ Methane is half natural, half anthropogenic, and all secondary gases (e.g., O<sub>3</sub>) are transported from upwind sources.</li> </ul>
<b>Particles</b>	<ul style="list-style-type: none"> <li>▪ TSP (0 to roughly 30 microns diameter) is mostly local,</li> <li>▪ PM<sub>10</sub> (including nitrogen and phosphorous particles) is largely local,</li> <li>▪ PM<sub>2.5</sub> (including nitrogen and phosphorous particles) is entirely local (winter), and half local, half transported (summer).</li> </ul>

### **3.0 Developing Air Quality Process Linkages for Management Use**

#### ***The Need for Models***

Neither air quality nor water quality at Lake Tahoe can be directly manipulated by humans. The air or lake cannot be filtered; there are no engineering solutions that can stop the flow of air into the Tahoe Basin; nothing can prevent emissions from circulating within the Basin; we cannot stop the movement of nutrients into the lake. Controlling pollution in the Basin must be done by managing local pollutants at their sources, and by harnessing natural processes to control the rates of nutrient transport to the lake. TRPA's challenge is to manage air and water quality indirectly by developing policies and regulations that result in adjustments in the timing, scale, and extent of human activities to produce changes in biogeochemical processes. Developing such policies and regulations requires mechanistic understanding of the structure of the environment and the dynamics of pollutant movement through it. Models are the tools used to describe the structure of the environment and to quantify the linkages among environmental materials and processes. Models provide analytical and calculational tools to predict how changes in material or process at one location will alter conditions or processes at other times and/or locations.

Models are abstractions; the whole environment is far too complex to represent in any model. It is neither practical nor necessary to individually account for every animal, plant, rock, drop of water, or puff of air. Models are created for many reasons, ranging from simply structured record keeping to academic exercises in computation. At the simple end of the scale, models organize data into a "snapshot" of various known aspects of a system. At the far reaches of complexity, they strive to demonstrate complete theoretical understanding by representing a complex system as a set of equations based on "first principles." Simple "tabular" models are easily understood and readily revised, but they lack the power to predict outside the range of the data from which they are constructed. The most complex "simulation" models make no sacrifices to practicality but are often weighed down by exorbitant computational and input data demands. These last limitations sometimes turn very "general" models into very specific ones, simply because the cost of assembling input data and running the model precludes frequent use.

Management models must be tailored to their applications; accurately depicting materials and processes of interest, while vigorously shunning any unnecessary complexity.

#### ***Models and Adaptive Management***

The modeling strategy described here is intended to be compatible with the broader ecological and management modeling strategy advocated in the recently completed Draft Lake Tahoe Watershed Assessment (Murphy & Knopp, 2000). That report defines the practice of adaptive management for the Tahoe Basin:

"Adaptive management is resource management informed by research and monitoring. ...With constant feedback and revision, management can become more effective, efficient, and account-able. Because adaptive management essentially entails "learning by doing," as well as "action based on learning," management actions, data gathering, and decision-making must interact and keep

pace with each other. Ideally, management and research are designed to maximize information gain, the course of management is readily evaluated in light of new information as it becomes available, and management direction is efficiently revised in response. To do so, coordination of science and management in the Lake Tahoe Basin will be paramount—new lines of communication and inter-organizational links will be necessary (Manley *et al.*, 2000:691).

Adaptive management involves a commitment to continual monitoring of the environment and regular reassessment of management policies and goals. The Watershed Assessment identifies four phases in adaptive management:

- Defining information needs
- Information acquisition and assessment
- Evaluation and decision-making
- Management action

For air quality, including characterizing pollutant sources and air quality effects, this report constitutes the first phase, defining information needs. The work plan of research and model elaboration recommended later in this report represents the second phase. TRPA's policy development in response to the findings of that research will constitute the third phase; and implementing those policies will be the fourth phase. However, in an adaptive management system, implementing policies is not the last phase. Once policies are in place, monitoring and research continue to provide feedback on the success of the policies, and to integrate new scientific findings into management and policy. Furthermore, adaptive management also regularly evaluates its institutional and sociopolitical environment to assess whether the program overall conforms to societal expectations – essentially asking the questions “is this going where we want to go?” and “are our efforts adequate?”

The necessity of linking monitoring to implementation is also articulated in the Watershed Assessment (Manley, *et al.*, 2000):

Monitoring will be an integral part of adaptive management of the Lake Tahoe Basin. ...an expanded definition that encompasses three different forms of monitoring is appropriate: monitoring of management activities in relation to planned activities (implementation monitoring), monitoring of the status and trends of resource conditions and their change agents (status and trend monitoring), and monitoring of the effectiveness of current management practices in achieving desired conditions or trends (effectiveness monitoring) (Manley *et al.*, 2000:695).

### ***Models for Adaptive Air Quality Management***

Although TRPA's resource responsibilities are significantly different from those of USFS, the principle of adaptive management is fully applicable to these problems as well. TRPA has the same need for developing initial plans that are based on the best information available, incorporating monitoring programs to regularly confirm that progress is going the desired direction, and having a structure that can flexibly respond to new data and new ideas.

To be useful in adaptive management, models, too, must be amenable to revision as new information comes to light and adaptable to new analytical perspectives and evolving databases.

The modeling strategy recommended in this chapter strikes a balance, providing the necessary conceptual and scientific validity while allowing for management flexibility and adaptability. The strategy employs a tiered structure, in which an overriding conceptual framework links together various submodels. Tiering allows flexibility and adaptability in the submodels while maintaining overall modeling cohesion.

The top of the modeling structure is the conceptual *framework model*. It is based on high level scientific constructs, incorporating ideas that are as generic as possible, and it strives to be independent of the specific databases and modeling technologies applied to specific problems. Its purpose is to provide a common linkage where specific submodels overlap, and to allow detailed submodels to be revised or developed as data or resources become available.

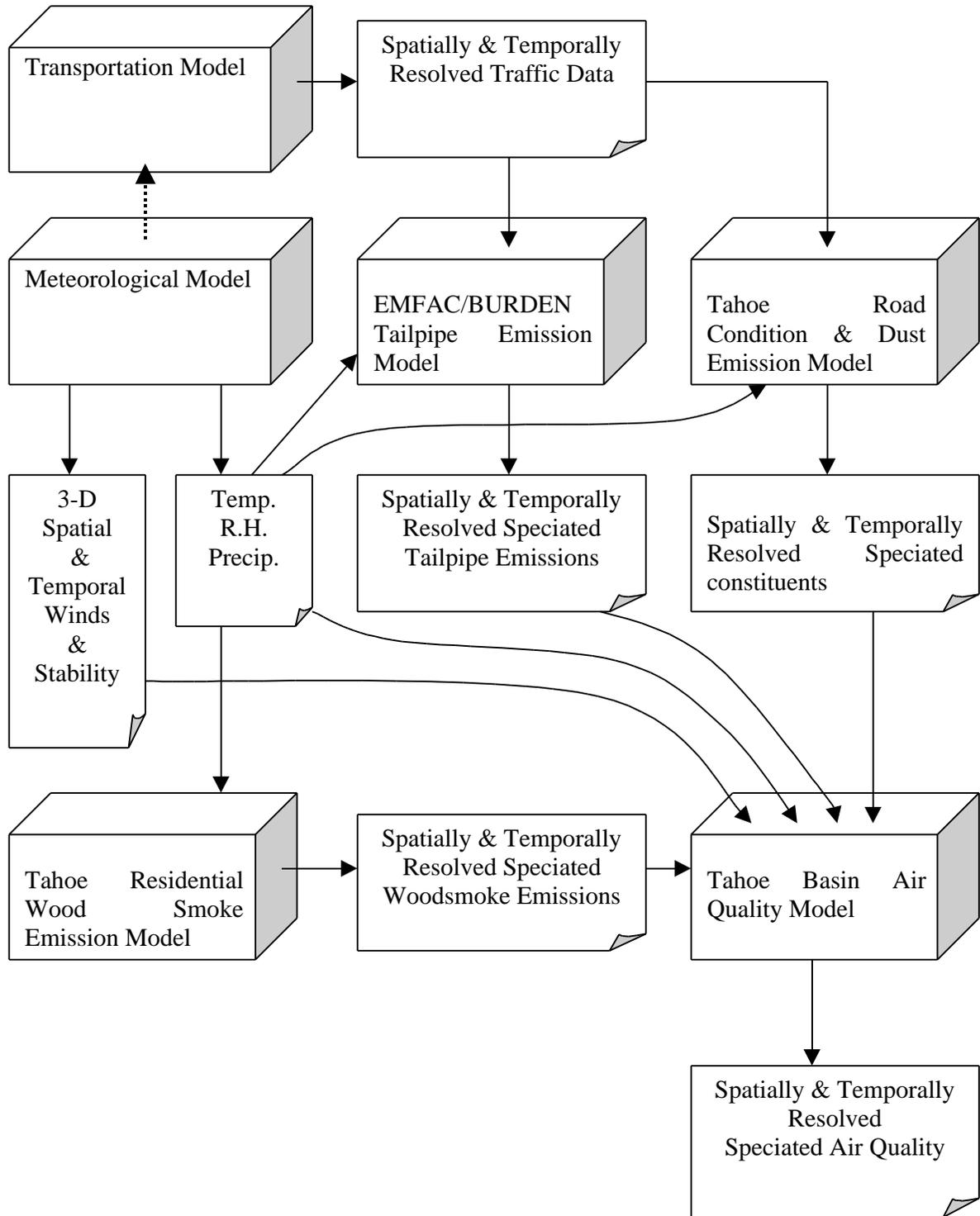
Beneath the framework model lie the topical *submodels*. In the air pollution arena, these include models for tracking pollutant transport from upwind areas, in-Basin circulation and deposition models, source activity models (traffic, wood burning, forest management), etc. Water quality submodels that must interact with the air quality submodels will address runoff, ground water, nutrient release from disturbance, etc. In this tiered modeling structure, each submodel can adhere to the dicta of fidelity to the materials of interest and minimal unnecessary complexity, yet each is free to grow and be revised as the data and demands of adaptive management dictate. By maintaining conformity with the framework model, submodels that rely on outputs of other submodels are protected from being cut adrift for lack of input data or by loss of communication with newer versions of sister models.

### **3.1 The Framework Model**

The framework model is not a computational structure. It consists of a web of linkages among processes and components in the environment, and it defines the interfaces among submodels, *within the context of TRPA's planning needs and regulatory authority*. The framework model expresses scientific definitions of linkages and pathways in the environment in terms of assignments of research and computational responsibilities. If a linkage is well understood, it points to a model or set of models that can calculate environmental effects of changes due to management actions or other factors. If a linkage is poorly understood, it points to a research need and identifies what information is needed to either interact with existing submodels or specifies that a new submodel is needed.

Building a framework model is an essential task. The general structure of a framework air quality-water quality model is quite simple; the challenge is to develop the details that make it a useful tool to direct the construction and application of the computational submodels. The general topical structure of the framework model will look something like Figure 2. A simplified example of framework information links is shown as Figure 3.

Figure 3. Subregional Framework: Model Linkages



### **3.2 Mechanistic Air Quality Modeling**

The elevation, meteorology, and geography of the Lake Tahoe Air Basin challenge the simplifying assumptions used in many air quality models. Never the less, in order to understand the complex relationships between air quality, lake clarity, forest health, visibility and human health in the Lake Tahoe Region, it will be necessary to create a rigorous air quality modeling structure. In order for this modeling effort to be successful, the information describing meteorology and emissions patterns in the Lake Tahoe Region will need to be improved.

A relatively simple parameterized air quality model that is specific to current conditions, the Lake Tahoe Airshed Model (LTAM) has already been developed as part of the Lake Tahoe Basin Watershed Assessment (Cliff et al., 1999). The LTAM can be used “as is” to roughly predict the air quality impacts of various real and hypothetical emission regimes. It also can be used heuristically to qualitatively (and, with caution, quantitatively) explore the relative importance of various emission sources and atmospheric processes in the Basin. Exercising the LTAM model in this fashion will be very useful for identifying and prioritizing research needs, both for refinement of knowledge of current air pollution sources and for inputs needed to predict the long-term effects of potential control strategies.

A more rigorous air quality model should also be developed for the Lake Tahoe airshed so that it will be possible to more realistically represent how pollutants are released to the atmosphere, mixed by turbulent diffusion, transformed by chemical reaction, and deposited to the Lake Tahoe watershed. In constructing such a model, emphasis should be placed on refining components that are associated with particular pollutants and processes that pose the greatest risks for the Basin’s resources, and those that can reduce uncertainty in predicted resource effects.

#### ***Emission Modeling***

The first step to improve understanding of air and water quality in the Lake Tahoe Region is to quantify the contribution of different sources to the current air quality problem. A combination of atmospheric measurements and model calculations are needed to accomplish this goal.

#### **Transportation**

Since motor vehicles are a significant contributor to air pollution in the Tahoe Basin, and because transportation, even absent its pollution impacts, impacts the quality of life in the Basin, TRPA must update its transportation data. This topic is covered in detail elsewhere in this report. The point we emphasize here is that new motor vehicle activity data, resolved to specific roadways by time of day and vehicle mix, are needed to generate realistic emission data both for tailpipe pollutants and road dust.

Tailpipe emissions are estimated using standardized models. These need to be validated for the Tahoe Basin. The usual practice is to estimate automobile emission data from fleet emission models. For example, the California Air Resources Board estimates in-use fleet emissions with the Motor Vehicle Emissions Inventory (MVEI) Models (CARB, 2000) a system of four models based on vehicle tests and field data. The data on which these models are based come from vehicle tests and speed and deterioration corrections tuned to warm weather at sea level (appropriate to the summer ozone problem in most urban areas). Since Lake Tahoe’s

environment is quite different from the “standard” conditions represented by these generic estimation tools, these estimates need to be validated by direct measurements taken in the Tahoe Basin. If emissions are significantly different, then Tahoe-specific emission models need to be developed.

Road dust emissions are likewise based on standardized models (USEPA 1998). These models are even less specific to circumstances in the Tahoe Basin. Road dust emissions in the Tahoe Basin will need to be measured under several conditions, then a road dust emissions model created. A Tahoe-specific road dust model must account for the numerous factors controlling road dust in the Basin, especially the day-to-day variation of soil on paved roads, the effects of rain, snow, and melt, and the seasonality of unpaved road soil moisture, and the timing of traffic.

### Residential Wood Combustion

Smoke from fireplaces and wood-fueled heaters is a major component of locally generated air pollution in the Basin. Smoke emissions are thought to be related to Basin population (variable by day-of week, season, etc.) and heating demand (Pitchford and Allison, 1984), but there are no definitive data on wood consumption and the emission factors available are uncertain and generic (U.S. EPA emission rates range from 8 to 35 lb per ton of firewood, depending on burner design) (USEPA, 1997). A study of wood consumption and burning behavior is needed, coupled with experimental measurements to generate Basin-specific emission data.

### Wild and Prescribed Fire

Wildfires are infrequent and generally exempt from regulatory scrutiny because they are considered “natural” or “acts of god”. As a result, little effort has been made to quantify wildfire emissions in the Basin. However, wildfire smoke does need to be quantified, if only in the context of water quality protection, since smoke and ash from fires are suspected as possible contributors to nutrient deposition. Prescribed fires, unlike wild fires, are subject to planning and smoke management regulations, but these programs, too, are not based on quantitative smoke emissions. Prescribed fire emissions and smoke transport and deposition dynamics need to be understood to properly deal with both the water quality and visibility impacts of burning, and to provide predictive tools to prevent the planned expansion of burning from possibly violating Federal and State the health-based air quality standards. At minimum, a combination of field monitoring and conceptual model creation will be needed to meet the need for a Tahoe-specific smoke emission estimation tool.

### ***Meteorological Modeling***

As of this writing, there is not enough detailed meteorological data available to drive a fully mechanistic air quality model for the Basin, let alone one that incorporates transport from upwind areas. As part of the modeling program a meteorological database needs to be built for the Tahoe Basin. This will require a combination of new meteorological monitoring and application of various modeling strategies. The development of the framework model will help to define the scope and extent needed in this new meteorological data.

## **Air Quality Modeling**

Recently, a parameterized air quality model specific to the current conditions in the Lake Tahoe airshed was developed as part of the Lake Tahoe Watershed Assessment (Cliff et al., 1999). The U.C. Davis Lake Tahoe Airshed Model (LTAM) is an Eulerian array of 1248-2.56 km<sup>2</sup> (1 mi<sup>2</sup>) cells across the Basin encoded on a Microsoft Excel spreadsheet. The domain is 72 km (45 miles) north to south (Truckee to Echo Summit) and 42 km (26 miles) west to east (Ward Peak to Spooner Summit) (Figure 4). All but the most southern end of the watershed is taken into account by the model. The LTAM is a parameterized transport and dispersion model that calculates the movement of atmospheric pollutants based on the limited air quality measurements taken at Lake Tahoe between 1967 and the present. Free variables (traffic flow, acres burned in the forest, population density, etc.) are assumed to be linear with pollutant emissions. The UCD Lake Tahoe Air-shed Model has two major goals:

To identify the relative fraction of in-Basin and out-of-Basin, and natural and anthropogenic components of the atmosphere, and

To evaluate the effects of atmospheric pollutants in the Lake Tahoe Air Basin on lake clarity, visibility, human health and forest health.

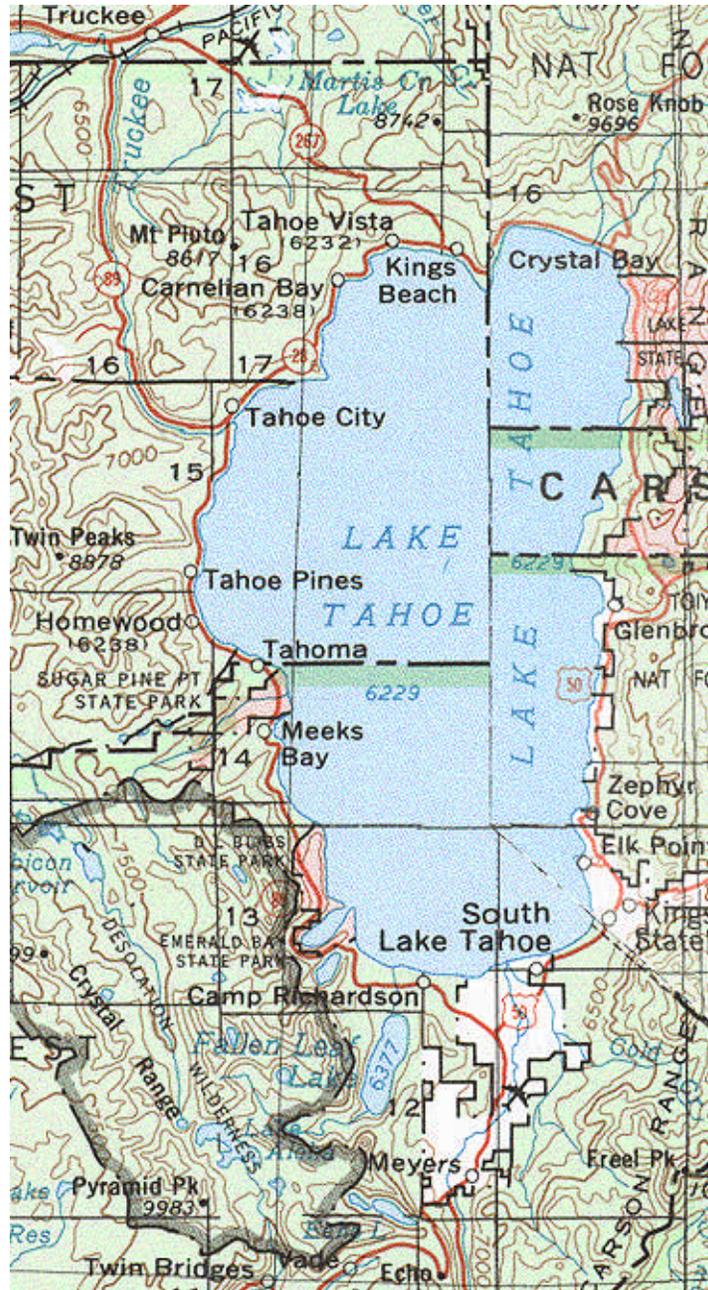
A thorough description of the model and outputs from scenarios are given in the Air Quality chapter of the Watershed Assessment (Cliff and Cahill, 2000).

The LTAM is designed as a parameterized pollutant transport model that does not take into account complicated transformation mechanisms and sink reactions, other than deposition, once a pollutant is emitted to the atmosphere. The purpose of the LTAM is to gather together the air quality information that currently exists at Lake Tahoe into a consistent framework. For example, the impact that current traffic patterns and current point source emission (such as prescribed fires) have on downwind receptors can be evaluated by looking at the atmospheric transport of pollutants from the source to the receptor (typically lake or forest). The LTAM is also useful when considering what the long term effects of current pollutant emissions will be if management strategies designed to improve air quality are not adopted. The LTAM is currently limited by poor knowledge of meteorological conditions, emission inventories (e.g. forest fire particulate N and P emission), deposition parameters, and pollutant concentrations for some important species (e.g. phosphorous) at Lake Tahoe. Presently, the LTAM is only able to predict pollutant concentration in a given location as a measure for the potential for deposition to the surface. Despite these shortcomings, valuable insight is gained from the construction and exercising of the LTAM. For example, the LTAM predicts that traffic along the highway 89 corridor may have substantially greater influence on pollutant concentration in the Basin than would be predicted based solely on vehicle counts due to transport of pollutants from the well traveled Interstate 80 corridor. This preliminary finding points to a relatively little studied area with respect to air quality within the Basin. Furthermore, long-term deposition measurements have been made at Ward Creek by the Tahoe Research Group at U.C. Davis indicating a substantial atmospheric input of pollutants tied to the loss of lake clarity. Therefore, the LTAM is a heuristic tool used to help identify what air quality research is necessary to construct scientifically sound management based models.

### ***Advantages of Mechanistic Air Quality Models***

Mechanistic air quality models rely on mathematical relationships to describe atmospheric processes at a fundamental level. The foundation of mechanistic air quality models is the set of fundamental equations governing the emission, transport, gas-phase reaction, aqueous-phase reaction, and gas-to-particle conversion of pollutants in the atmosphere. The overall objective of mechanistic air quality models is to solve the constitutive equations to predict airborne pollution concentrations at receptor sites

Figure 4. Area Covered by the Lake Tahoe Airshed Model (LTAM). West to east is modeled from approximately Ward Peak to Spooner Summit and north to south from Donner Lake to Echo Summit. There are 1248 individual cells that are used for calculating pollutant concentration for this portion of the watershed. This is the underlying map used to display pollutant concentration output from the LTAM results.



downwind from anthropogenic emissions sources.

The principle advantage of mechanistic air quality models relative to less rigorous models (such as transport only or linear rollback models) is the ability to account for the non-linear nature of atmospheric chemistry at a fundamental level. For example, nitric acid ( $\text{HNO}_3$ ) is produced in the atmosphere through a series of chemical reactions involving volatile organic compounds (VOC's) and oxides of nitrogen ( $\text{NO}_x$ ). The overall production rate of  $\text{HNO}_3$  depends on the intensity of solar radiation, temperature, and the relative abundance of VOC's and  $\text{NO}_x$ . In addition, the atmospheric concentration of nitric acid also is limited by reaction with gas-phase ammonia to form particulate ammonium nitrate; thus, the nitric acid system is extremely non-linear. Mechanistic air quality models that include a description of the fundamental equations that govern the behavior of the ammonia –nitric acid system can predict how the airborne concentration of nitric acid will change in response to altered meteorological conditions or emissions patterns. This ability is important in the Lake Tahoe Region because gas-phase  $\text{HNO}_3$  has a large deposition rate and high concentrations of gas-phase  $\text{HNO}_3$  will enhance the overall transfer rate of nitrogen from the atmosphere to the earth's surface and to Lake Tahoe.

While not all aspects of the Tahoe airshed will need fully mechanistic simulation, atmospheric chemistry is one area where additional model development should be focused. Since the conditions at Lake Tahoe are quite different from those in urban areas where most reactive gas-aerosol models have been developed, existing models cannot be simply adopted. Developing a chemical model for the Basin, will require research monitoring to assist model design (confirming precursor concentrations and reaction kinetics) and later monitoring to confirm model performance.

## 4.0 Generalized Air Quality Work Plan

### 4.1 Research and Monitoring Needs

To evaluate potential management strategies in the Basin, a scientifically sound management based conceptual modeling tool must be employed. The linkage between atmospheric pollutants and processes, transportation derived pollutants, and ecosystem effects must all be addressed. No longer effective is a research plan based solely on one ecosystem aspect. Only an integrated approach simultaneously addressing reduced clarity of Lake Tahoe, health of the surrounding forests, atmospheric visibility, human health, and socio-economic considerations will allow beneficial restoration of the Basin. This ecosystem approach to scientific understanding requires the combination of a concerted scientific research and monitoring effort and an enhanced institutional cooperation. Coordinated management models will be achieved only as a result of this proposed effort. As outlined in Chapter 2, a foundation for new threshold recommendation must be established by 2003. However, a research agenda continuing beyond 2003 is necessary to provide an adequate database for quality assurance of atmospheric data. Although continued monitoring and subsequent adaptive management based on new findings is recommended, an intensive five-year research program is outlined to form the basis for the 2007 Regional Plan.

The construction of a management based conceptual modeling tool for the Tahoe Basin requires that a large number of atmospheric species be understood. Chapter 3 illustrates the interaction between atmospheric constituents, processes, and ecosystem impact. To establish the link between air quality, transportation, and water quality a better understanding of pollutants and processes must be established. Understanding of species involves measurement of the size and time resolved composition of all gases and particles important for ecosystem effects in the Basin. These atmospheric species are summarized in Table 6. Better knowledge of processes will be gained by completion of the outlined research program. A first step toward building the management model involves the determination of the temporal atmospheric composition and transport of pollutants throughout the Basin. The species noted in Table 6 are but a small segment of the total atmosphere, however they represent the critical components needed to understand the link between the air and lake. Questions regarding impacts on water quality from events such as wildfires, prescribed fires, re-entrained road dust, etc. are largely unanswerable based on the current state of knowledge. Therefore, detailed research topics and protocols must be addressed. This generalized research work plan is designed to address six questions regarding the link between air quality, transportation, and ecosystem effects (i.e. visibility, lake clarity, forest health). They are:

What is in the ambient Lake Tahoe Basin atmosphere?

What is the relationship between atmospheric visibility and lake clarity?

What is the affect of air quality on lake clarity?

What is the transportation related source of unacceptable ecosystem effects?

What are the sources and sinks of atmospheric constituents (i.e. atmospheric budget) in the Tahoe Basin?

How are management decisions able increase air quality for ecosystem and human health?

The research needs are broken down into seven sections. This breakdown is meant to facilitate discussion and establish funding opportunities for individual portions of the entire program. However, it is imperative that this entire research program be completed to understand how to arrest the unacceptable loss of clarity at Lake Tahoe. These seven research sections are:

- 1) Identification of ambient atmospheric constituents. Prior to developing any conceptually based model of system linkages, an extensive inventory of pollutants and atmospheric species useful for process determination is imperative. Limited understanding of Basin processes will never be realized without a far-reaching sampling and analysis program. This inventory is the basis for any conceptual model development.
- 2) Locations of data gathering stations (i.e. sampling sites). In order to create a detailed inventory of ambient constituents in the Lake Tahoe Basin a number of new air sampling stations must be established. This section addresses the location of the new sites as well as sampler configuration.
- 3) Experiments to quantify atmospheric processes. Although it is known that P, N, and fine particles impact the clarity of Lake Tahoe, quantification of the sources of these atmospheric species is not well established. Successful management of the Basin relies on quantitative source, sink, transport and chemical transformation information for development of the airshed model. Once ambient constituents are established, atmospheric process information will lead to ecosystem linkages.
- 4) Enhanced meteorological measurements. Understanding atmospheric processes relies on detailed knowledge of atmospheric dynamics. Upwind transport, spatial distribution throughout the Basin, and transport downwind all are coupled to meteorological parameters. An example of process understanding that is dependent upon meteorological knowledge is the quantification of pollutant movement from source to impact point (e.g. from road dust to the lake surface).
- 5) Temperature and pressure effects on atmospheric processes. A unique aspect of air quality at Lake Tahoe is its relatively high, cold environment. Transportation related emissions, chemical transformation, and combustion related emissions (e.g. forest fires) are affected by atmospheric temperature and pressure. Better understanding of atmospheric transformation processes and quantifying sources is subject to knowledge of temperature and pressure effects at Lake Tahoe.
- 6) Transportation specific needs with respect to air quality. Transportation system parameters are currently used as an air quality threshold in the Tahoe Basin. Establishing the precise linkage between water and air quality and transportation is a key component of this study. Just as establishing ambient atmospheric composition provides a basis for conceptual model development, establishing sources of pollutants is equally important. Transportation is likely one of the major pollutant sources either through direct emission or re-entrainment of roadside dust.

- 7) Institutional coordination. In order to minimize duplication of research and monitoring effort as well as efficiently utilize existing resources (e.g. databases, sampling sites, management programs) a high level of coordination among institutions is necessary.

Each research needs section is designed to answer one or more basic questions about air quality in the Lake Tahoe Basin. Each section will outline specific questions the proposed research intends to answer. Finally, an estimate of the cost associated with the proposed research is established.

### ***Spatial and Temporal Identification of Ambient Atmospheric Constituents***

There are three major atmospheric species that contribute to Lake Tahoe water clarity degradation: bio-available nitrogen (gases and particles), bio-available phosphorus (particles) and fine soil particulate matter (PM). As explicitly outlined in Chapter 2, sources, transport mechanisms, and the ecosystem impact of gases and PM in the Basin are not well understood due to obsolete or limited data. Understanding the link between atmospheric source, transport, transformation and deposition is necessary to effectively manage the ecosystem with respect to air quality. There is a strong need to begin systematical data collection to help develop an airshed companion for coordination to the watershed model suitable to the Lake Tahoe Region. These needs are prioritized with respect to those three atmospheric species most concerned with the degradation of the lake; they are nitrogen, phosphorus, and fine particles.

Closure of atmospheric process understanding is gained with knowledge of all important atmospheric species. Therefore, it is necessary to understand atmospheric constituents other than those directly related to lake clarity in order to coordinate models for management use. In Table 6, the currently known importance of the species is listed. Although the linkage between water and air is most important, data quality assurance (QA) requires that components important for closure be measured as well. Data QA for PM requires, in part, that reconstructed mass and gravimetric mass are equivalent. That is, the sum of components of PM equals the mass physically measured on a scale. Hence, a number of species that are not necessarily directly related to water quality impacts must be measured for calculation of reconstructed mass (Malm et al., 1994). Also, gaseous species such as NO<sub>x</sub>, HNO<sub>3</sub>, and NH<sub>3</sub> are directly related to water quality reduction as nitrogenous nutrients. However, in order to achieve mass balance, hydrocarbon and oxidative gaseous species must be measured as well. Finally, conservative tracers are vital for determining transport and transformation processes of the important species.

#### **Phosphorus (P).**

Two of the outstanding questions associated with phosphorus are source of bio-available P and the transport pathway to the lake. Suspected sources include wildfire, prescribed fires and wood burning. No P containing gases are suspected at Tahoe. The rate of deposition of bio-available phosphorous PM is also poorly known. Study of atmospheric concentrations and deposition of phosphorus in all particle sizes side by side with detailed TRG deposition measurements is necessary to reduce the substantial uncertainty with which source, transport and deposition parameters are known. Work is also needed to examine transport mechanisms from possible terrestrial source areas to areas over the lake in order to better understand natural versus anthropogenic sources. Quantification of all P sources to the air, and subsequent transport to the

lake is necessary to understand air quality's impact on lake clarity. Policy directed toward protecting the lake from atmospheric components is established as the VMT threshold. In the case of P, this policy is misdirected. The transportation component of P is unknown other than the potential contribution of P from road dust (which needs to be evaluated). Currently, it is believed that roughly one quarter of the P nutrients (and approximately one-third of the soluble P) entering the lake are derived from the atmosphere (Reuter *et al.*, 2000). In light of this finding coupled with a P limited lake, greater understanding of processes involving bio-available P is imperative for successful restoration of the lake. Furthermore, new air quality thresholds need to be established that are more responsive to atmospheric impacts on the clarity of the lake.

### Nitrogen (N).

Nitrogen has long been identified as a major factor in lake eutrophication in addition to phosphorus. However, it is unclear as whether or not locally generated nitrogen species dominate those transported from out-of-Basin sources. Another critical unknown is nitrogenous nutrient deposition rate. Chapter 1 points out that the last complete survey of gaseous nitrogenous pollutants around Lake Tahoe was the 1973 ARB study. Such limited atmospheric measurements are unable to unambiguously tie anthropogenic bio-available nitrogen to lake deposition. This research should focus on the identification of all forms of nitrogenous atmospheric pollutants, including actual roadway emissions of gases and particles, especially in cold, winter inversion conditions. Identification of bio-available nitrogen deriving from urban activities, primarily wood smoke and space heating in cold, winter inversion conditions, and examination of transport mechanisms from possible terrestrial source areas to areas over the lake is central to understanding the role of nitrogenous atmospheric species in Lake Tahoe's water clarity reduction problem.

### Fine particles.

Insoluble fine particles scatter light in the water column, and like the atmosphere, reduced water clarity results. Unlike nitrogen or phosphorus, the sources and transport mechanisms of fine soil particles are better known. Fine particles are thought to be largely generated locally during Winter, and about half derived from out-of-Basin transport in spring and summer. Two uncertain issues regarding fine particles in the Tahoe air Basin exist, deposition rate and roadway source. Also, expanded detailed water column measurements are necessary to precisely define the impact of fine particles on the lake (Jassby *et al.*, 1999). Atmospheric experiments are needed to quantify the contribution of fine particles including bio-available P and N and their transport mechanism from roadways to the water. Also, a greater understanding of fine particle deposition rates is sorely needed to correlate concentrations in the atmosphere with reduced lake clarity, especially in light of substantial planned increases in prescribed fire activity in the Basin. Currently, PM<sub>2.5</sub> mass and composition measurements are routinely measured in air for monitoring of atmospheric visibility. Co-location of additional samplers with deposition measurements made by the TRG combined with detailed water column measurements will help unravel the unknowns regarding roadway and other source and transport to the lake of this ubiquitous atmospheric constituent.

### Other atmospheric species needed for quality assurance

In addition to those three most concerned particles, total suspended particulate matter (TSP) and PM<sub>10</sub> compositional measurements should be included in the sampling set. TSP and PM<sub>10</sub> data for the Lake Tahoe Basin are deficient because only PM<sub>2.5</sub> composition has been measured for visibility monitoring. PM<sub>10</sub> mass is measured for health effects, but past health regulations were not concerned with composition of PM. The potential source of bio-available P in TSP and PM<sub>10</sub> requires detailed study to determine P sources, as well as the direct contribution to reduction of lake clarity from all PM sources.

In addition to the species described above, data describing source locations and the release rate of gas-phase hydrocarbons (HC), carbon monoxide (CO), and oxides of sulfur (SO<sub>x</sub>) are also needed as QA for air quality predictions. The 1996 daily emissions rate in the Lake Tahoe Air Basin (Table 2) shows that on-road mobile sources in the Basin account for the majority of the emissions of gas-phase HC and NO<sub>x</sub>. These pollutants play a central role in the formation of ozone (O<sub>3</sub>) and other photochemical reaction products. However, on-road mobile sources account for negligible amount of the estimated tailpipe emissions of PM<sub>10</sub>. The majority of the particulate matter that is released to the atmosphere in the Lake Tahoe Region is emitted from “Area-wide” sources such as residential wood combustion, food cooking, and agricultural activities, although potentially significant combustion source PM from diesels in winter are not fully accounted for. To understand the complex interactions between gas- and particle-phase pollutants in the atmosphere above Lake Tahoe, it is necessary to construct detailed emissions inventories describing the pollutant emissions from both mobile sources and area-wide sources. These updated inventories must include an accurate description of both the location and activity level of each source.

Emission inventories are essential for management based models to be constructed. Future visibility thresholds rely heavily on detailed smoke emission inventories. For instance, current visibility guidelines include a reduction of smoke by 15% over 1981 base values. This regulation is impractical, however, due to insufficient smoke data for the 1981 baseline value, and lack of detailed smoke emission inventories. Therefore, detailed emission inventories of all relevant species in the Tahoe Basin must be quantified.

In addition to the chemical species listed in Table 2, other pollutant emissions also play a role in the atmospheric chemical reaction system in the Lake Tahoe Region. The species from Table 2 and additional species are listed in Table 6. The concentration of gas-phase ammonia in the atmosphere determines the partitioning of nitric acid between the gas and particle phases, and consequently determines the rate at which nitrate is transferred from the atmosphere to the earth's surface. Gharib and Cass (1984) constructed an ammonia emissions inventory for the South Coast Air Basin that surrounds Los Angeles and found that a variety of sources contribute to atmospheric ammonia concentrations including on-road vehicles, sewage treatment plants, fertilizer usage, and livestock operations. A detailed ammonia inventory must be constructed for the Lake Tahoe Region in order to perform mechanistic air quality modeling calculations.

Confidence in the ability of management models to predict airborne pollutant concentrations can only be established with a substantial database of ambient measurements. A management model can be constructed that is linked to the ambient measurements to predict impacts in regions

where measurements are neither practical nor cost effective. These validation exercises and construction of a large empirical database must be carried out before management models can be used to predict how ambient concentrations can be expected to change in response to different management decisions.

The data sets required for air quality model creation and validation must include measurements of all concerned gaseous and particulate species. In addition, measurements of O<sub>3</sub>, nitric oxide (NO), nitrogen dioxide (NO<sub>2</sub>) (NO + NO<sub>2</sub> = NO<sub>x</sub>), speciated hydrocarbons, hydrochloric acid (HCl), nitric acid (HNO<sub>3</sub>), sulfuric acid (H<sub>2</sub>SO<sub>4</sub>), and ammonia (NH<sub>3</sub>) are necessary for database QA. Conserved species such as CO or methane (CH<sub>4</sub>) that can act as a tracer for atmospheric transport and deposition routines must be measured.

Air quality management models that include a description of ecosystem response to aerosol processes must be validated against measurements of airborne particle size and composition. The time and size resolved composition of ambient Tahoe air Basin particles is necessary to provide an adequate database for the creation of a model. These particle measurements should be made by several different instruments that are based on alternative measurement principles so that the biases in any one technique will not invalidate the database. For instance, particle size distributions can be measured using optical particle counters (light scattering), differential mobility analyzers (electrical mobility) and aerodynamic particle sizes (aerodynamic resistance). Similarly, the chemical composition of airborne particles can be measured using instruments such as filter-based samplers, cascade impactors, and aerosol mass spectrometers. Particle-phase chemical components that should be measured as a function of size include sulfate (SO<sub>4</sub><sup>-</sup>), nitrate (NO<sub>3</sub><sup>-</sup>), chloride (Cl<sup>-</sup>), ammonium ion (NH<sub>4</sub><sup>+</sup>), sodium (Na<sup>+</sup>), elemental carbon (EC), organic carbon (OC), and soil species such as silicon, potassium, iron, titanium and calcium. A more detailed list is given in Table 6. Each of the instruments described above has different strengths and weaknesses when measuring these species concentrations.

In summary, detailed temporal and spatial size resolved compositional analysis of ambient gases and particles are essential to understanding atmospheric composition and processes in the Tahoe Basin. Species both directly related to water clarity reduction and necessary for data quality assurance must be analyzed. Specifically, constituents containing P, N, and also fine particles are most important, but a large number of other atmospheric species need to be measured for process closure and quality assurance. Most likely sources, such as road dust for fine particles and P, smoke for P, and tailpipe and upwind sources for N, should be established first. Once quantitative ambient concentrations are known, it is necessary to ascertain source apportionment. The management-based model will use the understanding of source and concentration parameters to determine the impact after linkages are determined. Cooperation with ongoing studies (see Institutional Coordination below) will greatly expand the sampling network to provide the necessary understanding of the link between ambient atmospheric species and impacts on the Lake Tahoe ecosystem.

**Table 6. Important atmospheric species in the Lake Tahoe Basin. Each major heading prioritizes need for modeling effort, and the importance for each species is listed (i.e. Lake = important for water quality/clarity issues, Closure = important for data quality assurance and modeling parameters, Forest = important for forest health, Human = important for human health, Visibility = important for atmospheric visibility concerns). Size and time resolved sampling of these species is necessary for model construction.**

Airshed Modeling		Transport Conformity		Water Quality Modeling	
<i>Particle Phase</i>					
Species	Importance	Species	Importance	Species	Importance
Phosphorous	Lake, Closure			Phosphorous	Lake, Closure
Phosphate	Lake, Closure			Phosphate	Lake, Closure
Ammonium	Lake, Closure			Ammonium	Lake, Closure
Nitrate	Lake, Closure			Nitrate	Lake, Closure
Chloride	Closure	Chloride	Closure	Fine soil	Lake, Closure
Sodium	Closure	Sodium	Closure		
Speciated organics	Closure	Speciated organics	Closure		
Soil elements (Fe, Si, Al, Ti, Ca, etc.)	Lake, Human, Closure	Soil elements (Fe, Si, Al, etc.)	Lake, Human, Closure		
Trace elements (Pb, As, Se, etc.)	Closure	Trace elements (Pb, As, Se, etc.)	Closure		
Isotopic analysis (O, N, and S species)	Closure				
Smoke	Visibility, Lake, Closure, Human				
<i>Gas Phase</i>					
Species	Importance	Species	Importance	Species	Importance
CH <sub>4</sub>	Closure	CH <sub>4</sub>		CH <sub>4</sub>	
NMHC	Closure	NMHC	Closure	NMHC	
NO <sub>x</sub>	Closure	NO <sub>x</sub>	Closure	NO <sub>x</sub>	Lake
PAN	Closure	PAN		PAN	
N <sub>2</sub> O <sub>5</sub>	Closure	N <sub>2</sub> O <sub>5</sub>		N <sub>2</sub> O <sub>5</sub>	
HNO <sub>3</sub>	Lake, Closure	HNO <sub>3</sub>	Closure	HNO <sub>3</sub>	Lake
NH <sub>3</sub>	Lake, Closure	NH <sub>3</sub>	Closure	NH <sub>3</sub>	Lake
CO	Human, Closure	CO	Closure	CO	
O <sub>3</sub>	Human, Forest, Closure	O <sub>3</sub>		O <sub>3</sub>	
SO <sub>x</sub>	Closure, Forest	SO <sub>x</sub>		SO <sub>x</sub>	

(Note: NMHC=non-methane hydrocarbon, NO<sub>x</sub>=NO and NO<sub>2</sub>, SO<sub>x</sub>=SO<sub>2</sub>)

### **Sampling Locations**

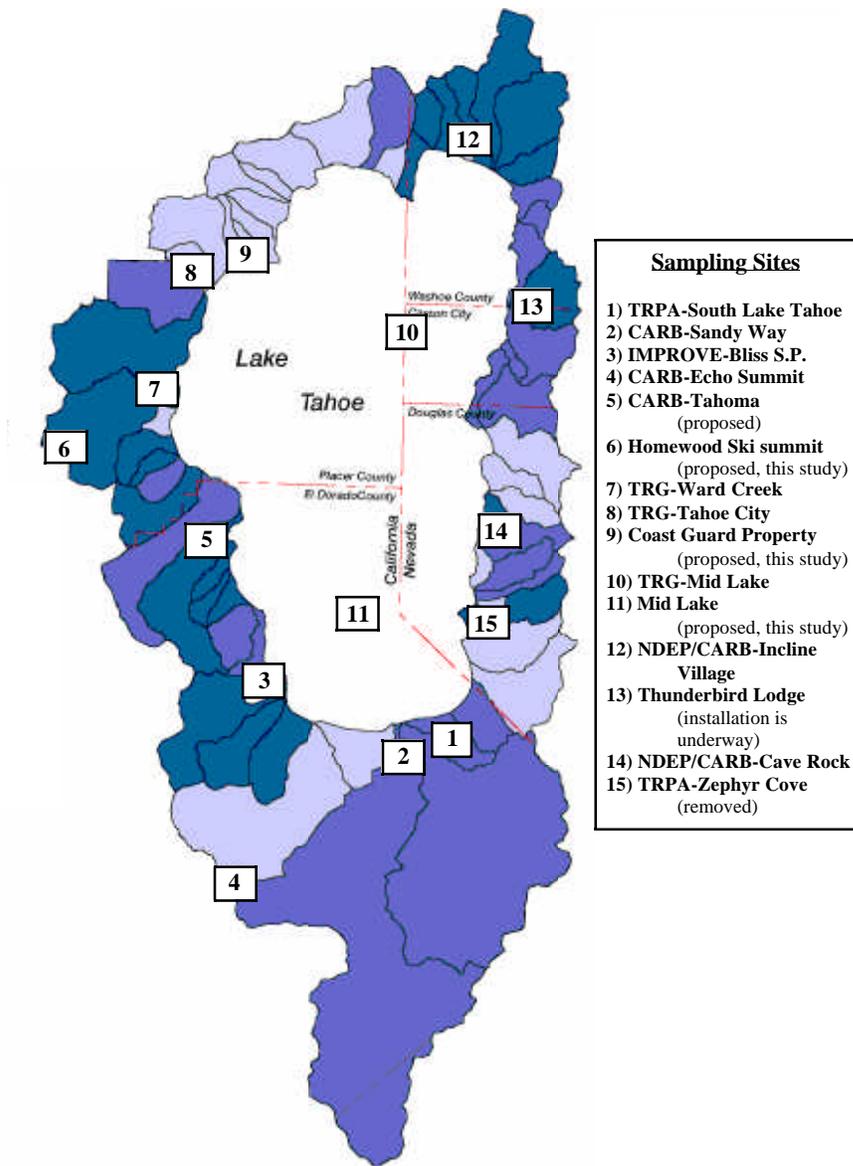
Recently, the ARB is closed one South Lake Tahoe site and added sites at Cave Rock, Incline Village, and is planning a west shore site (probably near Tahoma) and implement the site at Echo Summit. As part of this monitoring site extension, the South Lake Tahoe site at Sandy Way will be upgraded to collect a full compliment of air quality data. The TRPA has maintained aerosol-sampling sites for visibility monitoring at South Lake Tahoe and D. L. Bliss State Park since 1989. In November 1999, the Interagency Monitoring of Protected Visual Environments (IMPROVE) program adopted the Bliss site for monitoring of the Desolation Wilderness as a

Class 1 visual area. TRPA's ability to acquire data for the IMPROVE site is preserved. A map of the Basin showing current and proposed sampling and monitoring sites is shown in Figure 5.

To accomplish the task of determining process linkages in the Lake Tahoe Basin, fundamentally more monitoring sites are needed. Table 7 lists proposed monitoring sites for gaseous species, particulates, acid deposition and meteorological data. Ideally, these monitoring sites would be co-located with the already well-established TRG deposition network where applicable. Each new site should be evaluated for the potential for long-term monitoring, and ease of access for the proposed intensive research studies. Furthermore, enhanced deposition measurements to include conservative tracer data (sulfate concentration, isotopic analysis, etc.) will differentiate local from upwind sources of pollutants in the Basin.

The validity of any model prediction relies on the quality, and sometimes quantity of data used for model input. Due to the unique topography and land use pattern in the Basin, several sampling locations are necessary to adequately represent all atmospheric processes. Current sampling and monitoring (Echo Summit, South Lake Tahoe [2 sites], D.L. Bliss State Park, and Incline Village) are unable to collect data that represent all Basin processes. Because long term monitoring is necessary at fewer sites, the present sites are likely adequate to address visibility, and human health issues. However, short-term intensive research is required at many more sites. The new sites are given in Table 7, including ideal sampler configuration and locations. It is expected that 5 years of intensive work at each site will be necessary to provide an adequate database. At a minimum, each site should be outfitted with meteorological instrumentation (solar irradiance, wind speed, direction, temperature, humidity, atmospheric pressure), total particulate (TSP), PM<sub>2.5</sub> and PM<sub>10</sub> samplers, ammonia and nitric acid samplers, and deposition samplers equivalent to those used by TRG (Jassby *et al.*, 1994). Particulate samplers must be capable of size and time resolved sampling of PM combined with time integrated sampling methods used for quality assurance. In addition, samples for isotopic analysis and organic aerosol characterization should be collected. Budget considerations may limit the ability to analyze all collected samples, especially with high time resolution, but collection and archiving of samples is essential to provide an adequate database should further analyses prove necessary.

Figure 5. Current and proposed atmospheric sampling and monitoring sites in the Lake Tahoe Basin.



**Table 7. Proposed research sites and sampler configuration.**

<b>Data Type</b>	<b>Instruments</b>	<b>Proposed monitoring site</b>
<b>Meteorology</b>	10 meter met. tower w/ Solar irradiance, temperature, humidity, atm. pressure, wind speed and direction	Mid-lake (co-locate with TRG), Ward Creek (co-locate with TRG), east shore (Cave Rock), west shore (Tahoma), Tahoe City, upwind area, seasonal overflights with light aircraft.
	Radar profiler	West slope of Sierra Nevada (Georgetown).
	Acoustic sounder	One site lake level representative of Basin, and fully outfitted (e.g. Tahoe City).
	Radio-sondes	Intermittent use, co-locate with acoustic sounder. Collect met., solar and total UV irradiance.
<b>Gases</b>	<u>Concentration:</u> NO <sub>x</sub> , SO <sub>x</sub> , CO, O <sub>3</sub> , NH <sub>3</sub> , N <sub>2</sub> O <sub>5</sub> , PAN, CH <sub>4</sub> , NMHC. <u>Isotopic Analysis:</u> NO <sub>x</sub> , SO <sub>x</sub> , CO, O <sub>3</sub>	Mid-lake (co-locate with TRG), Ward Creek (co-locate with TRG), east shore (Cave Rock), west shore (Tahoma), Tahoe City, upwind area, seasonal overflights with light aircraft.
<b>Particulates</b>	TSP, PM <sub>2.5</sub> and PM <sub>10</sub> time-integrated speciation. Time and size resolved PM <sub>2.5</sub> speciation, organic speciation. Isotopic analysis of nitrate, sulfate, and organics.	Mid-lake (co-locate with TRG), Ward Creek (co-locate with TRG), east shore (Cave Rock), west shore (Tahoma), Tahoe City, upwind area, seasonal overflights with light aircraft. Complimentary water column data at lake sites co-located with TRG.
<b>Acid Deposition</b>	Nitric and sulfuric/sulfurous acid samplers.	Mid-lake (co-locate with TRG), Ward Creek (co-locate with TRG), east shore (Cave Rock), west shore (Tahoma), Tahoe City, upwind area.

### **Atmospheric Experiments**

A number of atmospheric processes in the Lake Tahoe Basin require study to further understand the role of air quality in the continuing decline of Lake Tahoe's famed clarity. The atmosphere is implicated as a source of nutrients and fine particles to the lake (*Jassby et al.*, 1994). However, knowledge is lacking about the precise link between air quality and ecosystem degradation. Thus, research and monitoring at Lake Tahoe needs to address several questions regarding sources, transport, transformation, and sinks of atmospheric pollutants before effective control measures can be implemented. Therefore, five essential questions about atmospheric processes in the Lake Tahoe Basin must be addressed in order to provide an adequate scientific foundation on which future management decisions will be based. They are:

- What is the relative contribution of in-Basin versus out-of Basin pollutant sources at Lake Tahoe?
- How are pollutants transported/distributed throughout the Basin?
- What is the local urban pollutant concentration falloff?

- What is the pollutant variation with elevation (i.e. air/lake interface, inversion height, long-range transport altitude)?
- What is the deposition of pollutants to the lake and forest, and ultimately how do these pollutants contribute to lake clarity reduction?

The transport of pollutants from upwind sources, California's Bay Area and Central Valley, to Lake Tahoe has yet to be quantified. As outlined in Chapter 2 of this document, both particles and gases in the Basin may be derived from upwind during the summer months. In winter, however, the Basin appears to be largely de-coupled from upwind sources. Better quantification of the in-Basin versus out-of-Basin sources of all pollutants needs to be achieved. There are several tools available for the research. Chapter 3 of the Lake Tahoe Watershed Assessment outlines specific research tools available to help quantify upwind transport into the Basin (Cliff and Cahill, 2000). Briefly, trace species ratio measurements, conservative tracer measurement, isotopic analysis, concentration measurements along a transect, and organic aerosol characterization combined will provide essential knowledge about in-Basin versus out-of-Basin pollutant sources.

Transport of pollutants within the Basin is a relatively unknown atmospheric process at Lake Tahoe. Insufficient knowledge regarding meteorological parameters and inadequate sampling stations exacerbate this problem. Varied distribution of sampling sites with temporal resolution of pollutant composition will allow quantification of transport within the Basin. Coupled with the enhanced meteorological measurements proposed, a complete picture of transport processes within the Basin will be developed.

Urban pollutant concentration falloff is addressed using organic speciation. Transformation of pollutants once emitted into the atmosphere occurs as a result of complicated chemical reactions. Knowledge about the resultant chemical species and chemical mass balance allows quantification of pollutant concentration falloff downwind of source. Measurements such as these will prove effective in not only determination of urban pollutant concentration falloff, but also in point sources such as in prescribed and wildfires.

Variation of pollutant concentration with elevation is addressed through the use of spatially diverse sampling locations. The coupling of data from on lake, shoreline, and watershed sites with occasional airplane overflights allows determination of column concentration of pollutants. Column concentration is particularly important at Lake Tahoe because of the sensitivity of the lake to nutrient and fine particle input. The persistent atmospheric inversions present at Tahoe in the summer in the mornings and continuously in wintertime interstorm periods enhance pollutant contact with the water surface. Modeling of deposition to the lake and forest surface requires detailed knowledge about the column concentration of pollutants, especially at the air/water interface.

Deposition to a surface is one of the least known parameters at Tahoe or anywhere. Complex dissolution processes coupled with meteorological unknowns make determining deposition rates more formidable. Co-located sampling of deposition buckets, air samplers and meteorology is essential to quantifying depositional parameters. Use of ambient organic tracers, isotopic

analysis of sulfur and nitrogen containing species, and trace species ratios all will aid in deposition quantification. Knowledge about the fate of atmospheric species, i.e. sink processes as deposition to a surface, is the critical link between air and water quality. Without specific knowledge about deposition rates effective model calculation and ultimately effective management strategies are likely to be ineffective. A vast sampling program with co-located samplers, innovative analytical technology, and simultaneous water column data will provide the necessary data to address questions about deposition, and the resultant water clarity reduction.

### ***Enhanced Basin and Upwind Meteorology***

Air quality modeling requires detailed knowledge of meteorological conditions such as temperature, relative humidity, wind speed, wind direction, atmospheric pressure and solar radiation to predict how pollutant concentrations will transport and transform in the atmosphere. Regardless of the quality or extent of atmospheric compositional data, no valid prediction of air quality or its impact may be performed without detailed knowledge of meteorological parameters. Typically, meteorological data are usually measured at fixed locations throughout the area of interest. These data are then used to extrapolate or interpolate values for meteorological parameters at all locations in the modeling domain before air quality calculations are performed.

One approach to creating the necessary meteorological fields is to interpolate between measurement locations using a weighted interpolation scheme (Goodin, *et al*, 1979). In this method, the influence of each monitoring station on interpolated values varies inversely with the square of the distance between the monitoring site and interpolation location. Simulated barriers are used to represent the effect of large topographic features so that measurements on one side of a mountain range do not influence interpolated values on the opposite side of the range.

The method for the creation of gridded meteorological fields that is described above works well when the measurements sites are close enough to resolve abrupt changes in atmospheric conditions. Since meteorological patterns in the Lake Tahoe Region are relatively complex, it will be necessary to obtain meteorological measurements at several surface locations including sites adjacent to the lake and sites in the surrounding mountainous regions. Each air-sampling site should be outfitted with 10-meter tower and meteorological measuring equipment as described above. Table 7 lists the site locations and necessary meteorological equipment for each site (also shown in Figure 5). An acoustic sounder at lake level and upwind radar profiler (e.g. at Georgetown) are necessary to provide a detailed record of atmospheric inversion height and characterize westerly flow of air into the Basin, respectively. Although long term use of the acoustic sounder on the lake and the upwind radar profiler is not practical due to cost considerations, characterization of a minimum of two summer and two winter seasons is necessary to provide adequate knowledge of meteorological parameters for the Lake Tahoe Basin. Detailed knowledge of meteorological parameters is essential to the construction of a management based air quality model.

### ***Temperature and Pressure Effects on Atmospheric Processes***

Due to its location and geography, Lake Tahoe presents many challenges to traditional air quality models. Several important atmospheric reactions proceed at a rate that depends upon ambient

temperature and pressure. Knowledge of air quality parameters is typically to sea level conditions and only the first 1000 meters of the atmospheric boundary layer are considered in the most model calculations. Under these conditions the hydrostatic pressure drop between the surface and the top of the modeling domain is less than 10% and pressure effects are generally assumed to be negligible. Since the mean elevation of Lake Tahoe is 1897 meters above sea level (ASL), the ambient pressure is approximately 0.76 atmospheres. In order to accurately model gas-phase chemical reactions in the Lake Tahoe air Basin it will be necessary to understand the pressure effect of relevant atmospheric processes. Furthermore, the temperatures and relative humidity unique to the Basin will affect both particle- and gas-phase processes. These processes are relevant to combustion sources, such as automobiles, fireplaces, and forest fires, and transformation processes, such as oxidation of hydrocarbons and nitrogen fixation.

Ambient temperature affects the rate of chemical reactions and the equilibrium behavior of solid species that form in the aqueous phase of airborne particles. This in turn affects the equilibrium distribution of chemical species between the gas and particle phases. Conditions specific to the Tahoe Basin, including wintertime inversions, make knowledge of unique processes imperative. The predominant wintertime meteorological condition is atmospheric inversion trapping local pollutants such as transportation related and fireplace emissions. Research regarding the emission and transformation of pollutants under these conditions is essential to understanding the air quality impact on lake clarity.

The total pressure of the system influences chemical reactions occurring in combustion systems. Since the ambient pressure at Lake Tahoe is 24% lower than at sea level, studies that contribute information to emissions source profiles conducted at sea level are inadequate to give a full understanding of processes at Lake Tahoe. For this reason, it is likely that results of these experiments will not be applicable to the Lake Tahoe Region. Currently, the largest combustion source in the Tahoe Region is fossil fuel combustion by on-road mobile sources. It is necessary to conduct experiments to characterize the chemical composition of the emissions released by representative mobile sources both at sea level and at conditions relevant to Lake Tahoe to determine the effect of reduced ambient pressure. Dynamometer wind tunnel tests and ambient on-road emission tests will both provide the information necessary for management based modeling.

### ***Transportation Needs With Respect to Air Quality***

Travel demand forecasting models had been developed almost exclusively for the purpose of travel demand forecasting, long-term transportation planning activities until the establishment of the Clean Air Act Amendments 1990 (CAAA 1990). CAAA 1990 tightened the linkage between travel demand forecasting activities and air quality modeling in that the use of travel demand forecasting models has been expanded to incorporate efforts that lead to emission inventory estimation. Such a linkage is especially important for Lake Tahoe.

To meet the legislative requirement in the CAAA 1990, a Tahoe Basin travel demand forecasting model should provide travel activity data, such as origin-destination data, vehicle speed, traffic volume, and VMT, as an input to emissions inventories as part of an overall conformity analysis for regional transportation plans and transportation improvement programs. The travel demand model should coordinate with the air quality model to provide the linkage necessary to make

accurate predictions of water quality impacts. The transportation and air quality models should be coordinated with the water clarity model such that a comprehensive understanding of the effect of management decisions can be made. In order to promote the evolution of current transportation models for management use at Lake Tahoe a number of parameters need to be studied.

#### Socio-economic and demographic characteristics.

One of the biggest problems associated with the current travel demand model is the continuous usage of the out-of-date travel activity data as well as socio-economic and demographic data. These data were collected from the 1974 Basin-wide origin-destination survey with incorporation of a home and hotel/motel survey from January to March and from July to September 1974. Although some data have been updated from various sources (e.g., 1990 census tract data, and 1995 land use data), visitor occupancy and population, hotel/motel occupancy and population, and campground occupancy and campground population are still utilizing the 1974 survey data. The lack of up-to-date travel and socio-economic data severely reduces the effects of the current efforts being made to improve the travel demand model. It is imperative that an updated accounting of transportation, socio-economic, and demographic parameters be made in order to make valid model predictions for management decisions.

#### Traffic composition data.

Traffic composition data include traffic volume by facility, and vehicle speed and type (e.g., passenger car versus sport utility vehicle, vehicle shape, and size). Fleet composition is established as a major factor in on-road emissions. Traffic composition affects re-suspension of road dust, which may be a major factor in the continuing decline of lake clarity. These traffic composition data should be collected on major arterial roads and highways as well as local streets; in cities as well as recreational areas (e.g., parks, campground sites).

#### Road surface conditions.

Road surface conditions refer to road surface moisture level and surface roughness. Road surface conditions effectively affect the mechanism and amount of road dust deposition and re-suspension. Road surface roughness is sometimes referred to road pavement condition. Surveys need to be conducted to find out the proportion of paved roads, paved roads with unpaved shoulders, unpaved roads, and the various surfaces and surface treatments available.

#### Specific Transportation Needs for Linkage to Air and Water Quality.

Three important transportation issues associated with air and water quality in Lake Tahoe have been identified in this section: 1) mobile source emissions; 2) VMT threshold; and 3) coordination of transportation and air quality models. There are many uncertainties and unknowns associated with each of the three issues. Thus, the major transportation research needs with respect to air and water quality in Lake Tahoe are highlighted:

- Mobile source emissions are major source of nitrogen (ammonia, NO<sub>x</sub>, etc.). Particulate matter derives partly from exhaust emissions and roadside dust re-suspended by passing vehicles. It is unclear what quantities of mobile pollutants are emitted from the vehicle fleet

and what quantity is transported to the lake. Furthermore, little is known about the composition of roadside dust. Therefore, traffic impact on lake water clarity is not yet fully understood. To better understand the impact, traffic composition data, meteorological data, road surface data, and mobile emission data are required. Roadside sampling experiments and traffic survey data are needed and these data must be gathered year-round to reflect seasonal variability.

- The VMT threshold reduction has been used by TRPA as both a traffic and water clarity control measure because Lake Tahoe has historically been nitrogen limited. However, recent studies have indicated a shift from co-limitation by nitrogen and phosphorous to phosphorus limitation. Such a shift has raised a question about whether a VMT threshold reduction is still meaningful as a Lake Tahoe water-quality/traffic control management tool. To better understand this issue, we propose a VMT threshold performance model to estimate the impact of VMT threshold reduction on mobile emission reductions and thus any concomitant air and water quality improvements. The model framework is shown in Chapter 5.2. One of the critical steps is the scenario design, which is reflected in the model constraints. Different scenarios result in different model constraints and therefore different optimal solutions. The scenario design involves a comprehensive policy making procedure that must rely on an improved travel demand model. TRPA's current model does not provide sufficient resolution to address the major questions. One possible model is described in Chapter 5.
- Since mobile source emissions contribute to the air and water quality of Lake Tahoe, there is a strong need to integrate transportation modeling practice and air quality modeling practice. To build such a model, it is necessary to understand the linkage between mobile activity and emissions, the linkage between mobile source emissions and air quality, and the linkage between air quality and water quality in Lake Tahoe. Thus, the model has to answer the following questions:
  - How much does traffic pollute and how is the emission associated with traffic activities?
  - What quantity of mobile emissions is dispersed into the air and in what form are they?
  - What quantity of particles is transported to the lake and what are their composition?
  - What is the transportation related impact on the lake clarity?

### ***Institutional Coordination***

The successful restoration of Lake Tahoe requires close coordination between the many institutions charged with managing the Basin. TRPA, USFS, USGS, CARB, NDEP, NDOT, CalTrans, California State Parks system (CalParks), and the Nevada State Parks system all make management decisions within the Basin. Forest health through a larger prescribed burning program and transportation related ecosystem impacts are two examples of where management decisions will be made that are part of the air and water quality linkage. Close coordination among these institutions and between these institutions and the scientific community is essential to attaining our collective restoration goals.

### Sampling sites.

The sampling sites maintained by the TRPA, CARB and NDEP should be incorporated into the air quality research work plan. Intensive research programs should supplement long-term monitoring at these sites. For example, alongside existing samplers at South Lake Tahoe, Echo Summit, and the west shore (i.e. Tahoma) site a continuous and consistent sampling protocol for research based samplers should be established. The existing sites collect data and monitor air quality typically for reasons other than water quality, but in light of the work by Jassby et al. (1994) a broader definition of air quality must be adopted. Direct funding, data sharing, and agency staff for sampler maintenance are all essential sources of assistance to scientific researchers. Currently, the TRPA and CARB employ extremely competent personnel capable of maintaining additional samplers at the existing locations. The use of these personnel will allow a larger network of sampling sites to be maintained without substantial additional costs. Furthermore, augmenting the existing and planned regulatory (e.g. Tahoma) baseline sites limits the costs associated with siting for the overall research study. Funding considerations will likely limit the number of samples that can be fully analyzed, but archiving of samples will provide an unmatched record in the future should additional data become necessary.

### Wildfire and prescribed fire monitoring.

Wildfire is thought to be one of the major sources of bio-available phosphorus. However, wildfire data are seriously deficient, and it remains unclear what the water quality effects of fire are. Furthermore, records of prescribed fires (dates, acreage burned, fuel type, etc.) are seriously deficient. Better coordination between agencies that use fire as a management tool, and better record keeping by individual management agencies will help reduce uncertainties in management models.

### Transportation data.

Traffic counts, vehicle fleet makeup, trip distance, vehicle speed, etc. are data necessary to develop an assessment of air and water quality impacts from transportation. Coordination between state and federal transportation departments with researchers and the TRPA to fund research, through grants to university researchers and agency studies, will lessen uncertainties about the linkage between air quality, transportation and water quality. Establishing new transportation thresholds relies on recent data and knowledge of water quality impacts due to transportation related pollutant sources. Furthermore, because enhanced knowledge of transportation parameters allows better prediction of management outcomes, less costly and more effective engineering strategies related to transportation can be implemented. For instance, more effective solutions are evident in the new road cleanup strategies employed at Lake Tahoe as a result of closer coordination between Lahonton Water District and CalTrans (*Osborn, 2000*). Close agency cooperation such as this will allow future efforts to be even more effective.

## **4.2 Summary and Cost Estimate**

Restoration of the Lake Tahoe Basin relies on effective management control strategies. An integrated ecosystem approach to management decisions is developed based on a solid foundation of scientific knowledge about the processes that lead to ecosystem degradation. Long

term monitoring of water and air quality is necessary to evaluate the effectiveness of management based controls. However in order to implement any environmental improvement program (EIP) for the Tahoe Basin requires fundamental scientific study to take place.

The estimated annual cost for the proposed work to establish the linkage between air and water quality is \$800,000. Since the atmosphere is reported (i.e. Jassby, 1994, Reuter et al., 2000) to be the single largest source of bio-available phosphorous and nitrogen, intense air quality research is imperative to gain a detailed understanding of the linkages between multi-media processes. It is likely that the funding need will vary year to year. For instance a heavy up-front cost is associated with siting and the purchase of new samplers. The cost estimate is reasonable due to the limited amount of funding spent on air quality related research to date, as well as the known importance of air quality impacts ecosystem. A breakdown of the estimated annual research cost is given in Table 8. This cost breakdown is meant to facilitate funding opportunities for individual portions of the entire program. It must be stressed that it is imperative that this entire research program be completed to understand how to arrest the unacceptable loss of clarity at Lake Tahoe.

**Table 8. Estimated annualized cost breakdown for air quality research for the Tahoe Basin. Proposed research will continue for five years to accommodate completion of the 2007 Regional Plan to be adopted by the TRPA. The final product of the research study will include a management based air quality model able to coordinate with other single medium (e.g. water quality or forest health) models in the Basin.**

<b>Research Need</b>	<b>Est. Annual Cost</b>
<i>Spatial and temporal identification of ambient atmospheric constituents.</i>	\$225,000
<i>Establishment of new and upgrading of existing air quality measurement sites.</i>	\$100,000
<i>Research experiments to address specific atmospheric processes at Tahoe.</i>	\$200,000
<i>Enhanced meteorological measurements to characterize Basin and upwind met.</i>	\$100,000
<i>Temperature and pressure-related source and transformation research.</i>	\$75,000
<i>Transportation research with respect to air and water quality.</i>	\$100,000
<b>Total Estimated Annual Cost</b>	<b>\$800,000</b>

Beyond this five-year generalized research plan, representative monitoring should remain in place. Long-term monitoring includes, but is not limited to, the established TRPA South Lake Tahoe visibility monitoring site, the new TRPA research site at the Thunderbird Lodge (east shore), the IMPROVE visibility monitoring site at D.L Bliss State Park, the ARB monitoring sites at Sandy Way, Echo Summit and the new site to be added on the north west shore, and finally a site co-located with long-term TRG deposition measurements (likely at Tahoe City/Lake Forest, and possibly one lake site). The management model constructed as a result of the proposed studies will allow coordination with other single-medium models specific to the Basin. Achieving complete Basin restoration will only be accomplished by coordination of these models. Finally, the linkage between air and water quality understood as a result of this work will be applicable to other restoration efforts, and will promote Lake Tahoe as one of the greatest environmental restoration successes.

## 5.0 Transportation

Transportation planning in the Lake Tahoe Basin is administered at several different levels. TRPA developed transportation plans for the Region since adoption of the bi-state compact. More recently, TRPA was designated as the Metropolitan Planning Organization (MPO) for the Tahoe Basin. This responsibility adds another layer to transportation policy within the Tahoe Basin; one that would meet through the MPO requirements, federal policy goals. The last policy level is with the local jurisdictions.

Current transportation policies administered by TRPA are primarily via the air quality thresholds. There has always been a strong linkage between transportation and the effects on air quality. Historically, TRPA's policies were developed around this linkage although there have been other transportation standards developed for the sake of transportation system performance alone. A good example of a transportation specific policy is TRPA's signalized intersection performance standards. The focus of TRPA's transportation policies, however, has been via the air quality thresholds.

Of the air quality thresholds, TRPA's Vehicle Miles Traveled (VMT) threshold (10% reduction below the 1981 value) and US 50 Wintertime Traffic Volume Reduction threshold (7% below the 1981 value) directly implicate transportation impacts with environmental attainment targets. The remainder of the air quality thresholds are either pollutant standards (similar in nature to federal and state standards) or are tied to visibility and wood smoke and do not directly involve transportation. The two thresholds most closely related to transportation were established as surrogates for transportation's causal effect on some other aspect of the environment. In the case of traffic volumes, the threshold is a surrogate for carbon monoxide (CO) levels, which were in violation of federal and state health standards in 1981. For VMT, it was for a reduction in nitrogenous tailpipe emissions and roadway dust re-entrainment.

The determination of VMT is and was accomplished through the use of a computerized transportation demand model. A model is traditionally used as a useful tool for the purposes of transportation planning; more than just a barometer to gage VMT levels. To the extent practical, TRPA utilizes their existing transportation model for planning as well as VMT assessment purposes although the initial development of the model satisfied threshold purposes.

In concept the transportation model that generated the VMT value has been a useful tool for transportation planning in its own right. As TRPA enters a new era as an MPO, it is recognized that transportation models are integral to the planning activities of MPOs throughout the country. However, the structure of the current model does not provide the utility required for effective transportation planning in the Tahoe Basin nor is the data that drives the model current; the relationships that drive transportation activity are based on 1974 survey data. The severe limitations in the current model are not sufficient to serve as a component to an airshed model nor are they sufficient to conduct rudimentary tests of policy for transportation planning's sake.

As explained throughout this document, further research is required to determine the air depositional effects from all sources, including transportation. With a shift from nitrogen to phosphorous limitation the policy role VMT reduction plays in arresting the degrading lake clarity is in question, certainly if tailpipe emissions themselves are examined. The linkage

between roadway re-entrained dust is also implicit in the threshold; however, the precise linkage between roadway dust and reduced lake clarity has not been established. The policy of VMT reduction as opposed to other factors such as speed for roadway dust is also questionable. Many of these questions are to be addressed by implementing the research identified in Chapter 4.

This chapter is a discussion of the transportation system trends, including transportation based pollutants, followed by a discussion of current TRPA modeling practices and their limitations. Finally, short and long term proposals are suggested to build a transportation model that satisfies the purposes of TRPA as both a regionally and federally designated transportation planning agency as well as transportation's role in the airshed understanding of the Lake Tahoe Basin.

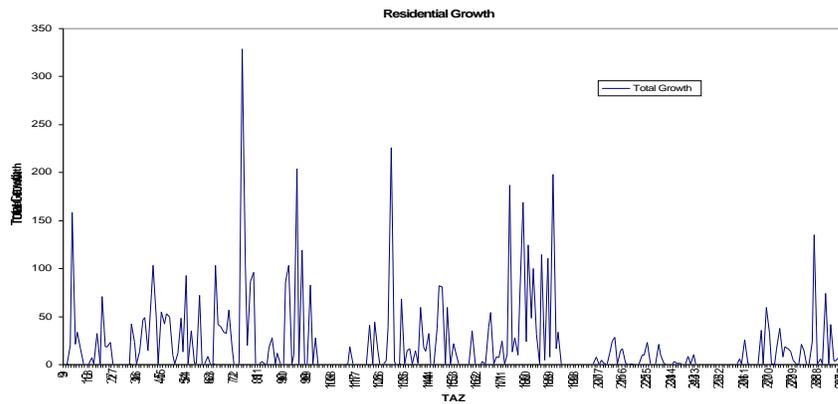
## 5.1 Transportation System Trends

Like many communities, Lake Tahoe is growing, both in residents and visitors, which increase traffic activity. The growth in “bedroom capacity”, however, is limited by the growth controls administered by TRPA. Growth in traffic is not regulated (other than indirectly through TRPA development restrictions) and is subject to the daily and seasonal variations in travel activity. The existing transportation modeling efforts for the 1995 base year and the forecast years indicate that growth in daily peak summer day vehicle activity has occurred. The 1995 Basin-wide total residential population was 51,086, and total visitor units are estimated to be 22,199<sup>1</sup>, with 9,684 occupied. In 1995 there were 11,583 hotel/motel rooms, and 2,465 campground sites. TRPA predicts that residential growth in housing units will increase by 1339 in 2001, by 3166 in 2006 and 4267 in 2016. Tourist accommodation units are expected to increase by 554 in 2001, 302 more in 2006 and 100 more in 2016. Figure 6 show the total predicted residential growth and recreation growth by traffic analysis zone (TAZ) for year 2001, 2006, and 2016. It is shown that the highest residential growth occurs on the north shore of the lake from Lake Forest all the way up to Brockway along SR28, and South Lake Tahoe along US50.

For recreational sites, high growth for day use is evenly distributed on the California side along the northwest-north shore of the lake, from Tahoma up to Brockway. On the Nevada side, high growth occurs in the areas adjacent to California, such as Incline Village and Kingsbury. A few TAZs in South Lake Tahoe are observed to have the highest growth in day use. Overnight use grows evenly throughout the lake relative to day use. Note that recreational/visitor-related socio-economic data are obtained from a transportation survey performed in 1974. At this point, it is unknown how occupancy rates may be shifting from second-home use to year-round use.

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<sup>1</sup> Visitor population is estimated based on the 1974 survey data.

**Figure 6. Total predicted residential growth for 2001,2006, and 2016**

A similar pattern in traffic growth by TAZ to the socio-economic growth can be expected. Unfortunately, comparing the trend of traffic growth by TAZ with population growth by TAZ at this point is not possible because the traffic counts by TAZ are not known. TRPA has provided travel data by trip purpose. Residential non-work-related trips increased by 18% in 1995 over that in 1981, visitor trips increased by 27% and through trips doubled. TRPA projected that in 2016 residential home-based other trips, residential non-home based trips and visitor external trips will increase in magnitude as compared to the 1995 data (Figure 7).

Traffic volumes have been fairly stable at each measured location throughout the Basin in the past twenty years (Figure 8). Compared among measured locations, locations along US 50 have the highest traffic volumes over time and peak month traffic volume has been subject to slight increase over the past twenty years. Traffic along I80-SR267-SR28 is also high. These results are consistent with the residential and recreational growth patterns discussed earlier. TRPA has set the threshold management standard in terms of traffic volume reduction to help with the reduction in carbon monoxide (CO) levels. Traffic volumes on US 50 are to be reduced by 7% from the 1981 base year, during the winter, between 4:00 pm and 12:00 midnight. The threshold standard for CO is to maintain concentrations at or below 6 ppm averaged over eight hours. CO levels have met the TRPA standard and trends continue to show a decrease (CARB-ADAM database, 1999) despite of slight increase in traffic volumes over time. Therefore, the traffic volume threshold tied to CO does not seem to be meaningful at this point.

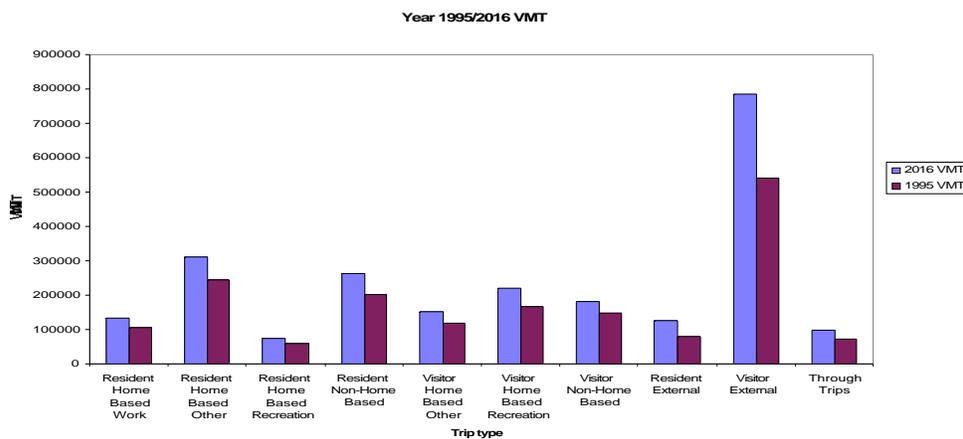


**Table 9. Base Year Trip Purpose VMT, Trips, and Miles**

Trip Purpose	1981 Base Year			1995 Base Year		
	VMT	Trips	Miles	VMT	Trips	Miles
<b>Resident Home Based Work</b>	147446	23465	6.28	106526	26801	3.97
<b>Resident Home Based Other</b>	216468	63483	3.41	242474	72994	3.32
<b>Resident Home Based Recreation</b>	53858	11571	4.65	57669	13191	4.37
<b>Resident Non-Home Based</b>	185517	61564	3.01	203031	72140	2.81
<b>Visitor Home Based Other</b>	191824	21105	9.09	118409	25074	4.72
<b>Visitor Home Based Recreation</b>	186269	19577	9.51	166473	22793	7.30
<b>Visitor Non-Home Based</b>	136468	32428	4.21	148285	39222	3.78
<b>Resident External</b>	60186	6428	9.36	79867	9958	8.02
<b>Visitor External</b>	428296	39879	10.74	540778	56793	9.52
<b>Through Trips</b>	42134	1998	21.09	71567	4025	17.78
<b>Totals</b>	1648466	281498	5.86	1735079	342991	5.06

Source: TRPA, 1995.

**Figure 9. Year 1995/2016 VMT**



VMT has been traditionally used as a vehicle travel parameter in mobile emission models (i.e., EPA’s MOBILE6 and CARB’s EMFAC) to develop running exhaust emission factors to figure the emission rates. This practice is part of the federal transportation conformity procedure in compliance with the Clean Air Act Amendments (CAAA) of 1990 (reinforced by the Intermodal Surface Transportation Efficiency Act (ISTEA) of 1991)<sup>2</sup>. The entire transportation conformity procedure includes: (1) using transportation demand models and mobile source emission models to make a 20 plus-year forecast of emissions from the transportation system, taking account of changing inputs including demographics, land uses, economic development, federally mandated improvements in auto emission systems, new transportation infrastructure and services; (2) comparing the predicted levels of emissions in several milestone years with the maximum emissions permissible under applicable state implementation plans (SIPs); and (3) making transportation planning and policy decisions within the bounds needed to bring the state into compliance with the national ambient air quality standards (NAAQS).

<sup>2</sup> The 1990 CAAA assures that transportation planning in non-attainment and maintenance areas are consistent with state commitments to meet national air pollution standards.

For the Lake Tahoe Region, transportation plans must not only be consistent with the SIP commitment to the NAAQS but also meet the regional stringent air quality standards that exist to improve human health, atmospheric visibility, and lake clarity. VMT threshold has played a critical role in NO<sub>x</sub> emission control because historically Tahoe has been nitrogen (N) limited. However, recent studies have indicated that there has been a shift from N limitation to phosphorous (P) limitation (e.g., Goldman *et al*, 1993), which presumably tied to a large transportation related nitrogen input. Since Tahoe is currently phosphorous limited, reliance on air quality thresholds centered on VMT is dubious. Hence, the continuity of VMT threshold as a transportation and air pollutant control measure is in question.

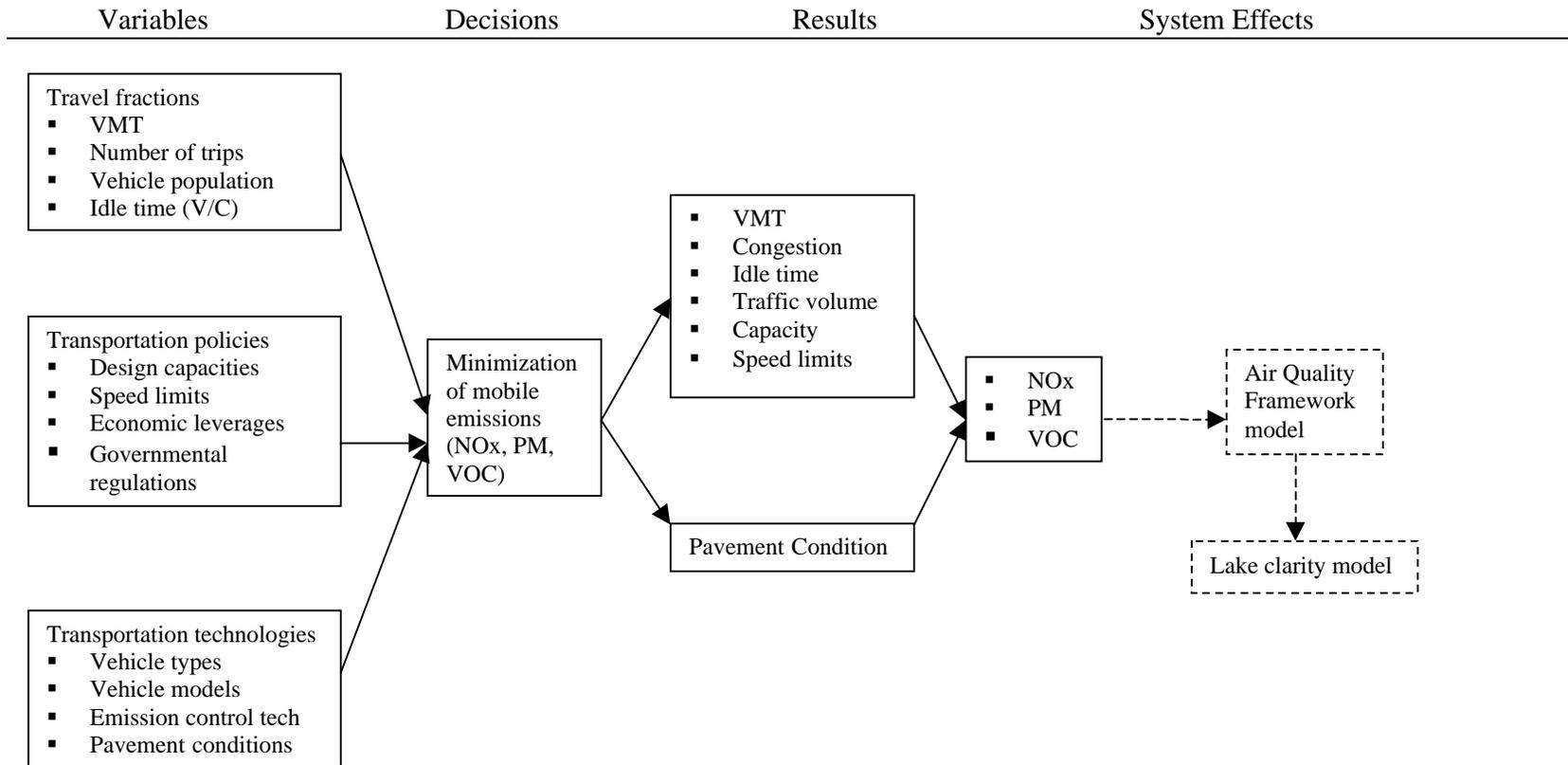
To answer this, a comprehensive analytical modeling technique is needed for evaluating the impact of VMT reduction, in combination with transportation technology, policy and other travel parameters (e.g., number of trips, vehicle population and idle time) on emission reduction thus on lake water clarity improvement. Such a model is known as a VMT threshold performance measurement model. The model structure is shown in Figure 10.

The model inputs include vehicle travel parameters, transportation policies as well as transportation technologies. The travel parameters consist of VMT, number of trips, vehicle population, and vehicle idle time in terms of traffic congestion or ratio of traffic volume and capacity (V/C). Values of these parameters can be obtained from the regional transportation demand model or actual ground counts. Transportation policy inputs include design capacities, speed limits, economic leverages (e.g., tax and toll collection), and governmental regulations. Transportation technologies take into account vehicle types, models, vehicle emission control technologies and pavement conditions, etc. The model outputs include NO<sub>x</sub>, PM, and VOC emissions from running exhaust, starts and hot soaks, diurnal and resting loss as well as roadside dust.

This performance measurement model utilizes optimal control theory in an off-model system (i.e., using the results of the travel demand model). The objective is to minimize the total mobile emissions given a certain level of vehicle travel, transportation policies and technologies as well as budget constraints. Solving this optimization problem yields the optimal traffic volumes, design capacities, congestion level, VMT, vehicle idle time, and amount of pavement improvement, etc. An illustrative example can be found in Donaghy and Schintler (1998). The emission outputs can be used as a process linkage in the air quality framework model (see Chapter 3). Varying the emission outputs from the performance measurement model while fixing pollutants from other sources enables us to understand the marginal contribution from mobile sources.

Model constraints are set up in a way that ensures reasonable outputs from the model. For instance, VMT constraint is determined through various reduction levels, from 10% reduction from the 1981 base year VMT to 20% reduction, etc. Similar rules are applied to other variables, such as number of trips, vehicle population and idle time.

Figure 10. VMT Threshold Performance Measurement Model



## **Exhaust Emissions From Vehicle Tailpipes**

The common tie between transportation and air quality is through vehicle tailpipe emissions. In the Tahoe Region federal, state, and TRPA human health--based standards are in place for most all of the traditional mobile emissions. At the federal level, the Tahoe Region is subject to the federal conformity process, which ensures that no federally funded projects contribute to any decline below the federal air quality standards. California, and to some extent Nevada, have specific emission standards which can affect transportation planning in the Tahoe Region. The TRPA, through the air quality thresholds, has emission standards that are similarly affected by vehicle emissions. As discussed previously, the VMT and traffic volume thresholds are surrogates for other air quality impacts of vehicle activity. Following is a discussion of the traditional tailpipe emissions, the standards, and what is known regarding trends and sources for each pollutant.

### Nitrogen Compounds

#### *Standards-*

There are state and federal numerical threshold standards for NO<sub>x</sub>. California mandates that ambient levels not exceed .25 ppm NO<sub>2</sub> (470 µg/m<sup>3</sup>) for 1 hour. Nevada mandates that NO<sub>x</sub> levels not exceed .05 ppm over an annual 24 hour average (TRPA, 1992a). The federal standard is 0.053 ppm (100 µg/m<sup>3</sup>), annual average (EPA, 1997a). The TRPA does not have a standard for nitrate deposition into the lake but there does exist a threshold standard for Dissolved Inorganic Nitrogen (DIN). It requires that DIN input from atmospheric sources be reduced to 20% of 1973-1981 annual averages (TRPA, 1992a). The 1973-1981 annual average has never been determined so the 20% reduction in DIN has not been assessed.

#### *Sources-*

The majority of oxides of nitrogen (NO<sub>x</sub>) come from both on-road and off-road vehicle sources. Automobiles contribute between 200 and 300 tons of nitrogen to the Lake Tahoe Basin each year (Cahill, 1991). The California Air Resource Board (CARB) estimated that NO<sub>x</sub> from total mobile sources was about 3 tons/day in 1996, with 2 tons/day from on-road motor vehicles (CARB-ADAM database, 1999). Due to emission reduction technology, CARB predicts that in 2010 NO<sub>x</sub> from the total mobile sources will have gone down to 2 tons/day in the Basin, with half of the NO<sub>x</sub> emissions from on-road motor vehicles (CARB-ADAM database, 1999).

As described in Chapter 2, the relative contribution of in-Basin versus out-of-Basin nitrogenous pollutants/nutrients is not fully understood. A large portion of the research program outlined in Chapter 4 is designed to address this uncertainty.

## Ozone

### *Standards-*

The federal threshold standard for ozone is set at .12 ppm for 8 hours, while the California standard dictates that ozone levels should not exceed .09 ppm for any given 1 hour period. In Nevada the level is set at .10 ppm. The TRPA has also set a maximum threshold standard for ozone exclusively within the Lake Tahoe Basin; it is a more stringent .08 ppm for a 1-hour period.

### *Sources-*

Ozone (O<sub>3</sub>) is formed by the photochemical oxidation of hydrocarbons, CO, NO<sub>2</sub> and other compounds in the atmosphere. Therefore, O<sub>3</sub> is a secondary pollutant requiring precursors that typically derive from automotive emissions. According to CARB about 85% of hydrocarbons and 96% of NO<sub>x</sub> from man made sources in the Basin are emitted by motor vehicles (Johnston, R.A., and Pederson, B., 1989). Thus the problematic ozone levels in the Lake Tahoe Basin can be directly tied to transportation. Ozone is detrimental to the Basin due to the role it plays in the oxidation process of SO<sub>2</sub> and NO<sub>2</sub>. When these gases are oxidized they become particulate sulfate and nitrate respectively, and are subsequently deposited in the Basin effecting both air and water clarity (TRPA, 1992a). Although water clarity reduction will not result directly from increased O<sub>3</sub> levels, it is known that O<sub>3</sub> affects vegetation. It is, however, possible that increased nitrate may result from a positive feedback due to increased ozone levels. Since Lake Tahoe is now phosphorous limited increased O<sub>3</sub> is unlikely to have any large effect on lake clarity.

Jeffery Pines, a ubiquitous tree in the Sierras, are especially sensitive to ozone exposure (Johnston, R.A., and Pederson, B., 1989). In a study done by Johnston and Pederson it was found that 75% of all sampling sites in the Basin show some sign of ozone damage. It was noted that the Lake Tahoe Basin has a relatively high background ozone level of .04-.06 ppm, due to conifer release of terpenes, so even minor transportation episodes can push the ozone level above state and TRPA thresholds.

## Carbon Monoxide

### *Standards-*

The Tahoe Regional Planning Agency has set a numerical threshold standard for Carbon Monoxide (CO) at 6 ppm over an 8-hour period. The California 8-hour standard is also 6 ppm. The federal (and Nevada) standard is 9 ppm over 8-hours. CO is the only pollutant within the Basin subject to conformity analysis as violations of the federal standards occurred in the past. The California portion of the Tahoe Basin is under a Maintenance Plan for CO and Nevada has petitioned EPA for a limited maintenance plan for the Nevada portion of the Basin. CO monitoring now shows attainment of all CO standards within the Tahoe Basin which is a trend expected to continue.

*Sources-*

Carbon Monoxide is an odorless gas produced by the incomplete combustion of fossil fuels (TRPA,1992a). It is a health hazard due to the fact that it replaces O<sub>2</sub> in the blood stream. The TRPA (1992a) has reported that 98.3% of CO is generated by mobile sources. In addition to the threshold standard for CO, TRPA also has a traffic volume reduction standard along US 50 that was in place to help foster CO reductions. Now that CO reductions are below the threshold standards, the purpose for the traffic volume standard has been accomplished. Consideration can be given to removing the standard for the purposes it was originally intended.

## **5.2 Transportation Modeling**

A transportation model is a computer simulation of traffic activity. A transportation model provides future VMT and link volume projections for use in air quality and level of services (LOS) analyses for various regional planning alternatives, including transportation planning. For TRPA purposes, VMT is also an environmental threshold measure that serves as a surrogate for nitrogen and re-suspended roadway dust deposition from the air to Lake Tahoe. On the federal and state side of transportation planning, planning decisions must be made within permissive pollution levels required by the state implementation plan (SIP), which ensures the state development without violating the national air pollution standards mandated by the Clean Air Act Amendments (CAAA) of 1990. The regulatory procedures are known as transportation conformity (or conformity).

### ***Transportation Conformity***

The Clean Air Act Amendments (CAAA) of 1990, reinforced by the Intermodal Surface Transportation Efficiency Act (ISTEA) of 1991, assures that transportation planning in non-attainment and maintenance areas are consistent with state commitments to meet national air pollution standards. This is accomplished by first using transportation demand models and mobile source emission models to make a 20-year forecast of emissions from the transportation system, taking account of changing inputs including demographics, land uses, economic development, federally mandated improvements in auto emission systems, new transportation infrastructure and services. The predicted levels of emissions in several milestone years are then compared with the maximum emissions permissible under applicable SIPs. Thus the transportation planning and policy decisions are made to keep transportation-related emissions within the bounds needed to bring the state into compliance with the national ambient air quality standards (NAAQS).

To ensure that transportation plans, programs and projects conformed to SIP commitment to meet the NAAQS, the conformity requires transportation performance measures. Emission reduction tests must be conducted for any particular pollutant and/or its precursors. Additional analytical requirements for PM<sub>10</sub> and ozone are needed. That is, PM<sub>10</sub> areas must perform both qualitative and quantitative analysis of PM<sub>10</sub> and its precursors. Ozone areas are required to perform emission reduction test for not only NO<sub>x</sub> but also VOCs. Furthermore, predicted emissions from the transportation network model are compared with the SIP mobile source budgets.

The conformity regulations challenge transportation planners to develop comprehensive analytical frameworks for managing transportation systems. This model can be used to evaluate and determine the optimal combination of transportation technology, policy, and emission reduction.

### **TRPA Transportation Modeling History**

In 1983 and 1984, the California Department of Transportation (CalTrans) developed a 1981 base year transportation demand model of the Lake Tahoe Basin. The model was based on the standard travel demand forecasting model, which involves trip generation, trip distribution, modal split, and trip assignment. Ten types of trips (Table 10) were considered in the trip generation stage. The original 1981 base year model was calibrated using 1974 Basin-wide origin-destination (O-D) survey (TRPA, 1995), and a home and hotel/motel survey conducted from January to March 1974 and July to September 1974.

**Table 10. Trip Purposes in the TRPA Transportation Model**

<b>RHBW</b>	Resident home based work trip
<b>RHBO</b>	Resident home based other trip
<b>RHBR</b>	Resident home based recreational trip
<b>RNHB</b>	Resident non-home based trip
<b>VHBO</b>	Visitor home based other trip
<b>VHBR</b>	Visitor home based recreational trip
<b>VNHB</b>	Visitor non-home based trip
<b>REXT</b>	Resident external trip
<b>VEXT</b>	Visitor External trip
<b>THRU</b>	Through trip.

In the late 1980's, TRPA purchased the modeling software package (TRANPLAN) and developed a 1987 base year model, relying mostly on the 1981 base year model input data with a few adjustments. These adjustments included relocation of several zonal centroids, and addition to left turn penalties, speed adjustments, and capacity changes on links throughout the Basin.

As a result of these refinements, the correspondence between computed volumes and actual ground counts on several network links was improved. The use of K-factors to weight the attractiveness of the four areas characterized by greater social, cultural and recreational attributes: South Casino Core, South Wye, Tahoe City, and Kings Beach, also helped to refine the forecasting model.

The last base year model update was in 1995 and included the following:

- Incorporation of all of the 1981 and 1987 validation measures;
- Revision of trip generation using a combination of different socio-economic source data and network data to better reflect the 1995 Tahoe Basin urban activity system;
- Update of the socio-economic data; and
- Model execution and results analysis.

One significant difference between the previous base year models and the 1995 update is the incorporation of current socio-economic data (Table 11). The updated socio-economic data includes resident population, resident income level, total number of hotel/motel rooms, and number of campground sites. The visitor trip data, however, have not been updated; these data include number of occupied visitor units, visitor population, number of hotel/motel occupied rooms, hotel/motel population, number of occupied campground sites, and campground population.

**Table 11. 1995 Socio-Economic Data Sources\***

Category	Source
Resident Population	1990 census block group level
Resident Income Levels	1990 census track
Visitor Units	Total units minus occupied units
# Occupied Visitor Units	Occupancy rates from 1974 survey
Visitor Population	Occupied visitor units times 1974 visitor persons per household
Visitor Income Levels	1987 transportation model census tract level income distribution to occupied visitor units
Hotel/Motel Total Rooms	1995 land use data (parcel level)
Hotel/Motel # Occupied Rooms	Occupancy rates from 1974 survey
Campground Total Sites	1995 land use data (parcel level)
Campground # Occupied Sites	Used occupancy rates from 1974 survey
Campground Population	Occupied campground sites times 1974 visitor persons per site
Total Visitor Population	Visitor plus hotel/motel plus campground populations

\* Employment category is not included in this table. Employment data sources vary from county to county. *Source: TRPA, 1995*

### Issues of Current Transportation Modeling at Lake Tahoe

The following eight major issues with respect to VMT estimation and emission modeling for the TRPA four-step transportation demand mode are identified:

1. The current TRPA travel demand model is a 24-hour model, meaning that the output link assigned traffic volume represents an averaged 24-hour volume. In other words, traffic volume is not currently differentiated by time of day. Historically, this may have made some sense, since travel was largely tourist-related. Since speed, road condition, temperature, and wind all play an important role in vehicle emissions and emissions generated under peak hour traffic conditions are different from those under non-peak conditions, the modeling of peak-hour condition may be important. However, due to a lack of data, it is not possible to identify whether or not incorporating peak-hour modeling is necessary. For example, if the hourly volume turns out to be fairly stable, using a 24-hour average may be adequate.

2. The current TRPA travel demand model produces estimates of peak summer daily VMT and number of trips by link. Traffic volume, however, varies by seasons in the Tahoe area due to the large in flux of visitor/recreational trips. Again, the air quality implication is that seasonal variation of traffic volume in addition to meteorology.
3. The current TRPA travel demand model is an aggregate model, calibrated and applied at the level of geographical zones. The basic assumption for an aggregate model is the homogeneity of the aggregate groups, which may not be true in the Tahoe Region because of the large visitor population and visitor trips represented in the total population and total trips. Furthermore, an aggregate model is poor in modeling a wider variety of travel-related behaviors, when compared to the dis-aggregate model.
4. The travel speed provided by the four-step travel demand model is not reliable. Travel speed is a significant variable in determining mobile source emissions and should be validated in the travel demand forecasting process. For historical transportation planning purposes, the link speeds together with numbers of trips were used only as interim measures to validate the volume of travel on the road networks. Hence the estimated speeds and numbers of trips were not validated separately from the volume of travel and were not precise.
5. The current TRPA travel demand model continues to use visitor socio-economic data from the 1974 O-D survey. Even though new resident socio-economic data have been used in the 1995 base year model, visitor data from 1974 O-D survey remain in the current model.
6. Model input factors were developed based on the 1974 O-D survey and used in the models. With changes in socio-economic characteristics, it is necessary to determine if any update to the explanatory trip variables is warranted.
7. The current model does not provide any parameters or off-model analysis to account for roadside dust treatments.
8. The current model utilizes the all-or-nothing algorithm to assign the external trip purposes (REXT, VEXT, and THRU) and the user equilibrium for the internal trip purposes (RHBW, RHBO, RHBR, RNHB, VHBO, VHBR, and VNHB). One of the problems associated with these two assignment algorithms is that capacity limitations are not taken into account.

In general, the TRPA travel demand model forecasting is currently unable to provide sufficient travel-behavior related information. Also, the information is not at a level that refined emission inventory estimation requires. According to TRPA, planning decisions have been postponed, action has not been taken, and entire programs, parking management, for example, have not been implemented because a lack of knowledge due to insufficient, inappropriate, or antiquated model information. There is a need for a new travel demand modeling effort that incorporates a more contemporary activity-based approach.

One major difference between Lake Tahoe and other urban areas in terms of travel patterns is its large proportion of visitor and/or recreational trips. According to the 1995 base year model output, visitor trips account for 42% of the total trips, and 56% of the total VMT. A visitor/recreational trip is a one-time activity rather than a regular daily-based activity such as a commute trip. Recreational trips normally involve an individual making choices from sets of

alternative destinations. A destination choice set is determined by many factors, including travel duration, budget, recreational type (e.g., fishing, camping), and travel season, as well as the standard socio-economic characteristics such as income.

For the Lake Tahoe Basin, there is a particular need for better linkage between evaluation of the travel demand modeling efforts and policy sensitive criteria, such as capacity, VMT, vehicle idle time, roadside dust emissions, and VOC emissions. These criteria fall both into the range of traditional transportation planning and the potential non-traditional linkage that may be tied to lake clarity. There is also a need to update the TRPA travel demand model to reflect the current travel patterns. This modeling regime is particularly applicable for Tahoe, where the journey to work pattern is not as dominant as in typical urbanized areas. In the next sections, recommendations are outlined for better understanding the role of roadside dust suspension as well as a revised transportation model. Developed understanding of roadside dust will be important if it is strongly linked to lake clarity effects. A new transportation model becomes a vital tool in transportation planning and should link to the airshed understanding once transportation's role in impacting lake clarity is better understood.

### Road Dust From Traffic

The role of roadside dust is suspected to play a role in affecting lake clarity. If this is demonstrated through the airshed research (Chapter 4) then emission factors from that source will be required. To develop emission factors for roadside dust treatment, an understanding of particle resuspension is needed. In this report, the term resuspension is used to include suspension or entrainment since it is not easy to distinguish between suspension and resuspension (Sehmel, 1980). With increased road traffic, the importance of vehicle activity as a resuspension mechanism becomes a key issue. The following factors are thought to affect resuspension.

Traffic related fugitive dust consists of geological material (mainly oxides of silicon, aluminum, iron, and some calcium (Hoosmuller, 1998)), tailpipe exhaust, pavement and tire wear, anti-skid material, and brake/clutch wear (Chow *et al.*, 1992). These materials are resuspended into the atmosphere by vehicular travel. Most of the resuspended dust deposits a short distance from its source, but a portion can be resuspended and transported for miles (Chow *et al.*, 1992). CARB has estimated that paved and unpaved road dust each contribute 2 tons/day to particulate matter (PM) totals, accounting for more than 50% of the total PM emissions in the Tahoe Basin (CARB website, 1999). Questions related to resuspended road dust include: What transport mechanisms dictate dust migration from road surface to Lake surface? What are the deposition rates? And what portion of the road dust contributes to water clarity reduction?

Emission factors for road dust are closely correlated to vehicular composition data, meteorology, and road surface conditions. The following parameters are thought to be important to road dust emissions.

### Transportation-Related Pollutant Control Measures

Measures which seek to limit the amount and type of traffic present on the road, or lower the mean vehicle speed may not be efficient because empirical experience indicated that emissions

were poorly correlated to speed raised to the power of approximately 0.3 (USEPA, AP-42 Ch.13.2.2). Effective enforcement of the new speed limit can also be problematic in that speed reduction conflicts with the concept of improved road capacity (i.e. less travel time). Currently available short-term tests suggest that the control efficiency afforded by speed reduction should be considered as linear (USEPA, AP-42 Ch. 13.2.2). That is, if the average speed is effectively reduced by 30%, a control efficiency of about 30% should be applied to the emission factor.

Road surface improvements include paving an unpaved road or shoulder. The high initial costs of paving roads and shoulders are often prohibitive. Emission control efficiency is determined by comparing emission factors for unpaved and paved roads in terms of the cost and social benefits. The costs of routine cleaning of paved road surfaces should also be taken into account when control efficiency is estimated. Conversely, the social benefits of paving, such as better air/water quality, and subsequent health improvements, can be potentially high and may outweigh construction and maintenance costs for paved roads. Controls of ambient NO<sub>x</sub> levels can not be solidified until the debate over pollutant source is settled. Both ozone precursors and CO are being reduced with emission control technology in each new fleet. As these steps may not be enough for the Lake Tahoe Basin to attain ambient levels below standard thresholds, traffic control measures in congested areas may become necessary.

*Road surface moisture* Resuspension mechanisms vary from dry surfaces to wet ones. In dry condition, resuspension may be caused by the effects of induced turbulence, generated as air is squeezed from beneath the tire as it rolls over the road surface, and tire shear generated by the rotation of the tire. On the other hand, under very wet conditions, tire spray can be an effective resuspension mechanism (Nicholson *et al*, 1990)

*Vehicle speed* Experiments have indicated a clear dependence of amount resuspended on vehicle speed. (Nicholson *et al*, 1990; Sehmel, 1973) As might be expected, a higher vehicular speed causes more efficient resuspension of material. The fraction resuspended per vehicle passage increases as a function of vehicle speed.

*Road surface roughness* Road surface roughness influences the resuspension process. As might be expected, the smoother the surface is, the less likely particles will stay on the surface. In fact, if the surface is rather smooth (e.g., 5 $\mu$ m), less than 20% of the particles will remain on the surface. When the surface becomes rougher (e.g., 250 $\mu$ m), nearly 0% of amount will be resuspended (Mollinger *et al*, 1993). This is due to the increase of adhesive force with increase of surface roughness (Corn *et al*, 1965).

*Particle size* There is a strong dependence of the amount resuspended on the resuspended particle size. Larger particle size increases amount resuspended (Nicholson *et al*, 1990). In other words, resuspension becomes more difficult with decreasing particle size because the smaller particles have the smaller areas on which shear stresses could act and the relative enlargement of the adhesion force with smaller diameters (Mollinger *et al*, 1992). However, Nicholson *et al* (1990) also observed a considerable overlap of the resuspension curves for 12 $\mu$ m and 20 $\mu$ m diameter particles.

*Meteorological conditions* The fraction of what resuspended depends on meteorological conditions, such as humidity and wind speed. Humidity reduces resuspension (Cohen, 1977;

Nicholson *et al*, 1990). The occurrence of high winds is thought to facilitate the movement of deposited material. The relationships between wind speed and resuspension rates vary from an experiment to another, which may indicate a dependence on the type of surface and environmental conditions. A major problem associated with wind is that upwind sources affect atmospheric concentrations, thus is believed to affect the resuspension factor.

*Type of vehicle* The type of car can have a tremendous impact on the resuspension, in particular, the distance of the vehicle model to the test surface and the shape of the model. For instance, the lower the bottom plate from the road, the higher the resuspension rate is (Mollinger *et al*, 1993). A truck seems to cause more resuspension than a car (Sehmel, 1973). Vehicle shape is, in fact, a very important factor that affects resuspension. Experiments (Mollinger, 1993) show that when all parameters stay the same but the vehicle shape, block-shape vehicles cause the highest resuspension rate, followed by the ellipse. Cylinder-shape vehicles cause the lowest resuspension rate among the three. The reason lies in the fact that the ellipse is longer than the cylinder. That is, both models have the same leading edge, but different volume. Vehicle size (weight) also contributes to particulate emissions. An experiment measuring particulate emission rates for unpaved shoulders along a paved road, conducted by Moosm Iler *et al* (1998), showed that significant dust entrainment were almost exclusively caused by large vehicles such as trucks, semis, and vehicles pulling trailers, traveling 50-65 mph.

*Particle deposition* Particle deposition process is an important component of the whole resuspension-deposition cycle. Various particle deposition patterns affect the subsequent particles resuspended. Sehmel (1973) found out that the particle deposition pattern is a function of whether the vehicle is driven by or driven through the source area. If a car is driven by on the lane adjacent to the source area, the cumulative deposition rate increases rapidly when the vehicle speed is less than 15 mph and decreases after the speed exceeds 15 mph, regardless the distance from the road. If a car is driven through the source area, deposition exhibits a very different pattern. The cumulative deposition rate decreases when the car speed is less than 30 mph and increases afterwards. In both cases, the cumulative deposition rate increases with the increase of distance from the road.

Other parameters such as traffic volume and seasonal factors are also important. The number of vehicle passes greatly affects the resuspension rate. In general, the higher number of passes, the higher the observed resuspension rates. With the increase of the number of passes, the resuspension rate quickly becomes flat. In the Tahoe Basin, travel activities change by season. Meteorological conditions display an episodic characteristic. Therefore, seasonal and episodic factors are also critical to the particle resuspension process.

Particle resuspension is a very complicated process. In practice, sometimes it is difficult and even impossible to discriminate between all factors that influence resuspension process. However, the variables that would be possible to influence from a policy perspective would include (i) traffic composition; (ii) vehicle speed; (iii) road surface; and (iv) shoulder surface. There exist a variety of options to control roadside particulate emissions from both paved and unpaved roads. These options include traffic controls limiting the speed, number of vehicles, or type of vehicles on the road, and surface improvements such as paving a road or shoulders.

These types of control measures seek to limit the amount and type of traffic present on the road or to lower the mean vehicle speed. As previously discussed, high vehicular speed creates a high resuspension rate; speed reduction is a clearly one viable control measure. However, the control measure must effectively reduce the fleet average speed to be effective because empirical experience indicated that emissions were poorly correlated with speed raised to the power of approximately 0.3 (USEPA, AP-42 Ch.13.2.2). On the other hand, effective enforcement of the new speed limit may prove problematic in that speed reduction conflicts with the concept of improved road capacity (i.e., less travel time). Currently available short-term tests suggest that the control efficiency afforded by speed reduction should be considered as linear (USEPA, AP-42 Ch. 13.2.2). That is, if the average speed is effectively reduced by 30%, a control efficiency of about 30% should be applied to the emission factor.

One obvious option for road surface improvements is paving an unpaved road or an unpaved shoulder. However, the high initial costs are often prohibitive and the emission control efficiency is determined by comparing emission factors for unpaved and paved road conditions in terms of the costs and social benefits. The predictive emission factor for paved roads requires estimation of the silt loading on the traveled portion of the paved surface. The costs of routine cleaning of the paved road surface should also be taken into account when control efficiency is estimated. On the other hand, the social benefits by paving, such as better air and water quality, and health benefits, can be potentially high and may exceed the total cost spent.

Other measures include VMT reduction and vehicle idle time in terms of traffic congestion or ratio of traffic volume and capacity (V/C). VMT is associated with hydrocarbon (HC) emissions from a light-duty automobile as well as other mobile emissions. VMT represents travel activity in the standard procedure for estimating emissions by the EPA's MOBILE emissions model as follows: emissions = emission factor  $\times$  vehicle activity. Therefore, accurate estimation of VMT is critical for emissions inventory estimation. Methods for estimating VMT are discussed and compared in Kumapley and Fricker (1996). The major idling vehicle emissions include volatile organic compounds (VOC), CO and NO<sub>x</sub> (PM<sub>10</sub> emissions are provided for heavy-duty diesel vehicles only). It is unclear how much NO<sub>x</sub> that contributes to atmospheric nitrogen comes from idling vehicle emissions, especially in cold, winter conditions.

Another consideration is the application of sand and salt to the roadways during snowy conditions and the removal of it from the roadway. The tie to roadway travel activity is independent of the amount of sand that may be present during any period of the year. The levels of sand present on the roadway would be subject to applications rates, the amount of snow precipitation, temperature, rain precipitation, and any dispersion or collection from the roadway after application. This may be a greater variable with respect to re-entrained roadway dust than the other transportation factors presented.

To evaluate the transportation system performance with respect to traffic volume, VMT, congestion, pavement condition, and thus the VOC, and roadside dust emissions, a transportation system performance model utilizing optimal control theory that characterizes the states of traffic volume, design capacities, congestion, and pavement conditions is necessary. The model also depicts the system and should ideally be based on activities not trips.

There are six important performance measures, which should be considered as model outputs for understanding the role of re-entrained roadway soil particles:

*Link Volume* Link volume is determined by the following parameters: (1) trip generation rate at origin, which is a function of household's or traveler's socio-economic characteristics; (2) travel time; (3) travel cost; (4) volume-to-capacity ratio; (5) design capacity; and (6) pavement condition.

*Design capacity* Design capacity is a policy variable. A change in the design capacity of a link is defined by the capacity addition through new construction.

*Pavement condition* Pavement condition can be specified as a function of (1) an indicator variable that indicates paved or unpaved surface, (2) pavement thickness, (3) surface roughness, (4) traffic capacity and volume, (5) vehicle speed, and (6) indicator variables denoting surface maintenance and improvement policy strategies.

*VMT* VMT is measured using link traffic volume and link (or trip) distance.

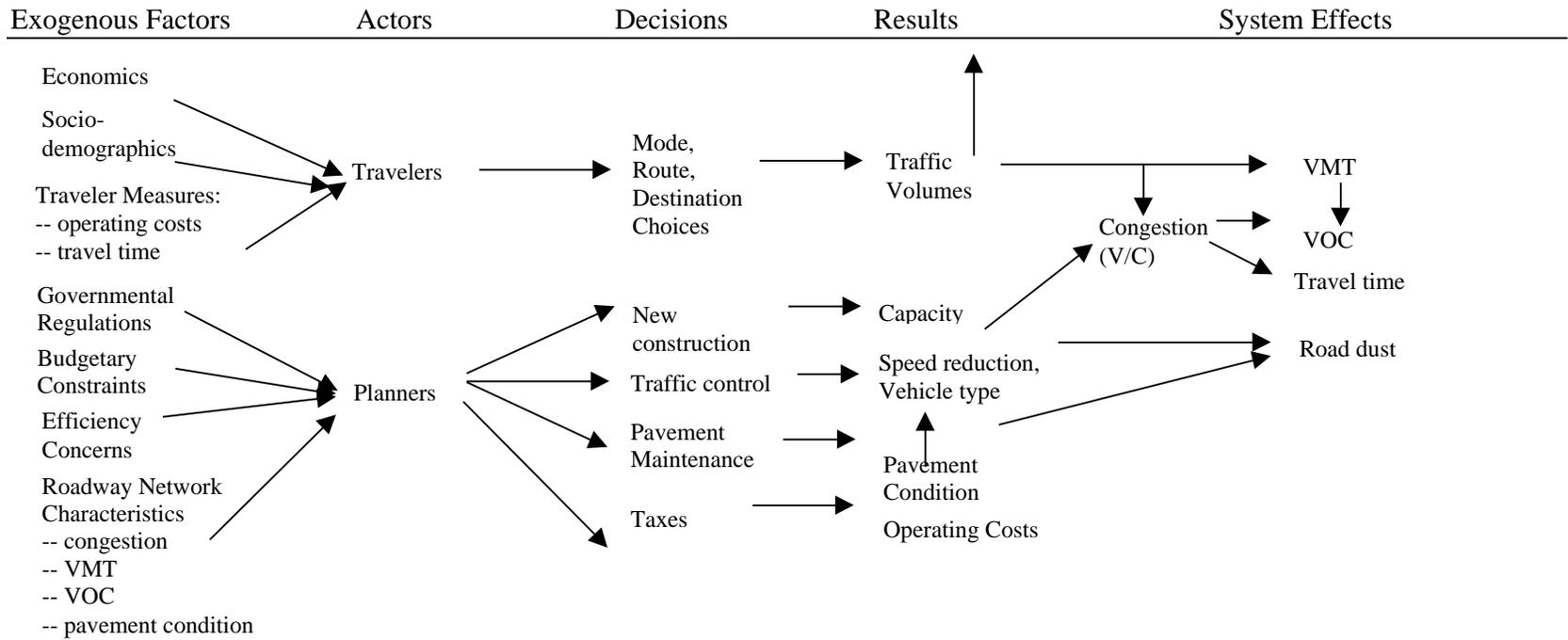
*Roadside dust emissions* Roadside dust emissions are measured as a function of traffic volume, road surface moisture, particle deposition rate and velocity, and roadside dust emission factors. Roadside dust emission factors are determined by vehicle speed, vehicle type (i.e., size, shape, etc.), pavement conditions, and meteorological conditions.

*VOC emissions* VOC emissions are measured using VMT, route distance, traffic volume, vehicle speed, and a VOC emission factor, which is determined by the average speed of travel over a link, the distance of the link, and the effect of vehicles operating in cold-start status.

To evaluate the transportation system performance, one could utilize optimal control theory in an off-model system (i.e., using the results of the travel demand model). For the Lake Tahoe area, if the interest continues to be in reducing VMT, roadside dust emissions, VOC emissions, and vehicle idling time, several objective functions could be formulated. For instance, the objective could be to minimize VMT, or minimize the sum of squared deviations from 0.80 of volume-to-capacity ratio. The optimal problem is subject to a budget constraint in which new construction, pavement condition improvement and maintenance are restricted. The pavement condition for each link must meet a minimal performance level. The total VMT must perform a 10% reduction from the 1981 VMT threshold and VOC emissions and roadside dust emissions must not exceed the levels mandated by the Clean Air Act Amendments (CAAA).

Solving this optimization problem yields the optimal traffic volumes, design capacities, congestion level, VMT, roadside dust emissions, VOC emissions, vehicle idling, and amount of pavement improvement. Comparing these results with current conditions, one may find out, for instance, how much new construction is allowed, how much surface improvement should be done within a specified budget constraint and desirable levels of traffic, congestion, VMT, and idling time, etc. An illustrative example can be found in Donaghy and Schintler (1998).

**Figure 11. Transportation System Performance Model**



### **Transportation Model: Short-Term Efforts**

For transportation planning purposes as well as those that can be anticipated from any lake clarity linkage, the model should be able to provide policies support for future transportation/air quality analyses to satisfy TRPA, state and federal planning requirements. The current four-step transportation model does not meet these requirements in that it is unable to provide sufficient travel behavior data in its own right or as any potential linkage to the air quality model, and eventually to the lake water quality model.

In developing a new TRPA travel demand model the intent is that it can be eventually incorporated in the entire understanding of water clarity influences at Lake Tahoe either as a major factor (as it is characterized today) or as a more minor contributor. This linkage will be explored in the implementation of air quality research outlined in Chapter 4. Regardless, whether for transportation planning purposes or as relevant to the air quality and watershed models for the Lake Tahoe Basin, the new travel demand model should provide travel activity that serves all these purposes. The following features are identified for consideration when developing a travel demand forecasting model:

1. The visitor/recreational trip should be modeled separately from a resident trip.
2. The conventional trip-based model should be replaced with a tour-based model. A *tour* is defined as a sequence of trip segments that start and end at the same location. Specifically, for a resident tour, the location is referred to his/her home. For a visitor tour, the location is referred to the zone that is not within the area being modeled. The advantage of utilizing tour or trip chaining over single trip lies in that it's more consistent with a person's actual daily travel pattern. A trip chain is sequence of activities that are temporally and spatially connected. Introducing the concept of tour or trip chain leads to an activity-based modeling approach, which is discussed next.
3. An activity-based model provides more information on traveler behavior than a trip-based model that models every single trip. An activity-based approach defines a trip through individual activities. There have been numerous studies on activity-based modeling approaches. Jones, Koppelman, and Orfeuil (1990) argued that an activity-based approach has a deeper understanding of traveler behavior, both of travel itself and the characteristics of households and their activities, which relate to it, directly or indirectly.
4. The new model should focus on destination choice, applicable to both resident and visitor travel activities, and describe the dependency and the interrelationship between the destinations in a given tour. A recreational tour is a typical application of a destination choice model. Unlike a work trip, which normally has a fixed destination, i.e., the destination choice set has only one choice, a recreational trip involves a decision making process of selecting one destination from several feasible ones.
5. A time-of-day trip distribution should be incorporated into the travel demand forecasting process. This module provides the hourly volume and peak period volume useful to the air quality model. This is a very important step in the whole modeling process because it bridges the gap between travel demand modeling and air quality modeling. Historically,

travel demand and mobile emissions are modeled separately, using different algorithms and output formats. However, these two efforts and outputs are causally related. The modeling efforts ought to be jointly carried out, and combined where feasible. The time-of-day distribution should also be facility specific.

### ***Coordination of Transportation and Air Quality Models***

Transportation demand modeling practice is very important for the regional air quality modeling practice because it provides future VMT and link volume projections for use in air quality and level of services (LOS) analyses for various regional planning alternatives, including transportation planning. For TRPA purposes, VMT is also an environmental threshold measure that serves as a surrogate for nitrogen deposition from air to the lake. Lake Tahoe transportation planning decisions must be made within permissive pollution levels required by both the regional air quality standard and the state implementation plan (SIP), which ensures the state development without violating the national air pollution standards mandated by the Clean Air Act Amendments (CAAA) of 1990. A four-step transportation demand model was originally developed for the purpose of regional transportation planning instead of regional emission control. In practice these two close related activities, vehicle activity and mobile emissions, are modeled separately. Therefore, there exists a mismatch between the purpose that a transportation model serves and its modeling process. The transportation demand model is not able to provide necessary inputs to the emission model. For TRPA purposes, transportation activities and mobile emissions should relate to the air quality model and eventually the watershed model of Lake Tahoe. Questions such as what transportation parameters are air quality indicators, and how to link transportation to air quality have yet to be answered. The first section gives a little background information of the TRPA transportation modeling. In the following sections, the importance of transportation parameters that we think should be considered in air quality modeling is discussed.

Two categories of pollutant sources are identified in Chapter 2, out-of-Basin sources and in-Basin sources. Mobile source emissions contribute to the in-Basin pollutant input directly and indirectly through out-of-Basin input for species such as O<sub>3</sub> and nitric acid. Therefore, transportation and mobile emission models should be incorporated into the air quality modeling framework. A coordinated transportation and air quality model as part of the Lake Tahoe Water Clarity Model should be able to evaluate policies for future transportation and air quality analyses to aid management decisions by TRPA. The coordinated modeling approach is shown in Figure 12 and is discussed in Chapters 3 and 4.

Mobile emissions models (e.g., MOBILE used by USEPA and EMFAC used by California) estimate running exhaust emissions by the product of an emission factor and a travel activity (VMT). The estimation process begins with the basic emission rates (BERs) measured in grams per mile under a standard test condition. To account for operating mode variation, temperature impact, tampering effect, different fuel types, and different speeds of travel, correction factors are applied to BERs. Later, an adjusted BER is multiplied by VMT by vehicle type or by speed and vehicle composition data, such as model year, vehicle class, and vehicle technology, and forms a composite emission factor (CEF). Finally, the running exhaust emission is calculated as the product of CEF and VMT.

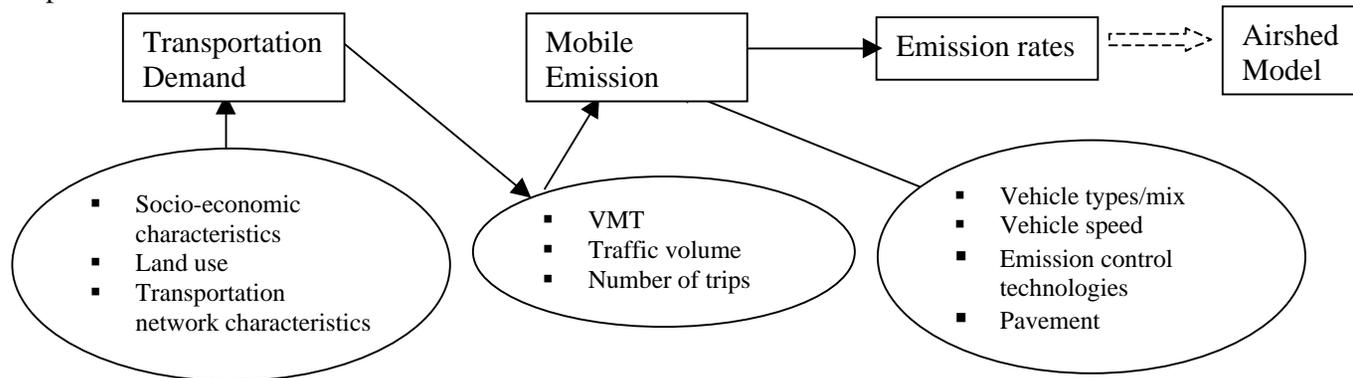
VMT is used in estimating mobile emissions because the travel demand model can provide VMT easily and  $\text{NO}_x$ , a major pollutant from transportation, is closely correlated to VMT by speed. Note that VMT only represents running exhaust and running evaporative emissions. Cold/hot start and soak emissions are estimated by using trip fraction parameter. Diurnal and resting loss emissions are estimated by using vehicle population parameter. Roadside dust involves traffic conditions, vehicle mix and road conditions, etc. Therefore, using only VMT as the traffic control measure may not be sufficient if the non-VMT emissions contribute a non-trivial portion of the total vehicle emissions.

Travel speed is one of the most important factors that influence vehicle emissions and fuel consumption (e.g., Trozzi *et al*, 1996; Hassel *et al*, 1995; Joumard *et al*, 1995; Hansen *et al*, 1995; and Andre & Pronello, 1997). For instance,  $\text{NO}_x$  emissions with or without a catalyst are high at the low and high ends of the speed spectrum. CO and HC emissions decrease almost monotonously with increase of speed.  $\text{NO}_x$  emission has a very similar profile to the mileage-speed curves (Trozzi *et al*, 1996). There are various techniques of estimating vehicle speeds both spatially and temporally for mobile source emission inventories, for instance, emission model default values, observed travel speed surveys, HPMS outputs, TDM trip assignment outputs, and volume-to-capacity ratios. More detail descriptions can be found in Decker *et al* (1996).

Other important transportation related parameters include vehicle type and mix. TRPA transportation demand model categorizes vehicles into six different types, light duty automobile (LDA), light duty truck (LDT), medium duty truck (MDT), heavy duty gasoline vehicle (HDG), heavy duty diesel vehicle (HDD) and motorcycle (MC). The vehicle mix consists of around 90% of LDA, less than 10% of LDT, and very small percentage of MDT, HDG, HDD and MC. However, its representation of today's vehicle mix in Lake Tahoe is doubtful as sport utility vehicles (SUVs) become more and more popular for travel in Lake Tahoe. Some SUVs currently do not meet the same standards as regular passenger vehicles, pollute up to 3-5 times as much and make up large fraction of the vehicles in the Tahoe Basin today. Heavy-duty diesel trucks can be another potential source of HC,  $\text{NO}_x$ , and particulate matters. Even though TRPA (1991) concluded that diesel vehicles were not a significant source of fine particulate carbon due to a relatively small number of diesel trucks in the Basin, the major concern is that emissions from diesel trucks may have been underestimated and may have grown since 1991 in the Lake Tahoe Basin. Current travel demand and fleet composition data are needed to achieve meaningful results from any transportation model.

Figure 12. Integrated Transportation and Air Quality Model

Transportation Sources



### **Transportation Model: Long-term Efforts**

A major difference in travel patterns between Lake Tahoe and other urban areas is its large proportion of visitor and/or recreational trips. According to the 1995 base year model output, visitor trips account for 42% of the total trips, and 56% of the total VMT. A visitor/recreational trip is a one-time activity rather than a regular daily-based activity such as a commute trip. Recreational trips normally involve an individual making choices from sets of alternative destinations. A destination choice set is determined by many factors, including travel duration, budget, recreational type (e.g., fishing, camping), travel season, and standard socio-economic characteristics such as income.

The following features should be considered when developing a travel demand forecasting model:

- The visitor/recreational trip should be modeled separately from a resident trip.
- The conventional trip-based model should be replaced with a tour-based model. A *tour* is defined as a sequence of trip segments that start and end at the same location. Specifically, for a resident tour, the location is referred to his/her home. For a visitor tour, the location is referred to the zone that is not within the area being modeled. The advantage of utilizing tour or trip chaining over single trip lies in that it's more consistent with a person's actual daily travel pattern. A trip chain is sequence of activities that are temporally and spatially connected. Introducing the concept of tour or trip chain leads to an activity-based modeling approach, which is discussed next.

An activity-based model provides more information on traveler behavior than a trip-based model that models every single trip. An activity-based approach defines a trip through individual activities. There have been numerous studies on activity-based modeling approaches. Jones, Koppelman, and Orfeuil (1990) argued that an activity-based approach has a deeper understanding of traveler behavior, both of travel itself and the characteristics of households and their activities, which relate to it, directly or indirectly.

- The new model should focus on destination choice, applicable to both resident and visitor travel activities, and describe the dependency and the interrelationship between the destinations in a given tour. A recreational tour is a typical application of a destination choice model. Unlike a work trip, which normally has a fixed destination, i.e., the destination choice set has only one choice, a recreational trip involves a decision making process of selecting one destination from several feasible ones.
- A time-of-day trip distribution should be incorporated into the travel demand forecasting process. This module provides the hourly volume and peak period volume useful to the air quality model. This is a very important step in the whole modeling process because it bridges the gap between travel demand modeling and air quality modeling. Historically, travel demand and mobile emissions are modeled separately, using different algorithms and output formats. However, these two efforts and outputs are causally related. The modeling efforts ought to be jointly carried out, and combined where feasible. The time-of-day distribution should also be facility specific.

In the next few sections we describe the basic framework for a residential and a visitor travel demand forecasting effort is described. In both cases, the basic unit of analysis is the trip chain with associated destination choices.

### Resident Trip Chaining Model

The resident trip-chaining model is motivated by the Boise model (Shifan, 1998). The Boise model is an application of a tour-based (or trip chaining) model with incorporation of an activity-based model. This model was developed to provide updated travel forecasts for the Boise Metropolitan Area in Ada County, Idaho. There are two types of resident tours in the model. A tour that includes one or more work destinations is defined as a work-related tour (WRT) and all other tours are defined as non-work-related tours (NWRT). Once again, a tour is defined as a sequence of trip segments that start at home and end at home. This effort can be more rigorously defined using a nested logic model structure, with the following two assumptions.

Initially, the time of day and the duration of different activities within the trip chain will be disregarded. (Note that trips will be distributed by time of day and facility type in the later stage.) The model should be estimated at the individual level.

One change different from the basic Boise model is that the Boise model is estimated at the household level. Neither the model proposed nor the Boise model includes a mode choice component. However, our proposed model does have a vehicle type component because of its importance to constructions of emissions factors.

The proposed model consists of two parts: an activity model and a tour model. An activity model (Figure 13a) is used to estimate how many tours of each type (i.e., home-based work (HBW) and home-based other (HBO) tour) an individual will make. A tour model determines the tour type (See Figure 13 for the definitions) and its destination. Structures of the WRT and NWRT are shown in Figure 13b and c respectively.

As indicated by the definition, a tour can have multiple destinations associated with it. The assumption is that each tour has a primary destination. For a WRT, the primary destination is the work place or the major work place (in the case of multiple work places). For a NWRT, the primary destination is defined as the one with the longest travel time from home.

In a WRT, the first level from the top is work destination. The next level is the tour type that is determined by two decision variables, the number of secondary destinations in the tour and whether or not the tour includes a midday sub-tour. Six alternatives are defined (See Figure 13 notation for the definitions.). Vehicle type is a very important estimation process for the later air quality modeling. The final decision level is the secondary destination set and the midday destination set. A midday subtour is defined as a portion of a tour that starts at work and returns to work. A midday subtour is considered only if the person is leaving and coming back to the same work place. If the person is going from his or her main work place to another work place, the other work place should be treated as a secondary destination.

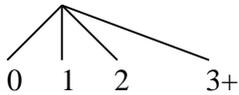
The NWRT structure is similar to the WRT case. The difference between these two approaches is that the top level decision of a NWRT is the number of destinations instead of the work destination. Another difference is that a midday activity is no longer specified in the NWRT

since it's simply one among all of many activities, contained within a tour. The vehicle type decision is next to the primary destination decision.

**Figure 13. Resident Tour Model: (A) Activity Model, (B) WRT Model, (C) NWRT Model**

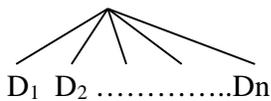
A.

HBW/HBO Tour Frequency

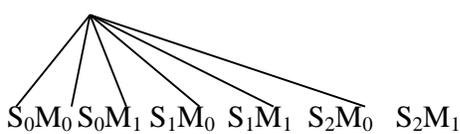


B.

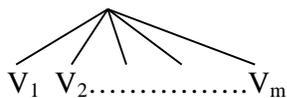
Work Destination



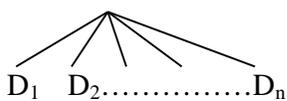
Tour type



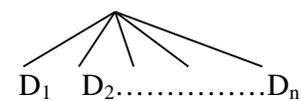
Vehicle type



Secondary destination

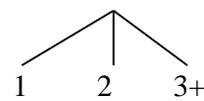


Midday destination

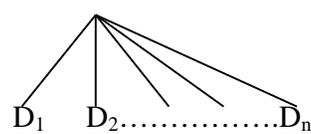


C.

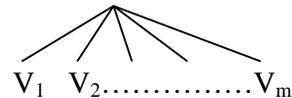
Number of Destination



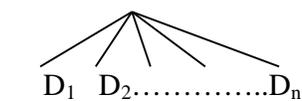
Primary Destination



Vehicle type



Secondary destination



Notation:

$S_0M_0$ : A simple tour- a person travels to work and directly back home with no midday subtour.

$S_0M_1$ : A simple tour with a midday subtour.

$S_1M_0$ : A person stops at one additional destination on the way to or from work with no midday subtour.

$S_1M_1$ : A person stops at one additional destination on the way to or from work and makes a midday subtour.

$S_2M_0$ : A person stops at an additional two or more destinations on the way to or from work with no midday subtour.

$S_2M_1$ : A person stops at one additional two or more destinations on the way to or from work and makes a midday subtour.

### Visitor/Recreational Tour Model

There have been numerous efforts modeling various types of recreational activities. Most of these models share a common feature – they are destination choice logit models. Most of these studies have focused on a single decision. Ribaudo *et al* (1984), Smith (1988), and Smith and Kaoru (1986) focused on frequency choice. Kealy and Bishop (1986) focused on the total time spent at a site. Tay and McCarthy (1994) forecasted the destination choice.

A few studies have estimated multi-dimensional models of destination, duration and frequency choices. For example, Brown (1979) estimated a three stage nested logit model with a hierarchical structure of frequency choice, duration choice and destination choice modeled sequentially from top to bottom. Caulkins *et al* (1985) estimated a nested logit model of destination choice conditioned upon taking a trip. Bockstael *et al* (1984) estimated a nested logit model of destination choice conditioned upon type of recreational activities, while Tay *et al* (1996) estimated a multi-dimensional logit model (also called joint logit model) of frequency choice conditioned upon region visited and duration.

The proposed Tahoe visitor/recreational tour model utilizes a multi-dimensional nested logit model, which estimates the frequency choice conditioned upon the destination choice, duration, recreational type, and travel season. The model structure is shown in . The recreational tour model shares a similar structure with the resident model and also consists of two parts: the activity model and the tour model (See Figure 14). The activity model is used to estimate the number of trips within a period of predetermined length, with vehicle type estimated separately but simultaneously.

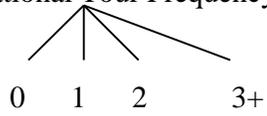
In the tour model, the top hierarchy decision is trip duration, where recreational activity is a one-time activity. The next level is the recreational activity choice conditioned upon the travel duration and travel season. For example, snow skiing takes place in the winter; fishing and water skiing occur largely in the summer. Once the recreational type has been identified, the primary and secondary destinations are then estimated. Primary destination is defined as the destination with the longest travel time from home.

The Boise model was developed within the budget allocated by the Metropolitan Planning Office (MPO) for model development with no additional external funds, which may indicate that a tour-based model system is feasible within a model development budget given the same data collected for a four-step traditional model development. As previously discussed, however, contemporary data, in particular visitor data, are not currently available for the Lake Tahoe Region. Activity-based and/or tour-based surveys (or trip diary), with respect to origin-destination information, traffic composition information, and visitor socio-demographic information throughout the Basin, should be conducted in the near future.

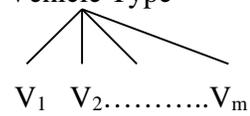
Figure 14. Recreational Tour Model: (A) Activity Model, (B) Tour Model.

A.

Recreational Tour Frequency



Vehicle Type

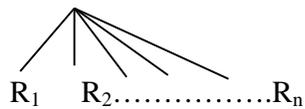


B.

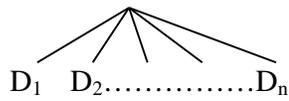
Duration



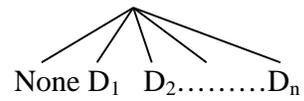
Tour type



Primary destination



Secondary destination



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