Final Report

Evaluation of Ozone and HNO_3 Vapor Distribution and Ozone Effects on Conifer Forests in the Lake Tahoe Basin and Eastern Sierra Nevada

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Acknowledgements

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List of Abbreviations

µg	Microgram (10^{-6} g)
ARB	(California) Air Resources Board
ESRI	Environmental Systems Research Institute
h	Hour
HNO_3	Nitric Acid (Vapor)
L	Liter
m	Meter
m^2	Square Meter
m^3	Cubic Meter
mg	Milligram (10^{-3} g)
mL	Milliliter
NH_3	Ammonia
NH_4^+	Ammonium (cation)
NO_2^-	Nitrite (anion)
NO_3^-	Nitrate (anion)
O_3	Ozone
OII	Oxidant Injury Index
ppb	Parts per billion
USDA	U.S. Department of Agriculture

Abstract

Two-week average concentrations of ambient ozone (O_3), nitric acid vapor (HNO_3), and ammonia (NH_3) were measured during the 2002 smog season in selected areas of the Sierra Nevada, California (i.e., Lake Tahoe Basin, San Joaquin River Drainage, portions of the eastern and southern Sierra Nevada). In the Lake Tahoe area, local generation of photochemical smog appears to be the main cause of increased O_3 and HNO_3 concentrations within the Basin. High O_3 concentrations were present along the San Joaquin River Drainage and southern Sierra Nevada throughout the summer. Ozone levels were also elevated in the eastern Sierra Nevada, although they were lower than in the San Joaquin River Drainage. The transport of nitrogen oxides, carbon monoxide, and volatile organic compound emissions generated by the McNalley fire, is postulated to have contributed to the very high O_3 concentrations that occurred in August. In the San Joaquin River Drainage, ambient concentrations of HNO_3 and NH_3 were highest near the San Joaquin Valley and decreased gradually toward the east. In addition, an evaluation of O_3 injury symptoms was conducted on ponderosa pines in the Lake Tahoe Basin and along the San Joaquin River Drainage. At 25-sites in the Lake Tahoe Basin, 23 percent of the trees evaluated had symptoms of foliar O_3 injury, but only slight injury to the pines occurred in this area. Ozone injury was, on average, only slight along the San Joaquin River Drainage.

Executive Summary

Two-week average concentrations of ambient ozone (O_3), nitric acid vapor (HNO_3), and ammonia (NH_3) were measured during the 2002 smog season in selected areas of the Sierra Nevada, California (i.e., Lake Tahoe Basin, San Joaquin River Drainage, portions of the eastern and southern Sierra Nevada). In addition, an evaluation of ozone injury symptoms was conducted on ponderosa pines in the Lake Tahoe Basin, San Joaquin River drainage and eastern Sierra Nevada.

In the Lake Tahoe area, local generation of photochemical smog appears to be the main cause of increased O_3 and HNO_3 concentrations within the Basin. Our data indicate that the Sierra Nevada, west of the Lake Tahoe Basin (i.e., Desolation Wilderness), poses a barrier that prevents polluted air masses from the Sacramento Valley and Sierra Nevada foothills from entering the Basin. High O_3 concentrations were present along the San Joaquin River Drainage throughout the summer. Ozone levels were also elevated in the eastern Sierra Nevada, although they were lower than in the San Joaquin River Drainage. In the southern Sierra Nevada, O_3 concentrations were similar to those found in the San Joaquin River Drainage. In August, most of the San Joaquin River Drainage, and eastern and southern Sierra sites exhibited elevated O_3 levels, with some locations recording very high values (e.g., 167 ppb at Olancha Pass, 186 ppb at Squaw Dome; and 132 ppb at Mammoth Mountain). The transport of nitrogen oxides, carbon monoxide, and volatile organic compound emissions generated by the McNalley fire (in Sequoia National Forest), is postulated to have contributed to the very high O_3 concentrations that occurred in August. Comparison of O_3 levels between the Sierra Nevada areas studied in 2002 is difficult due to the occasional spikes of very high O_3 concentrations caused by the McNalley fire. However, in general O_3 concentrations were the highest in southern Sierra Nevada, followed by the San Joaquin River Drainage, eastern Sierra, and the lowest levels in the Lake Tahoe area.

In the San Joaquin River Drainage, ambient concentrations of HNO_3 and NH_3 were highest near the San Joaquin Valley and decreased gradually toward the east. In the first half of August, elevated concentrations of HNO_3 were recorded at several sites, and could have been influenced by emissions from the McNalley fire. Similarly, emissions from the McNalley fire may also have indirectly affected NH_3 concentrations in the first half of September (by increasing soil ammonium) that were substantially higher than during any other sampling period.

The average OII (oxidant injury index) was 17.3 in the Lake Tahoe Basin, which indicates only slight injury to the pines occurred in this area. No discernable spatial patterns of injury were observed between sites. Differences in the number and severity of ozone injury between sites are likely due to microsite growing conditions, and genotypic and phenotypic responses of individual trees to ozone air pollution. Ozone injury was, on average, only slight along the San Joaquin River Drainage. Surveys indicate that ambient ozone affected sites well into the interior of the mountains, but had only little affect on easterly interior and eastside sites, except for a few sensitive trees. Sites along the western side of the transect had higher percent of trees with injury, and had more severe injury than sites located in the interior and east side of the drainage.

I. Introduction

The ecological health of the Lake Tahoe Basin is of increasing national concern. Several well-documented environmental problems, including negative air quality and effects on forests, water quality, and occasionally human health, all affect the quality and the existence of natural amenities. In this regard, reliable information is urgently needed to assess the spatial and temporal distribution of air pollutants. A large portion of the air quality problem in the Lake Tahoe Basin is due to the emissions generated by a local population of 60,000 year-round residents, and an additional 23 million visitor-days. Another factor is emissions from the San Francisco-Sacramento urban areas, which may contribute to local air pollution by wind-driven transport of pollutants.

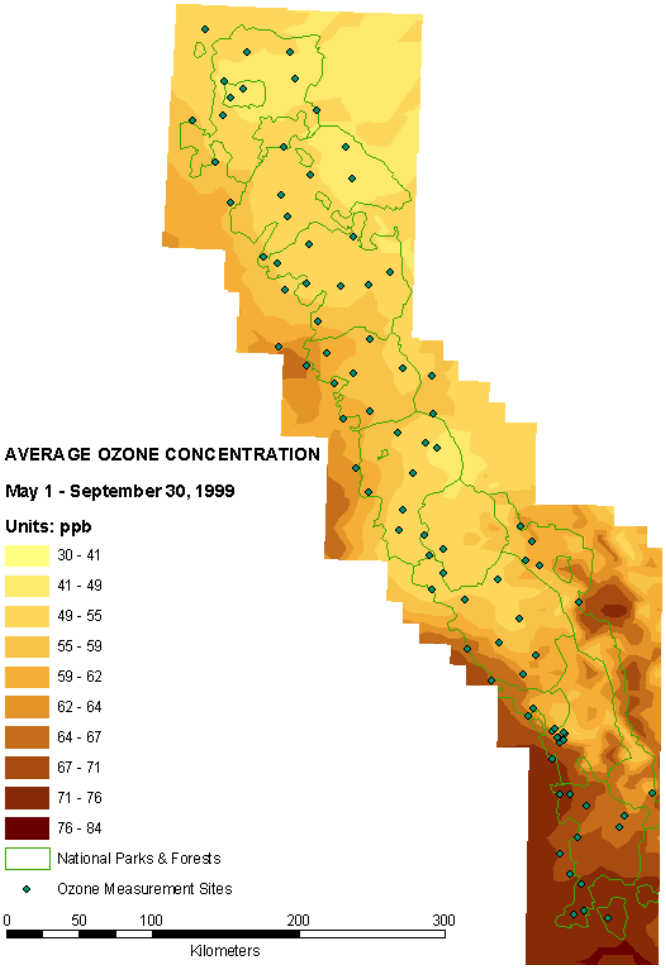

Figure 1. Distribution of Seasonal Average O_3 Concentrations in the Sierra Nevada: 1999.

In terms of impacts to forests, ambient ozone (O_3) levels in the Lake Tahoe Basin have increased since 1982 (e.g., annual average). While information on O_3 distribution in the Sierra Nevada bioregion is now available (Arbaugh and Bytnerowicz, 2003), a local-scale understanding of the temporal and spatial distributions of ambient O_3 within the Lake Tahoe Basin is lacking (Murphy and Knopp, 2000). While large-scale distribution maps of the Sierra Nevada bioregion provide evidence that ambient ozone concentrations east of Sacramento and approaching the Lake Tahoe Basin are elevated (Figure 1), it is not known if those elevated pollutant levels contribute to increased ozone concentrations in the Lake Tahoe Basin. At projected ambient levels (e.g., seasonal 24-hour average levels of 50-63 ppb, and two-week, 24-hour averages exceeding 100 ppb; cf. Frączek et al., 2003), O_3 may be phytotoxic (Krupa et al., 1998), and can adversely affect tree health and forest biodiversity (Arbaugh et al., 1998). Ozone has been reported to cause crown injury to ponderosa and Jeffrey pines in the central Sierra Nevada (Miller and Millecan, 1971), including the Lake Tahoe Basin (Pedersen, 1989).

Anthropogenic air pollution is postulated to be responsible for nearly half of the total nitrogen (N) inputs to Lake Tahoe, and is postulated to be a contributing factor to lake eutrophication. Although some information on the distribution of nitrogenous air pollutants

within the basin is available (Tarnay et al., 2001), the relative contribution from in-basin and out-of-basin sources has not been established (Murphy and Knopp, 2000). Similar to the Lake Tahoe Basin, there is only limited information on the distribution of O_3 and N pollutants in the eastern and southern parts of the Sierra Nevada (Bytnerowicz and Fenn, 1996; Frączek et al., 2001) (Figure 2). Seasonally elevated O_3 levels in Mammoth Lakes (Bytnerowicz et al., 2002), and reports of O_3 injury to Jeffrey pines in several locations in the eastern Sierra Nevada (Dan Duriscoe, personal communication), and typical regional airflow patterns suggest that polluted

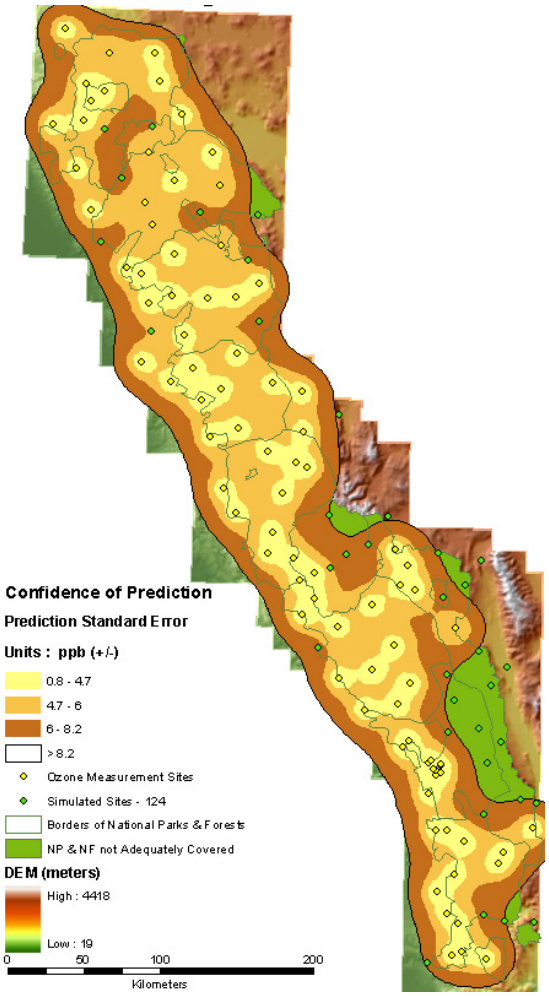

Figure 2. Confidence of Predicted O_3 Concentrations in the Sierra Nevada: 1999.

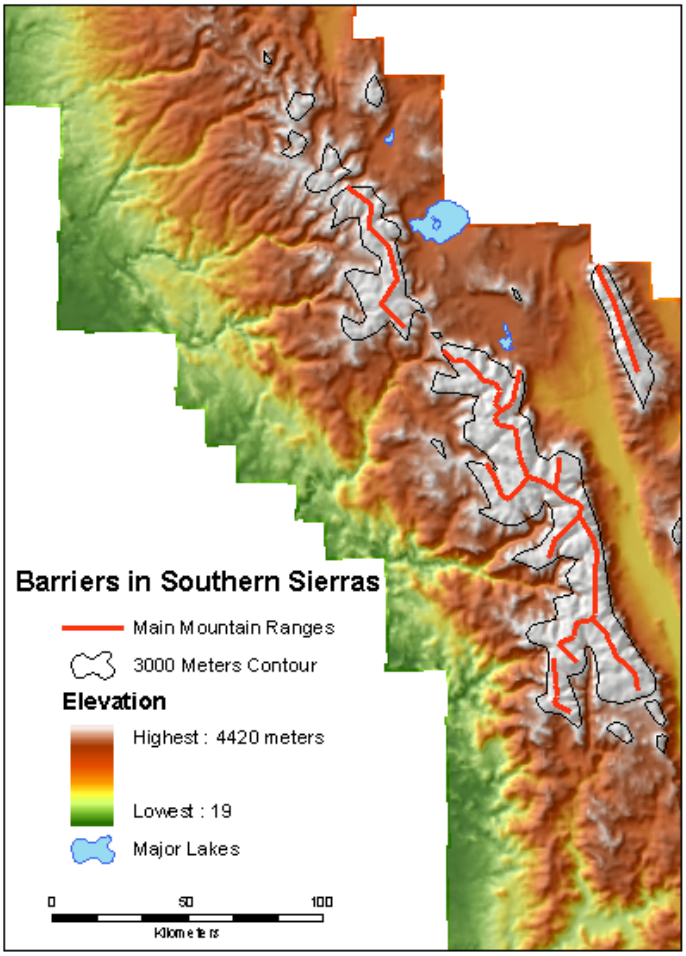

Figure 3. Postulated Trans-Sierra Air Pollution Transport Corridor: San Joaquin River Drainage. (Note: Mammoth Mountain is the northeast outlet of the drainage).

air masses from the San Joaquin Valley may be transported across the Sierra Nevada (Figure 3). As such, there is a clear need to develop a better understanding of O_3 distribution and its phytotoxic potential in the Lake Tahoe Basin and the eastern Sierra Nevada.

It is well established that ambient O_3 has pronounced, adverse effects on forest health and the biodiversity of California's mountain regions (Arbaugh et al., 1998). Since 1992, under the Forest Ozone Response Study (FOREST), administered by the U.S. Department of Agriculture (USDA), Forest Service (Porterville, California), tree injury amounts and O_3 air quality have

been monitored at ten locations along a north-south transect in the Sierra Nevada (including the Tahoe National Forest), and in the San Bernardino Mountains. Tree response to ambient O_3 has been analyzed using several, commonly used exposure indices (Arbaugh et al., 1998). While our ability to extrapolate tree responses across the Sierra Nevada landscape has improved in recent years, further improvements are needed to project impacts at sites more distant from active monitoring stations. An initial effort, using a simple elevation and distance model to produce a map of crown injury caused by O_3 in the San Bernardino Mountains found a strong spatial relationship (Miller and Rechel, 1999). An analysis of this kind has not been done for the forests in the Lake Tahoe Basin, which would be useful to assessing the sustainability of forest ecosystems and the levels of air pollution stress they experience. Information of this kind would be especially useful to land managers charged with conducting Ecological Risk Assessments (EcRA), as they must ultimately develop strategies to preserve and maintain forest resources for multiple uses.

The present project addressed a number of data needs identified in the Lake Tahoe Presidential Forum and provides decision-makers with important information concerning the ecological risks posed by ambient O_3 concentrations to forests in the Lake Tahoe Basin. Data needs regarding O_3 distribution increase, when characterizing and assessing risk from multiple stressors in mountain forest ecosystems (Bytnerowicz et al., 1998). Currently, data for mountainous areas are sparse, and measurement points with active monitoring systems are expensive to establish and maintain. However, with the advancements in passive samplers for gaseous air pollutants, robust networks for monitoring air quality can be established at lower cost. By deploying passive samplers in combination with a subset of active O_3 monitoring stations, such as in the present project, models can be used to depict the spatial and temporal distribution of O_3 in the mountains of California (Arbaugh et al., 2001). Understanding of the distribution of air pollutants is of great significance to assessing potential ecological changes and to making science-based ecological risk, management, and policy decisions in the Lake Tahoe Basin.

II. Project Objectives

The objectives of the project were:

(1) To understand the spatial and temporal distribution of ambient ozone concentrations in the Lake Tahoe Basin using data collected from a network of passive O_3 samplers; and

(2) To examine the exposure-response relationship between ambient ozone levels and ozone-caused tree injury in the Lake Tahoe Basin.

This project was conducted as part of a larger effort to evaluate ozone, nitric acid, and ammonia concentrations throughout the Sierra Nevada bioregion. Funding for the surveys to assess foliar ozone injury to ponderosa pines in the Lake Tahoe Basin, and two transect studies was secured from USDA Forest Service sources. The transect studies were conducted in the San Joaquin River Drainage (to examine the potential for trans-Sierra pollution transport from the San Joaquin Valley to the eastern Sierra Nevada), and along a north-south gradient in the eastern

Sierra Nevada. Results from all four projects are presented in this report for Air Resources Board (ARB) Contract No. 01-334.

III. Methodology

In general, the methodologies that were developed and tested under ARB Contract No. 98-305 (Arbaugh et al., 2001) were also used in this study. For ozone monitoring, the same passive samplers used to collect data for the study entitled *"Ambient ozone patterns and ozone injury risk to ponderosa and Jeffrey pines in the Sierra Nevada"* were used. Pollutant distribution maps were developed with one of the models developed in the same study, using the Geostatistical Analyst (ESRI, Redlands, California) software. In addition to being used in the above-mentioned study funded by the ARB, the Geostatistical Analyst software has also been used to study ambient O_3 impacts in the Carpathian Mountains of Central Europe (Bytnerowicz et al., 2002; Frączek et al., 2001). Evaluations of crown injury were conducted using the Ozone Injury Index (OII) methodology employed in a number of studies conducted by the Forest Service in the Sierra Nevada and the San Bernardino Mountains (Miller et al., 1996).

III.A. Monitoring Network

Monitoring sites were selected in open-terrain locations such as forest clearings, burnt areas, forest nurseries, etc. The monitoring sites were located on a western aspect, at least 100-m (300 ft) from a local road, and 200-m (600 ft) from main roads. Free air movement from all directions was required, however, sites exposed to continuously strong winds were avoided (to minimize site-to-site variation in airflow). In addition, sampler stands were placed at a distance at least two-times the height of the tallest tree from forest edges. Allowances were made for sparsely dispersed smaller trees or shrubs that did not directly obstruct the samplers. Passive samplers with sampler caps were hung on a wooden stand about two-meters (7 ft) above ground level (Figure 4).

Figure 4. Ozone Passive Sampler Mounted on a Wooden Stand 2-m Aboveground – Fish Creek site on the San Joaquin River Drainage.

The locations of the air quality monitoring and pine evaluation sites are shown in Figure 5. In the Lake Tahoe Basin, O_3 and HNO_3 concentrations were monitored with passive samplers at 31-sites (Table 1 and Figure 6). In addition, at three sites (Echo Summit, Cave Rock and White Cloud), real-time concentrations of ozone were monitored as part of the ARB's statewide air monitoring network. Following each two-week sample collection, the samplers were stored at –18^{o}C prior to chemical analysis. At the end of the project study period, the filters from the passive samplers were extracted, and chemical analyses conducted to determine two-week average concentrations of

ozone and nitric acid vapor. The chemical analyses were performed at the chemical laboratory in the USDA, Forest Service, Pacific Southwest Research Station, in Riverside, California.

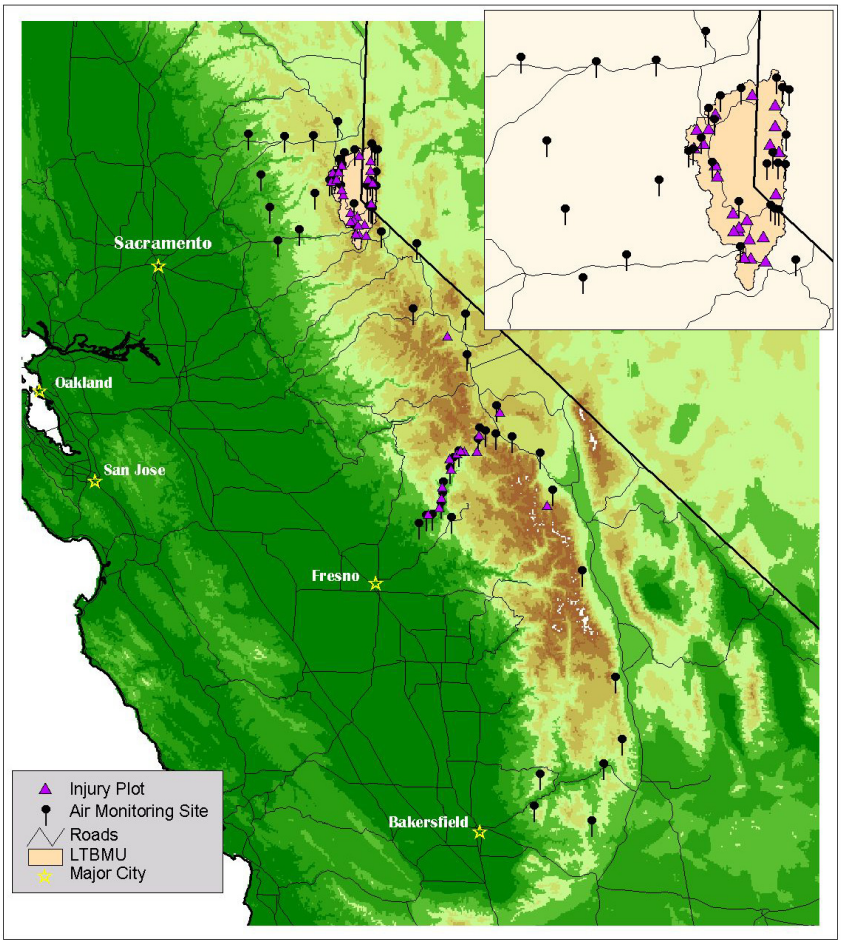

Figure 5. Locations of the Air Quality Monitoring and Pine Evaluation Sites in the Study.

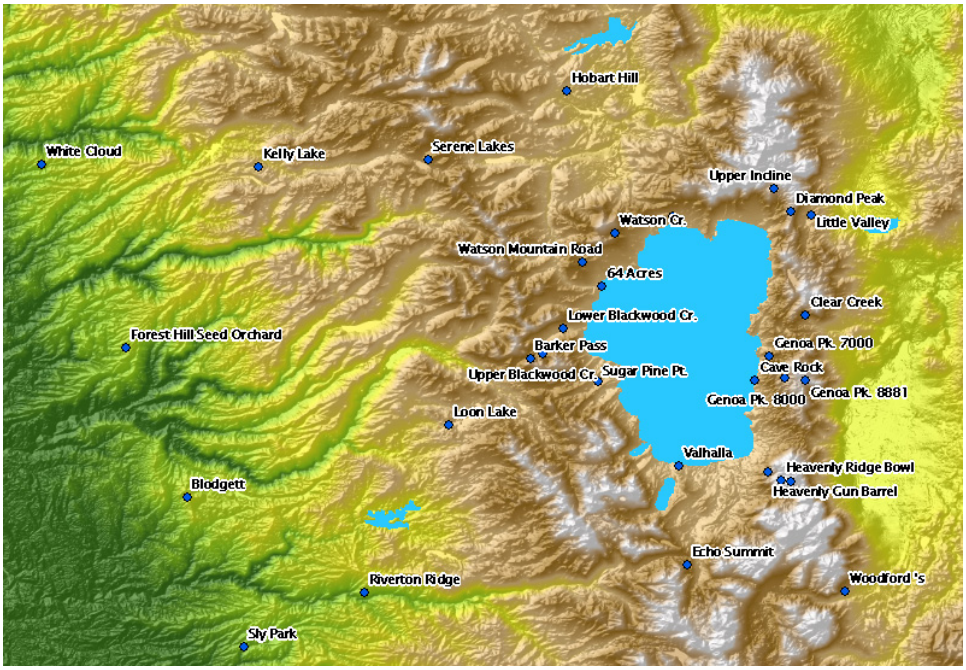

Figure 6. Locations of Ozone and Nitric Acid Monitoring Sites in the Lake Tahoe Basin.

III.B. Ozone Passive Samplers

Ogawa passive samplers (Pompano Beach, Florida) were used to measure two-week average ozone concentrations (Koutrakis et al., 1993). In each sample, two replicate nitrite (NO_2^-) saturated filters were exposed for 10 two-week periods during summer-fall 2002 (June 18 through October 9). In the Ogawa samplers, nitrite (NO_2^-) on the cellulose filters is oxidized by ambient O_3 to nitrate (NO_3^-). To extract the nitrate (NO_3^-) formed by the oxidation of nitrite by O_3, 5-mL of ultrapure water was added to the vials containing a sample filter. The vials were shaken for 15 minutes on a wrist-action laboratory shaker. A 1-mL aliquot of the filter extract was then diluted with 4-mL of ultrapure water (i.e., a 5-fold dilution) and the resulting NO_3^- concentration (mg/L) was determined by ion chromatography (Dionex, Model 4000i). The rate of NO_3^- formation (i.e., the amount of NO_3^- formed on the filter during the sampling period) served as a measure of two-week average ambient O_3 concentration at the site. Rates of NO_3^- formation in the passive samplers were compared to real-time O_3 concentration measurements by UV absorption (Thermo Environmental, Model 49). The empirically derived coefficients were used to calculate two-week average ambient O_3 concentrations at the passive sampler monitoring sites. The precision of the O_3 passive samplers was generally less than 5%.

III.C. Calculation of Two-week Average Ambient Ozone Concentration

To determine the two-week average ambient O_3 concentration at each site, the following calculations were performed:

(1) Mass of NO_3^- formed (μg):

= [(mg NO_3^-/L in the diluted sample) – (mg NO_3^- /L in a diluted blank)] x 5 x 0.005 L/sample x 1000 [μg/mg]

Note: "5" = correction for 5-fold dilution of the filter extract

(2) Rate of NO_3^- formation (μg NO_3^-/h):

= (μg NO_3^-) ÷ (Sampling Duration (h))

Note: Use (1) to calculate μg NO_3^-; two-week sampling duration (336 h)

(3) NO_3^- to O_3 concentration conversion factor:

= (Two-week average O_3 concentration (ppb) from the proximate active O_3 monitor) ÷ (Rate of NO_3^- formation in passive samplers collocated with the active monitor (μg NO_3^-/h))

(4) Two-week average O_3 concentration (ppb O_3):

= (μg NO_3^-/h) x (NO_3^- to O_3 concentration conversion factor (ppb O_3/μg NO_3^-/h))

Ozone data from three active monitoring sites were used to calculate the conversion factor for translating nitrate formation rates into two-week average ambient ozone concentrations (ppb). The detailed results from three collocated sites (Echo Summit, Cave Rock and White Cloud) are presented in Table 2. The average conversion factor derived from the Echo Summit data was ~10% higher than the average conversion factors from the Cave Rock and White Cloud sites. The conversion factor used for calculation of all O_3 concentrations was derived by averaging 22 readings from all three sites during the entire study. We believe that such a factor from the sites located in different parts of the study area and during the entire study period was most adequate for reliable calculations of ambient O_3 concentrations. The calculated conversion factor (684.5) was only 1% higher than the factor used in the 1999 Sierra Nevada study (678.2). For each site/sampling period, the two-week average O_3 concentration represents the mean ± one standard deviation of two replicate filters.

III.D. Nitric Acid Passive Samplers

The nitric acid passive samplers used in the study were developed by the USDA Forest Service (Bytnerowicz et al., 2001). Nylon filters, used to trap HNO_3 in ambient air, were placed in 250-mL Erlenmeyer flasks. Twenty mL of ultrapure H_2O were added to the flasks, flasks were covered with Parafilm®, and shaken for 15 minutes on a wrist action laboratory shaker. Nitrate concentrations in sample extracts were immediately analyzed by ion chromatography (Dionex, Model 4000i). Concentrations of NO_3^- in extract solutions were expressed as mg/L.

III.E. Calculation of Two-week Average Ambient Nitric Acid Concentration

To determine the two-week average ambient nitric acid concentration, the following values were calculated:

(1) Deposition of NO_3^- (mg/m^2):

= [(mg NO_3^-/L in the filter extract) – (mg NO_3^-/L in a blank)] x (0.02 L) ÷ (0.002389 m^2)

(2) HNO_3 dose ($\mu g\ HNO_3/m^3$ x h):

= (59.982) x (mg NO_3^-/m^2)

Note: "59.982" is derived from a calibration curve developed by comparing passive samplers against annular denuder systems (data not shown); "mg NO_3^-/m^2" is determined by (1)

(3) HNO_3 concentration ($\mu g/m^3$)

= ($\mu g\ HNO_3/m^3$ x h) ÷ [time of exposure (h)]

III.F. Geostatistical Analyst

Maps of the spatial distribution of ambient O_3 were prepared by Witold Frączek, an Application Prototype Specialist at the Environmental Systems Research Institute (ESRI) (Redlands, California) using the Geostatistical Analyst Extension to ArcGIS 8.3 (cf. Johnstone et al., 2001). The Geostatistical Analyst uses values measured at sample points at different locations in the landscape and interpolates them into a continuous surface. Using a set of ozone concentration measurements in a given study area, a spatial model of O_3 concentration is constructed (Frączek et al., 2003). In this study, ordinary kriging techniques were used to develop prediction maps of ozone and nitric acid distribution for the individual two-week sampling periods and for the entire season. The ordinary kriging produced the smallest prediction errors when compared with other kriging techniques. Correlation between O_3 concentrations and elevation change was weak and therefore the co-kriging techniques were not used in this study.

IV. Results & Discussion

IV.A. Distribution of Ambient Ozone in the Lake Tahoe Area

In the suite of maps of ozone distribution (Figures 7a-7h) the highest two-week and whole-season average levels of ozone occurred in the Sacramento foothills, west of the Lake Tahoe Basin. Near the Lake, especially in the vicinity of the west shore, concentrations were much lower (i.e., by 20-25 ppb). This suggests that locally generated ozone or ozone-precursors (i.e., nitrogen oxides and hydrocarbons) in South Lake Tahoe and nearby communities could be the source of higher O_3 concentrations in other parts of the Lake Tahoe Basin. This was indicated by higher concentrations of O_3 on the eastside of the Lake compared with to west. In addition, O_3 levels east of the Lake generally increased with distance from South Lake Tahoe on the south shore of the Lake.

A clear temporal pattern in O_3 concentration over the course of smog season was observed. The lowest two-week average levels occurred in the first half of July (Figure 7a), and the first half of October (Figure 7g). The highest two-week average concentrations were recorded in the second half of August (Figure 7d). The elevated O_3 concentrations southeast of the Lake that were observed in the second half of August through the second half of September, could have been caused by O_3 precursors emitted in the McNalley fire (July 21 through August 26, 2002), which burned over 150,000 acres in Sequoia National Forest. This is postulated based on satellite images showing that the smoke plume from the McNalley fire moved up the San Joaquin River Drainage in the second half of August.

IV.B. Distribution of Ambient Nitric Acid in the Lake Tahoe Area

In general, the distribution of two-week and whole-season average HNO_3 concentrations in the Lake Tahoe Basin and vicinity (Figures 8a-8i) was similar to the distribution of ambient O_3 (Figures 7a-7g). The highest concentrations of HNO_3 were observed in the Sacramento foothills, west of the Lake Tahoe Basin. It appears that the mountain range west of the Lake Tahoe Basin (i.e., Desolation Wilderness) creates a barrier that prevents polluted air masses from Sacramento metropolitan area and the foothills of the Sierra Nevada from entering the Lake Tahoe Basin. This is further supported by observations of the lowest pollutant concentrations, only slightly higher than background levels in the Sierra Nevada, occurring on the western

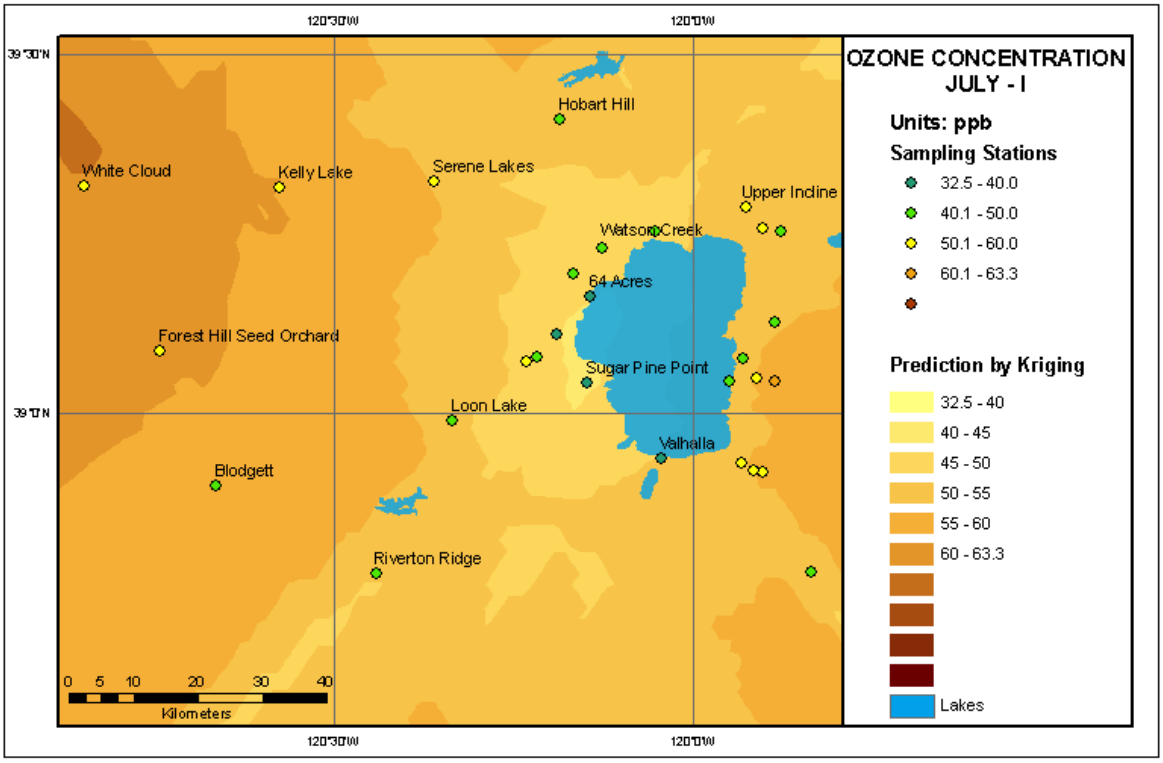

Figure 7a. Distribution of Two-week Average Ambient Ozone Concentrations (ppb) in the Lake Tahoe Study Area: July 2-16, 2002.

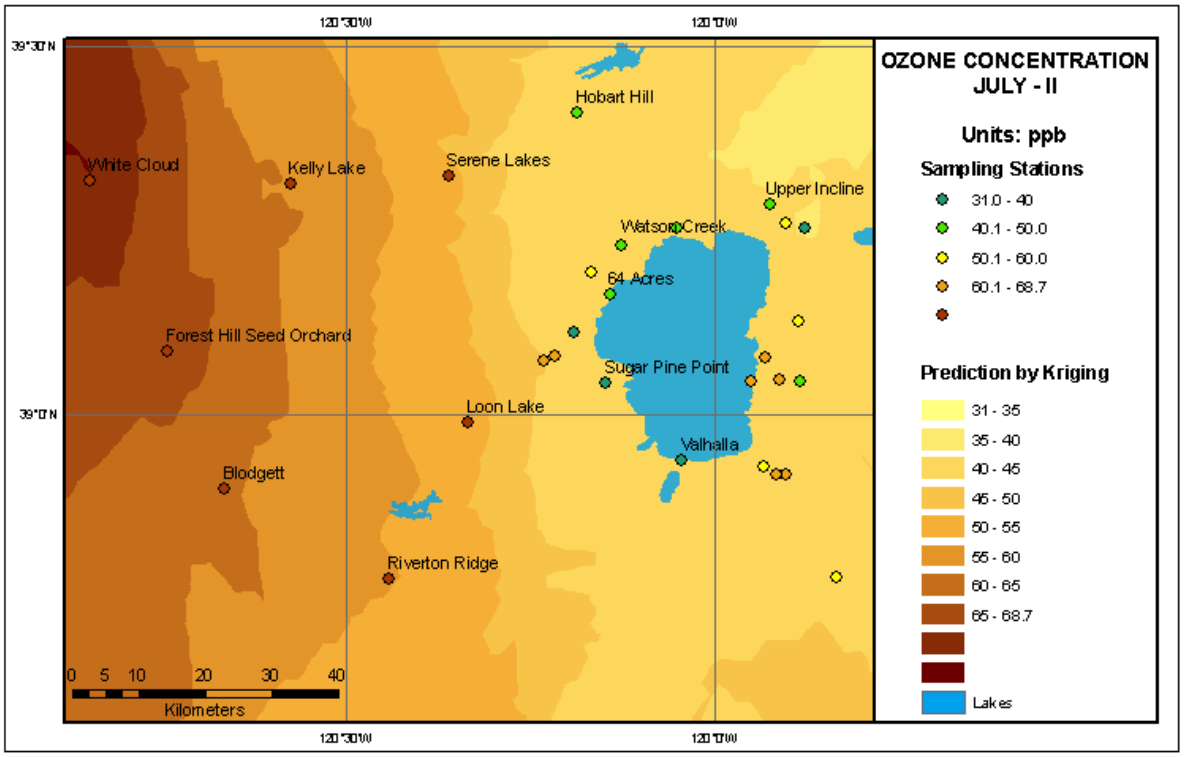

Figure 7b. Distribution of Two-week Average Ambient Ozone Concentrations (ppb) in the Lake Tahoe Study Area: July 16 through July 30, 2002.

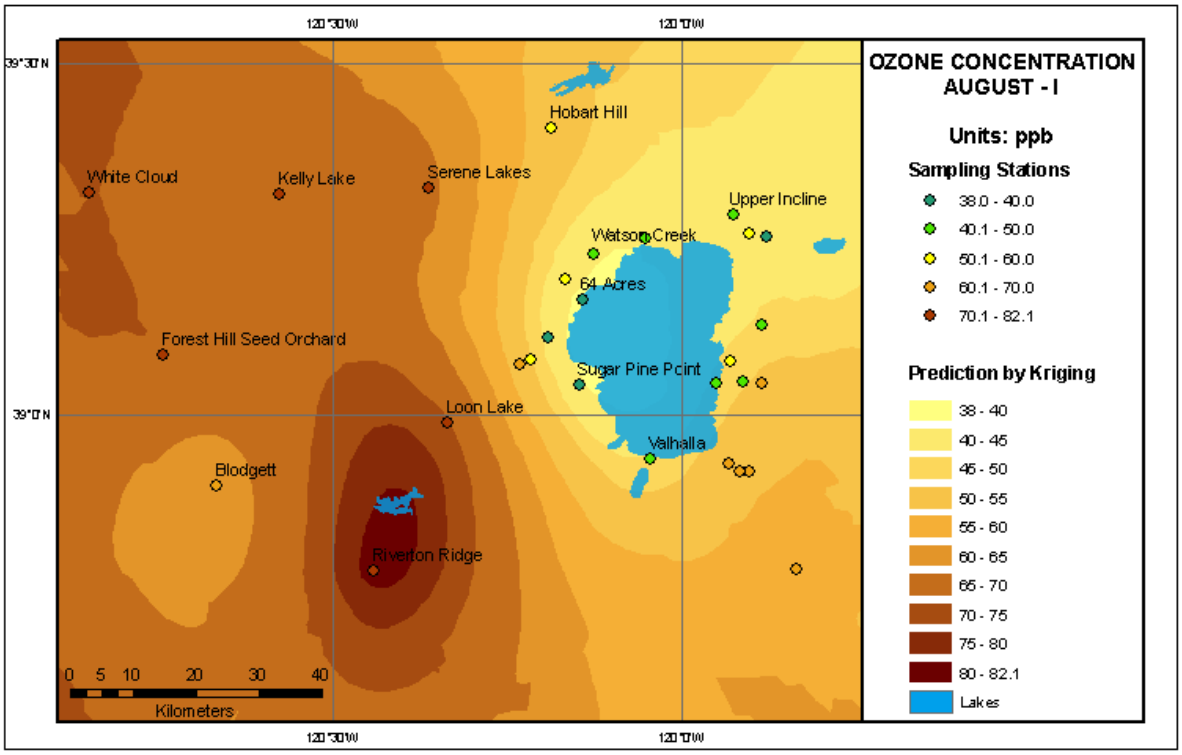

Figure 7c. Distribution of Two-week Average Ambient Ozone Concentrations (ppb) in the Lake Tahoe Study Area: July 30 through August 13, 2002.

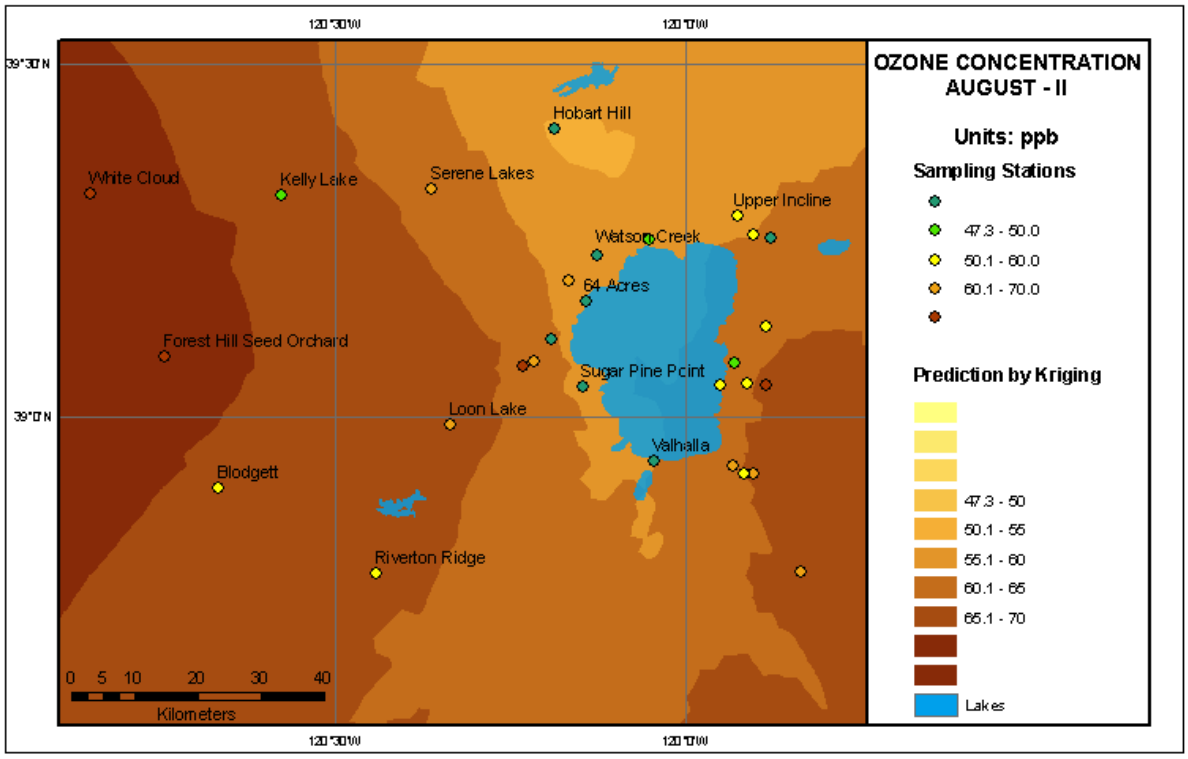

Figure 7d. Distribution of Two-week Average Ambient Ozone Concentrations (ppb) in the Lake Tahoe Study Area: August 13-28, 2002.

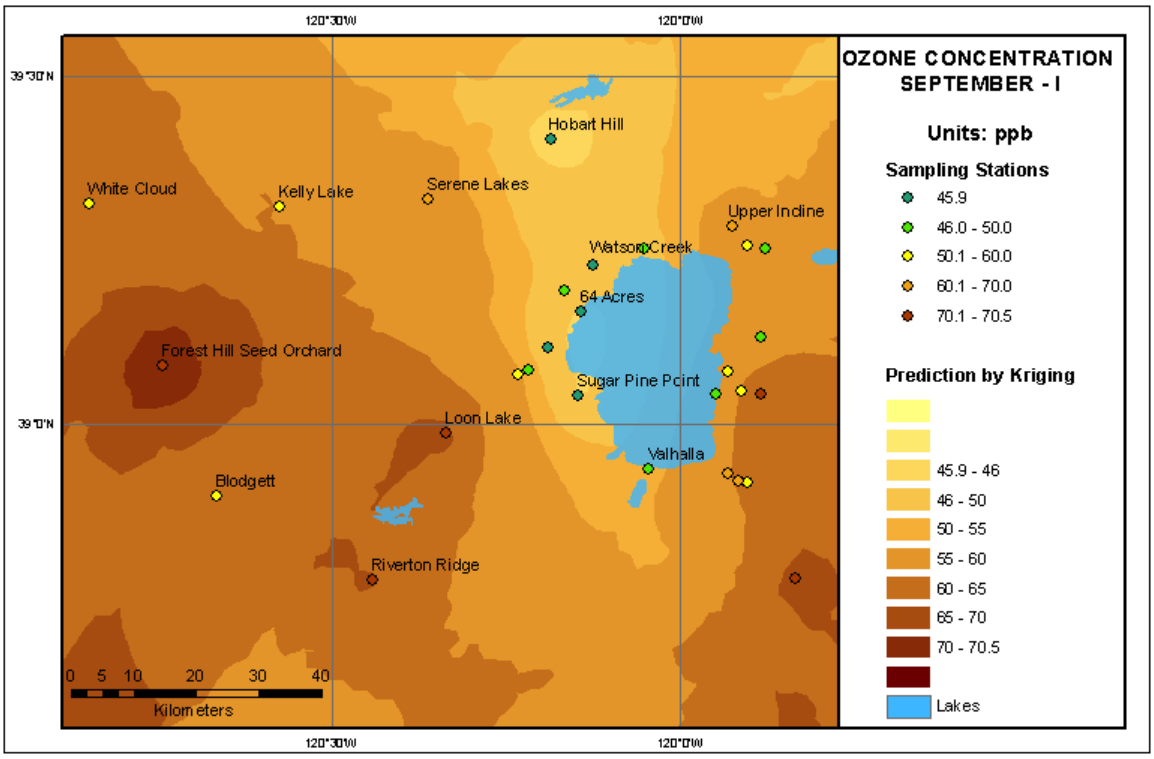

Figure 7e. Distribution of Two-week Average Ambient Ozone Concentrations (ppb) in the Lake Tahoe Study Area: August 28 through September 11, 2002.

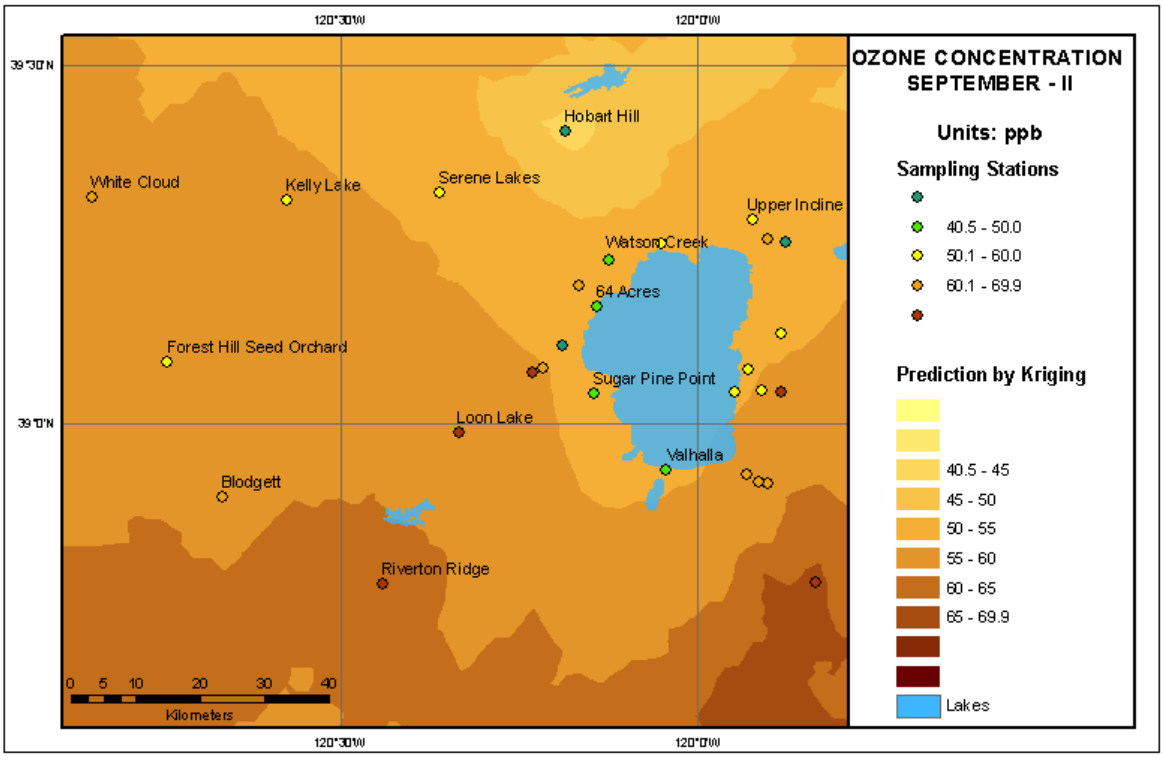

Figure 7f. Distribution of Two-week Average Ambient Ozone Concentrations (ppb) in the Lake Tahoe Study Area: September 11 through September 25, 2002.

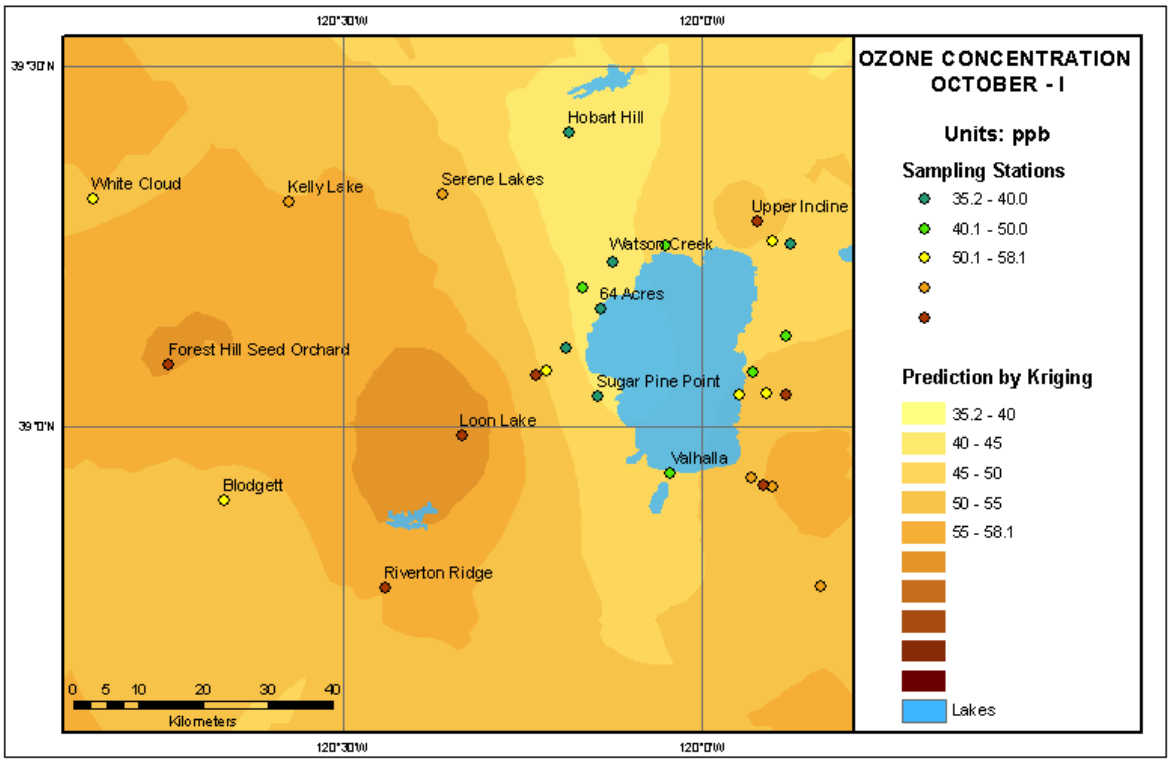

Figure 7g. Distribution of Two-week Average Ambient Ozone Concentrations (ppb) in the Lake Tahoe Study Area: September 25 through October 9, 2002.

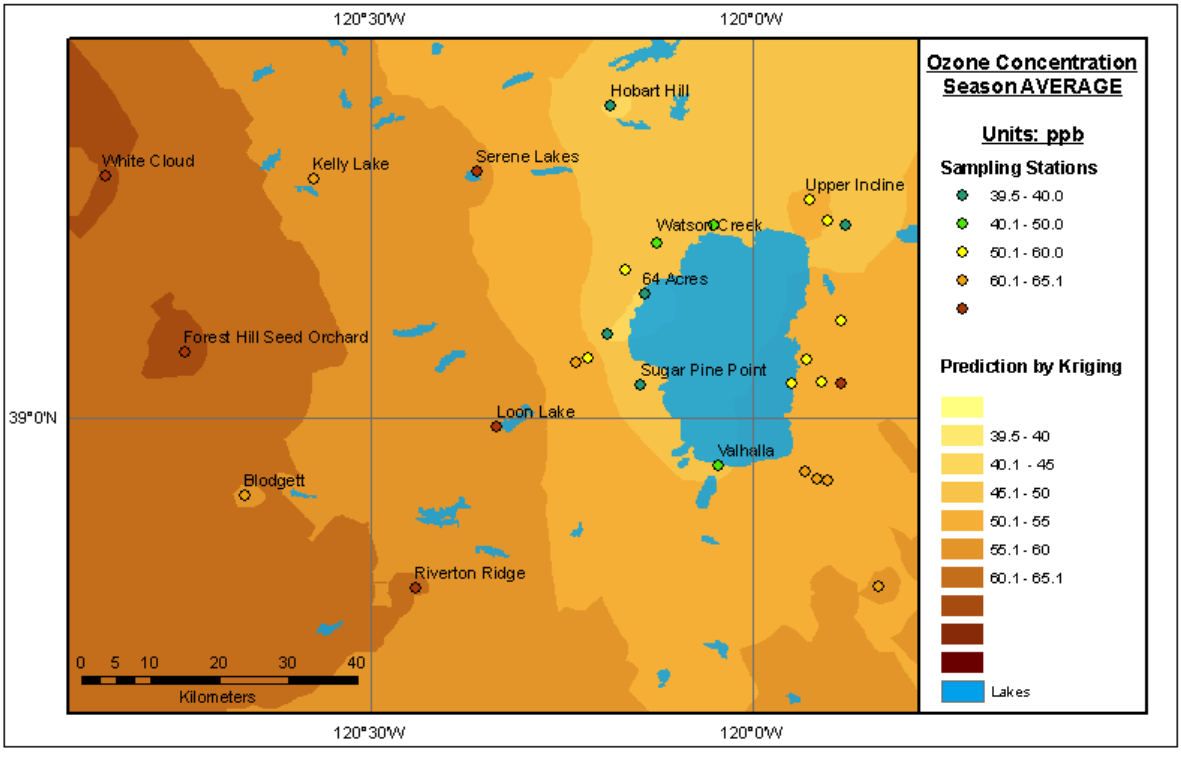

Figure 7h. Mean Summer-Fall Two-week Average Ambient Ozone Concentrations (ppb) in the Lake Tahoe Study Area: July 2 through October 9, 2002.

shores of the Lake. Concentrations of HNO_3 were higher on the east shore of Lake Tahoe indicating local pollutant production in South Lake Tahoe and other communities. Ambient average concentrations were much lower in the beginning and end of the season (Figures 8a, b, and h) than in the middle season, especially in the second half of August (Figure 8e) and first half of September (Figure 8f).

Ambient concentrations of HNO_3 diminished more rapidly with altitude than O_3, due to its rapid deposition to landscape features such as rocks, soils and trees. Elevated levels of HNO_3 in the southeastern part of the Lake Tahoe Basin observed in the second half of June and the first half of July (Figures 8a-b) may also indicate effects of local forest fire emissions. The Walker fire, which started in mid-June and burned for several weeks, occurred only 20-25 km from the Lake Tahoe Basin. Thus, the observed increase of HNO_3 concentrations in the Lake Basin in August through September (Figures 8d-g) could have been influenced by pollutant emissions from both the Walker and McNalley fires, as proposed for the elevated O_3 concentrations occurring at the same time (cf. Kita et al., 2000).

IV.C. Pollutant Distribution in the San Joaquin River Drainage, Eastern & Southern Sierra Nevada

High concentrations of O_3 were observed in the San Joaquin River Drainage throughout the season (Table 3, Figure 9). It appeared that ozone concentrations did not significantly diminished with distance from the San JoaquinValley. This indicates that O_3 at high concentrations may be transported long distances from source areas (Fiore et al., 2002). This may be especially true for high elevation mountain terrain where sparse vegetation is not an effective scrubber of ambient O_3. Ozone concentrations were generally higher than those found at high-elevation sites of the Sequoia National Park in summer 1999 (40-85 ppb) (Bytnerowicz et al., 2002). Although lower than the concentrations measured in the San Joaquin River Drainage, O_3 levels were also elevated in the eastern Sierra Nevada (Table 4). In the southern Sierra Nevada, O_3 concentrations were also high (Table 4) and similar to those found in the San Joaquin River Drainage (Table 3). Very high O_3 concentrations in the southern and western Sierra Nevada were caused by polluted air masses from the Central Valley. On the other hand, elevated O_3 levels in the eastern Sierra Nevada may be due to the long-range transport of pollutants from the Central Valley (along passages in the San Joaquin River Drainage) and/or by smog from the Los Angeles Basin (through passes to the west and east of the San Gabriel Mountains, then across the Mojave Desert). In August, extremely high concentrations of O_3 were recorded both in the San Joaquin River Drainage and in the eastern Sierra Nevada (e.g., 167 ppb at Olancha Pass, 186 ppb at Squaw Dome, and 132 ppb at Mammoth Mountain) (Tables 3 and 4, Figure 9). During this period, all of the southern Sierra Nevada locations (Table 4) also exhibited elevated O_3 levels. We also postulate that these very high concentrations of O_3 were caused by pollutant emissions (nitrogen oxides, carbon monoxide, and hydrocarbons) from the McNalley fire. Comparison of O_3 levels between the Sierra Nevada areas studied in 2002 is difficult due to the occasional spikes of very high concentrations caused by the McNalley fire. However, in general O_3 concentrations were the highest in southern Sierra Nevada (range of 2-week averages 57-93 ppb, seasonal average 80 ppb), followed by the San Joaquin River transect (range 49-186 ppb, seasonal average 76 ppb), eastern Sierra (range 33-132 ppb, seasonal average 67 ppb), and the lowest levels in the Lake Tahoe area (range 31-73 ppb, seasonal average 51 ppb).

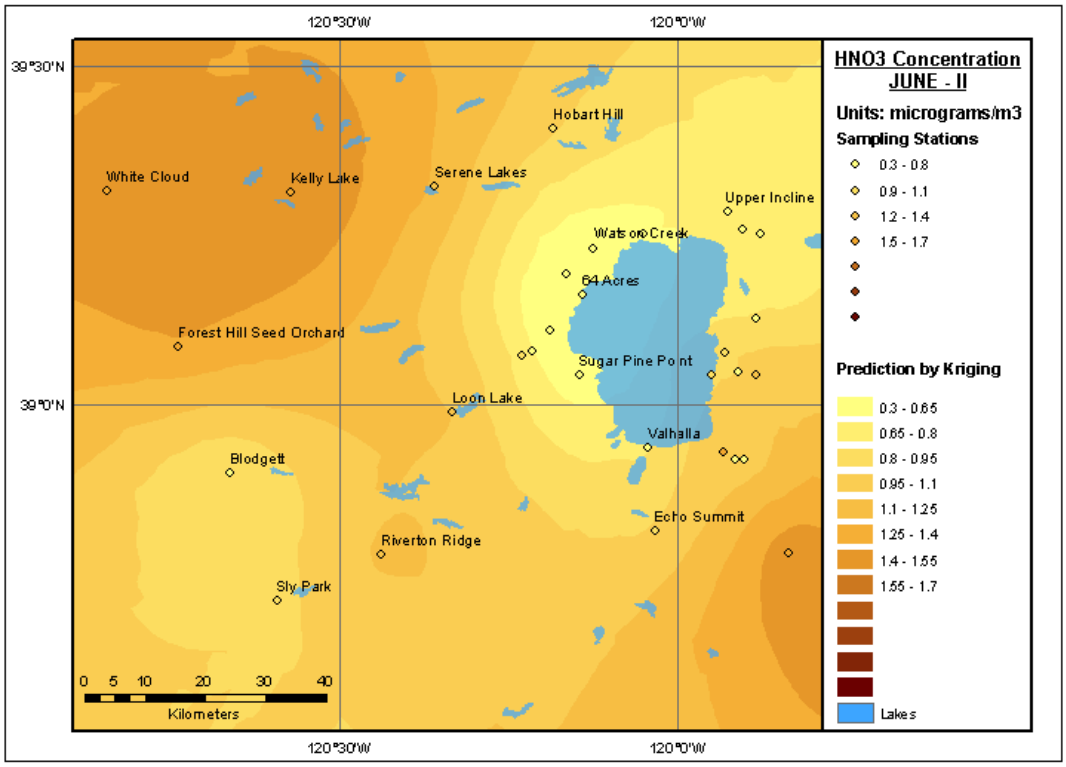

Figure 8a. Distribution of Two-week Average Ambient Nitric Acid Concentrations (µg HNO_3/m^3) in the Lake Tahoe Study Area: June 18 through July 2, 2002.

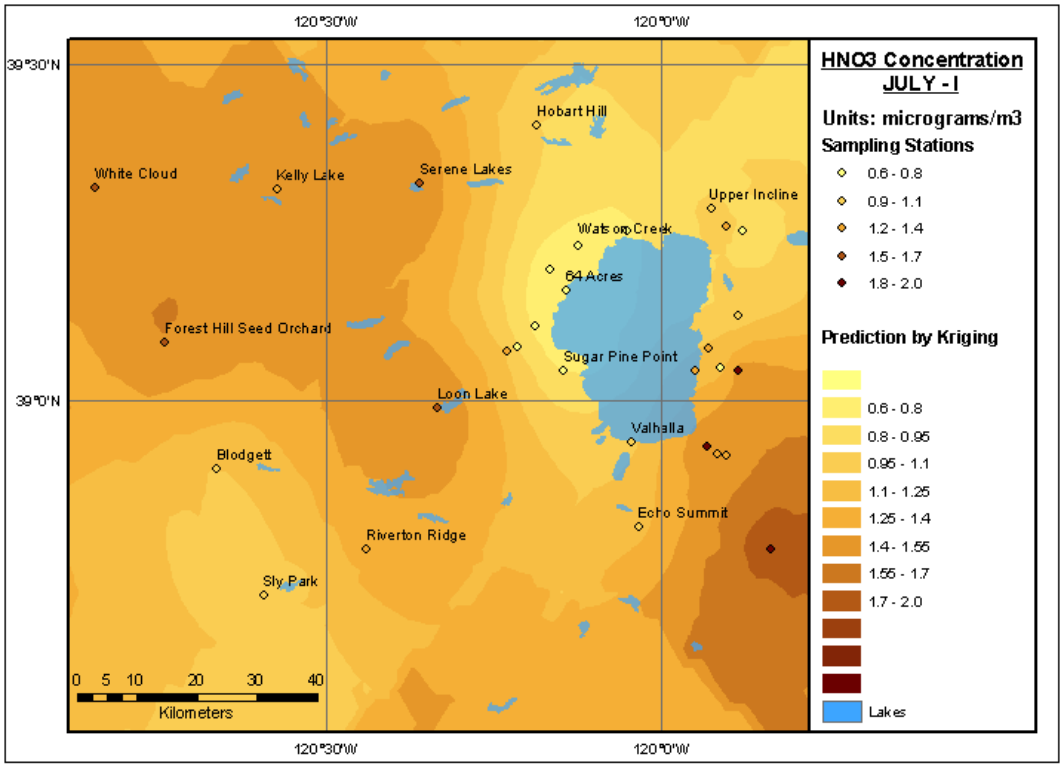

Figure 8b. Distribution of Two-week Average Ambient Nitric Acid Concentrations (µg HNO_3/m^3) in the Lake Tahoe Study Area: July 2 through July 16, 2002.

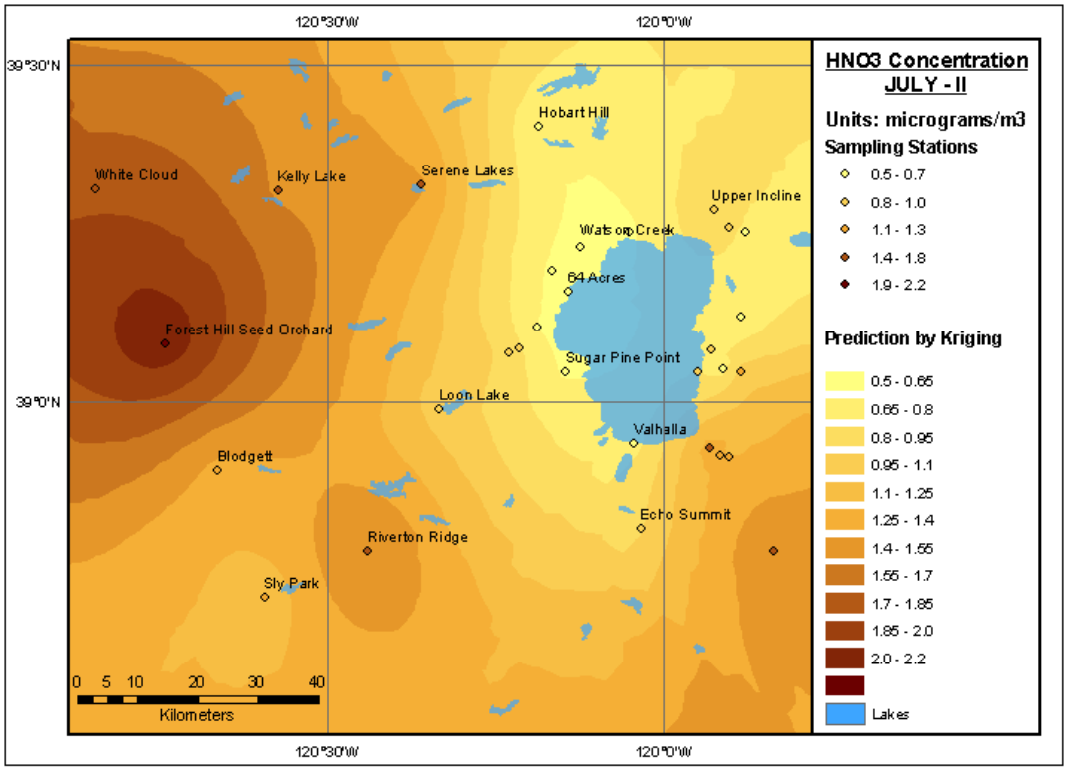

Figure 8c. Distribution of Two-week Average Ambient Nitric Acid Concentrations (µg HNO_3/m^3) in the Lake Tahoe Study Area: July 16 through July 30, 2002.

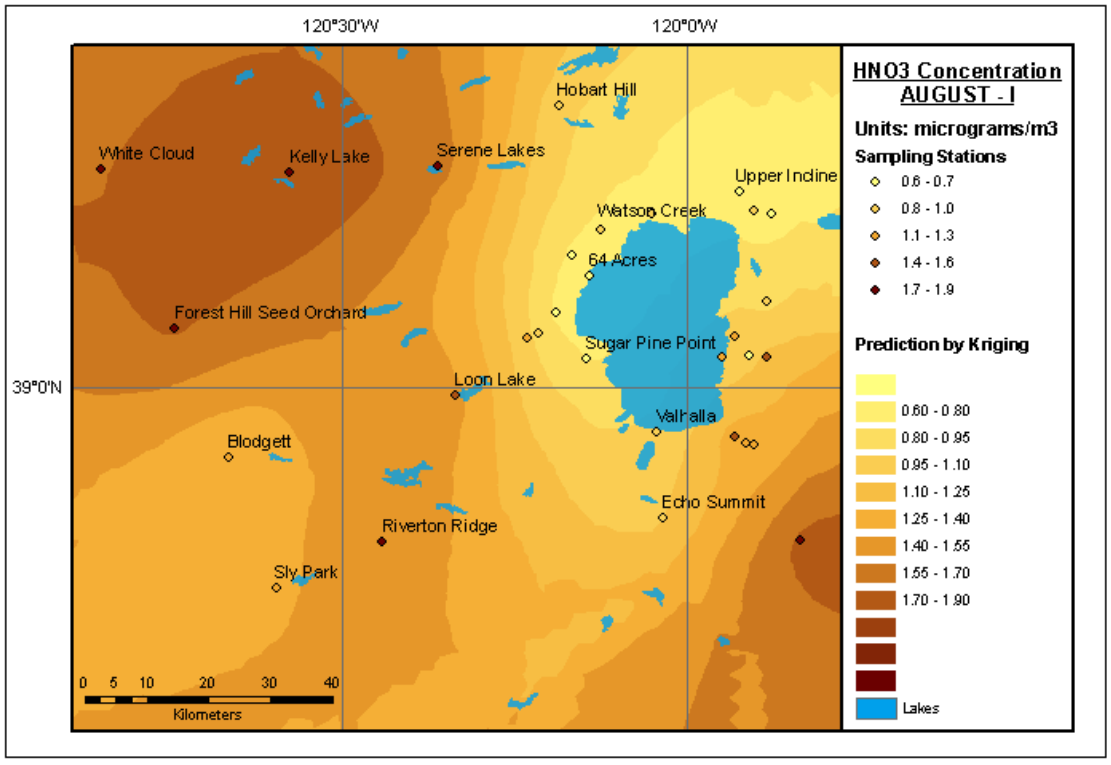

Figure 8d. Distribution of Two-week Average Ambient Nitric Acid Concentrations (µg HNO_3/m^3) in the Lake Tahoe Study Area: July 30 through August 13, 2002.

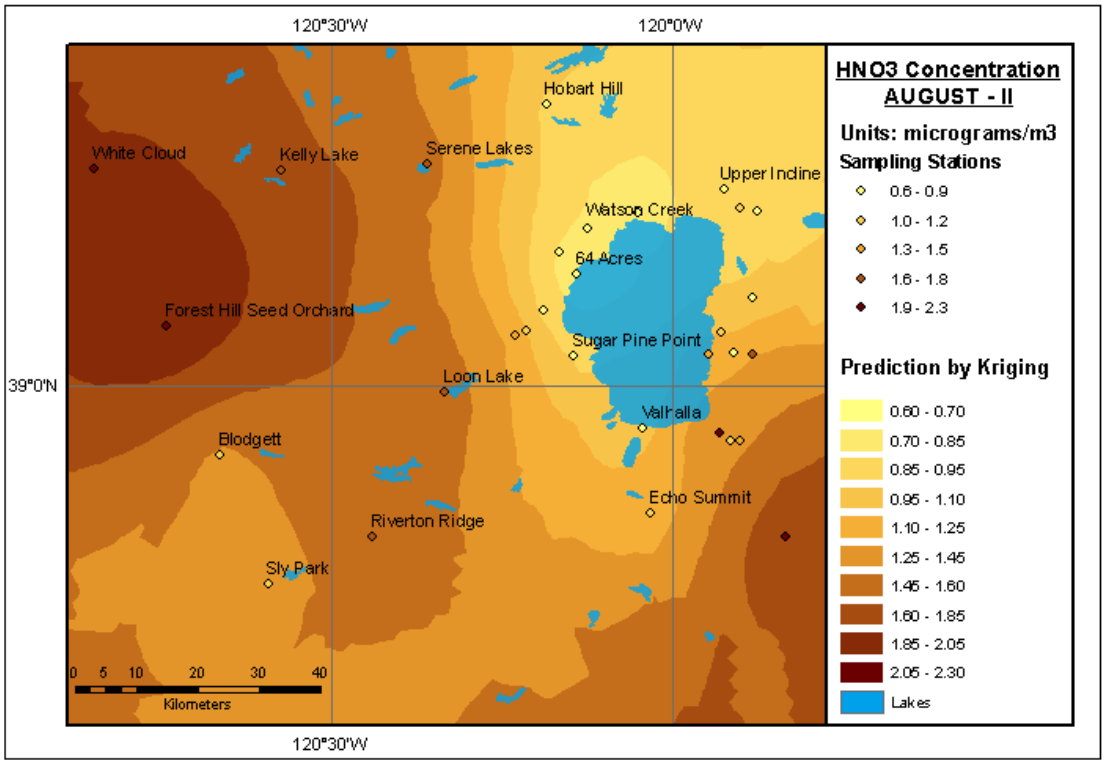

Figure 8e. Distribution of Two-week Average Ambient Nitric Acid Concentrations (µg HNO_3/m^3) in the Lake Tahoe Study Area: August 13-28, 2002.

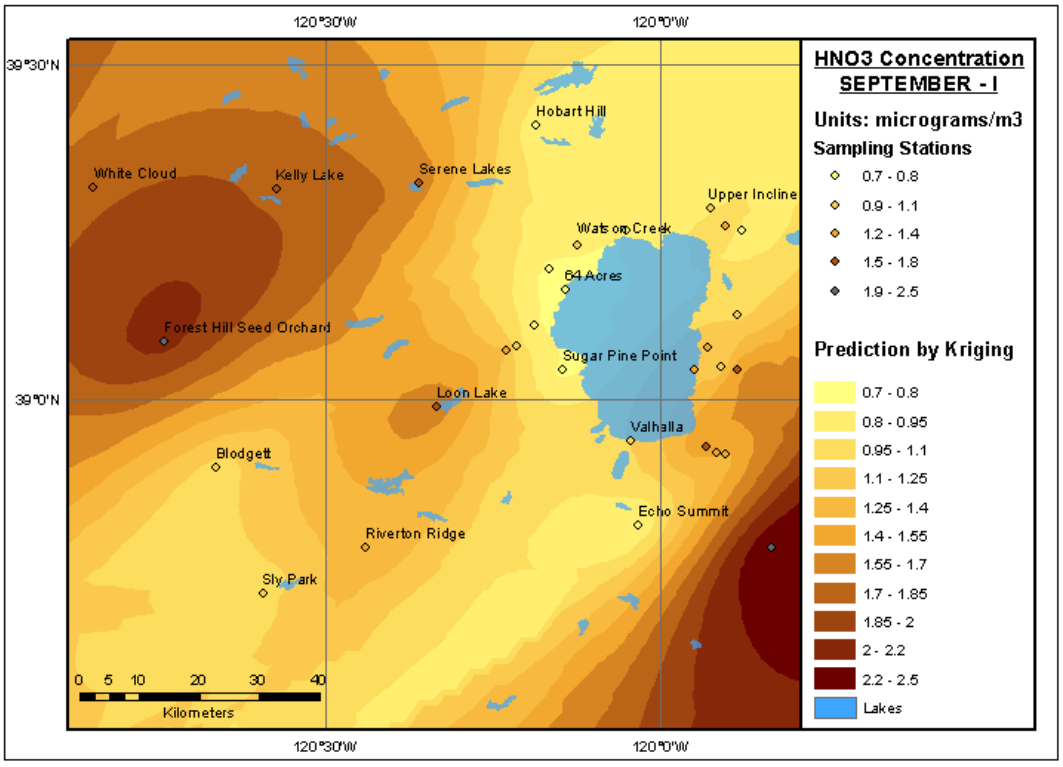

Figure 8f. Distribution of Two-week Average Ambient Nitric Acid Concentrations (µg HNO_3/m^3) in the Lake Tahoe Study Area: August 28 through September 11, 2002.

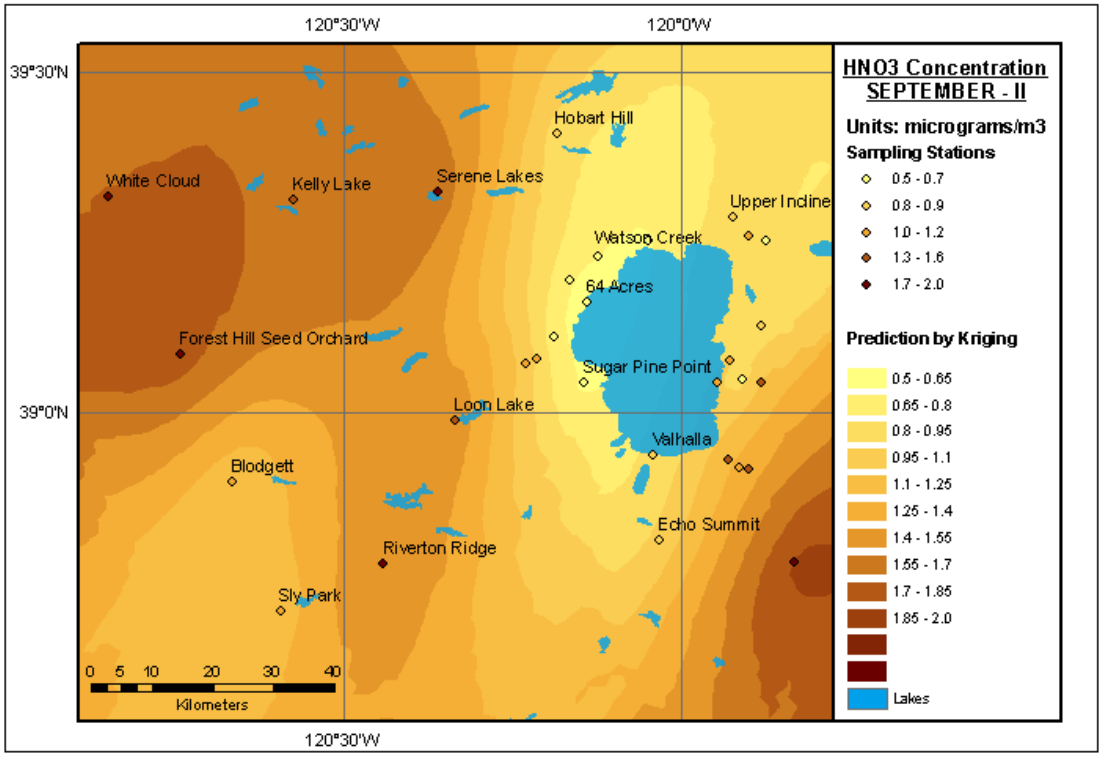

Figure 8g. Distribution of Two-week Average Ambient Nitric Acid Concentrations (µg HNO_3/m^3) in the Lake Tahoe Study Area: September 11-25, 2002.

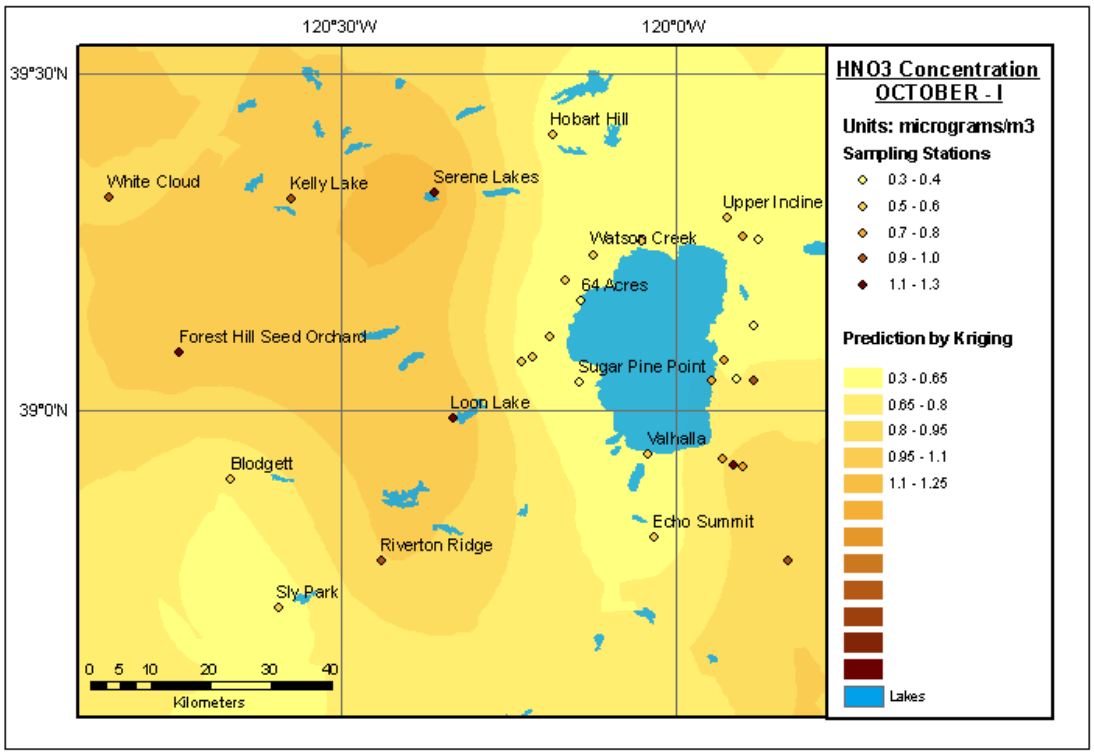

Figure 8h. Distribution of Two-week Average Ambient Nitric Acid Concentrations (µg HNO_3/m^3) in the Lake Tahoe Study Area: September 25 through October 9, 2002.

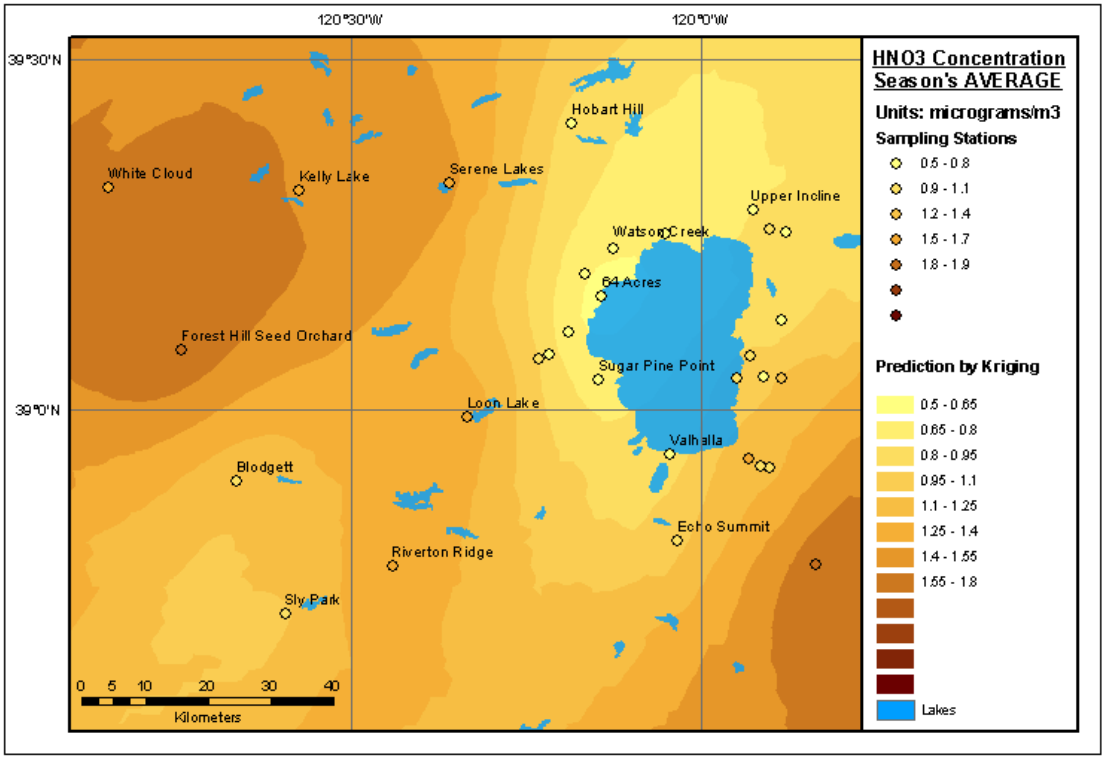

Figure 8i. Mean Summer-Fall Two-week Average Ambient Nitric Acid Concentrations (µg HNO_3/m^3) in the Lake Tahoe Basin Study Area: June 18 through October 9, 2002.

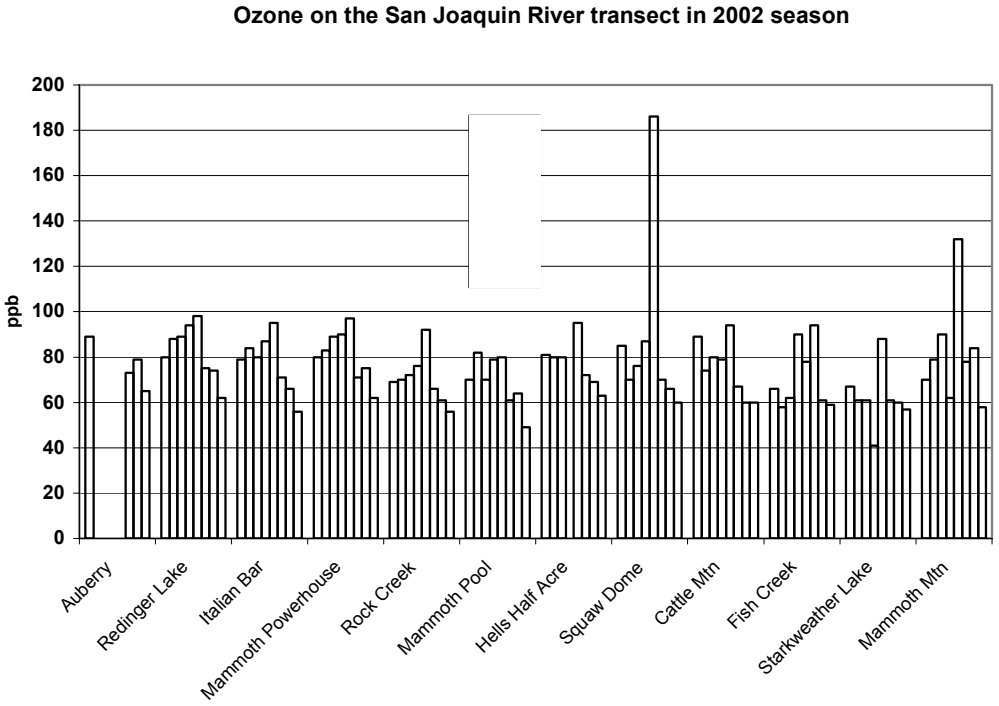

Figure 9. Distribution of Two-week Average Ambient Ozone Concentrations (ppb) along the San Joaquin River drainage during the 2002 season.

In the San Joaquin River Drainage, nitric acid concentrations were the highest near the San Joaquin Valley and gradually decreased eastwards (Table 5; Figure 10). This phenomenon is apparently caused by a high deposition velocity of HNO_3 to various landscape features, such as rocks, water bodies or vegetation (Hanson and Lindberg, 1991). In the first half of August, elevated concentrations of HNO_3 were recorded at Italian Bar, Rock Creek, and Mammoth Pool. These episodes could also be related to the McNalley fire (i.e., increased generation of HNO_3 from emissions of NO_x). In general, the observed two-week average HNO_3 concentrations were above background levels for the Sierra Nevada (Fenn et al., 2003) as well as the concentrations measured in Sequoia National Park in 1999 (Bytnerowicz et al., 2002). The six western sites on the San Joaquin River transect had higher HNO_3 concentrations than those measured in the Lake Tahoe area. The other five sites located in the middle and eastern part of the transect (from Hells Half Acre to Starkweather Lake) had much lower levels, similar to those found in the Lake Tahoe Basin. The only exception was a clearly elevated HNO_3 concentration at Starkweather Lake in the second half of August that was probably caused by the McNalley fire.

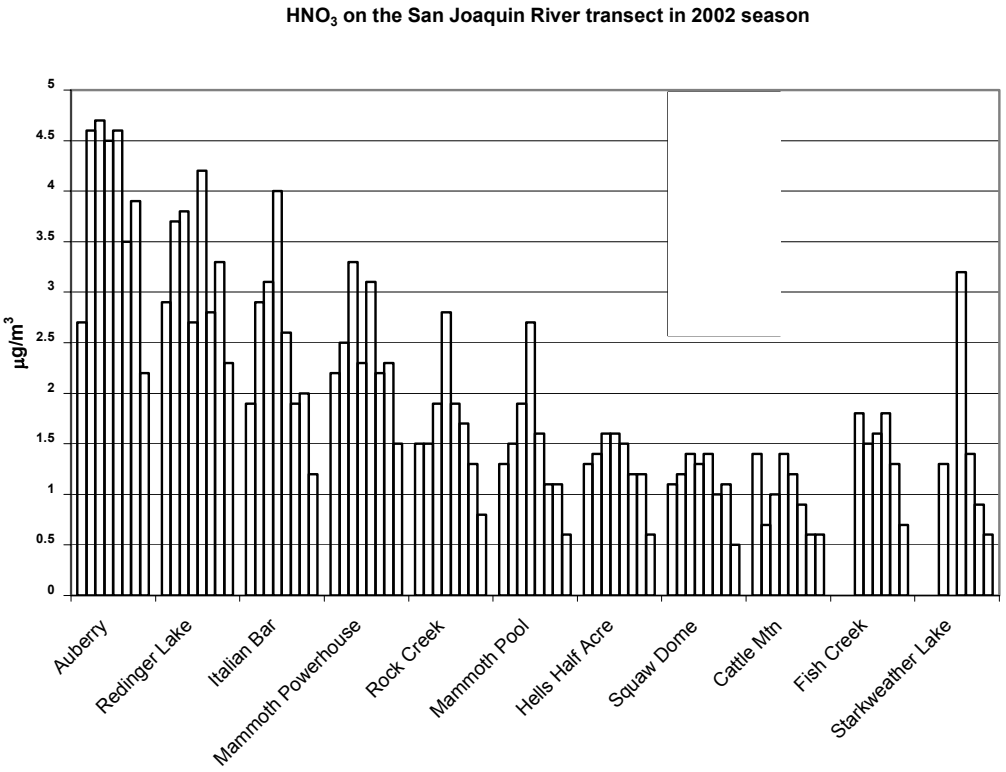

Figure 10 Distribution of Two-week Average Ambient Nitric Acid Concentrations (µg HNO_3/m^3) during the 2002 season.

Ammonia (NH_3) concentrations on the San Joaquin River Drainage were highest at Auberry, the site that would be most heavily affected by emissions of nitrogenous compounds from agricultural activities in the San Joaquin Valley. In general, NH_3 concentrations decrease gradually with distance from the San Joaquin Valley (Table 6), and were similar to those found in Sequoia National Park in 1999 (Bytnerowicz et al., 2002). In the first half of September, NH_3 concentrations were significantly higher than in any other period, including the sites farthest from agricultural sources in the San Joaquin Valley (i.e., Mammoth Powerhouse). Relative to

the potential influence of the McNalley fire, concentrations of ammonium (NH_4^+) in soil increase greatly after fires (e.g., an order of magnitude or more) that may be caused by soil heating and additions of NH_4^+ from ash particles. Soil concentrations of NH_4^+ may remain elevated as a result of both the increase in NH_4^+ production and a decrease in NH_4^+ consumption by plant and microbes (Fisher and Binkley, 2000). Volatilization of NH_4^+ from soils could then occur and contribute to elevated ambient NH_3 concentrations. In addition, elevated ambient NH_3 levels could also arise from the emission of gaseous NH_3 from the smoldering biomass, humus, and organic soil.

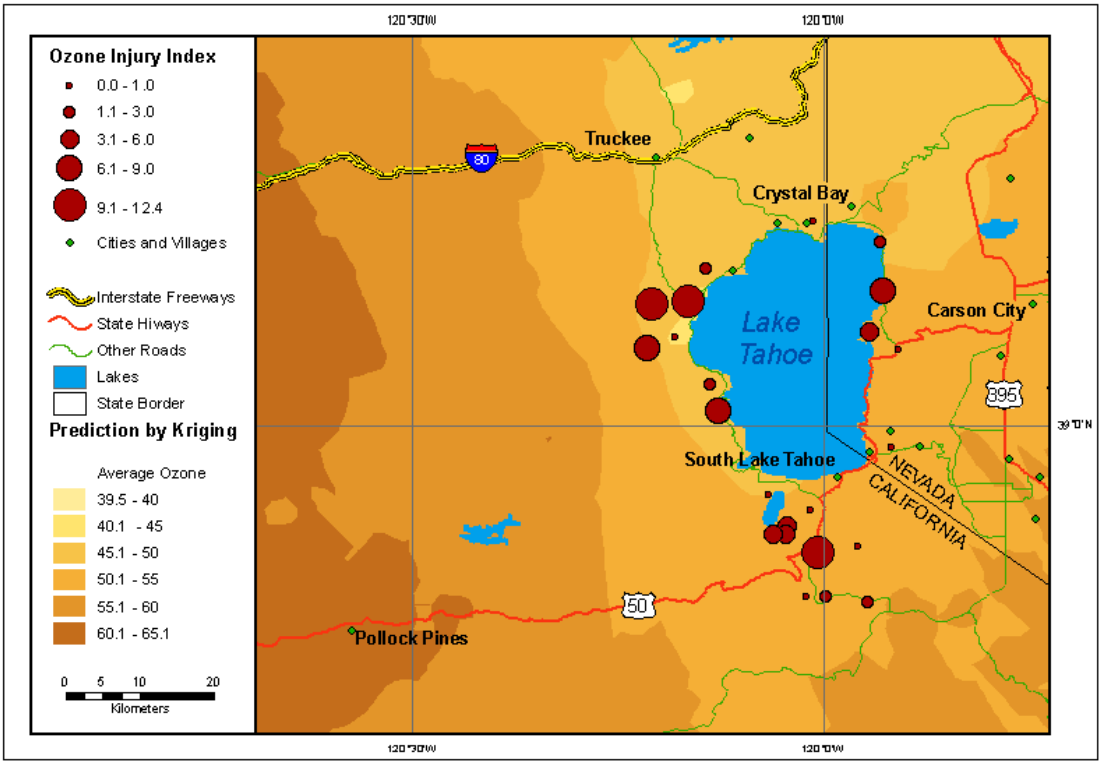

Figure 11. Ozone Injury Index (OII) Values for Ponderosa Pine Stands in the Lake Tahoe Basin: Summer-Fall 2002.

IV.D. Current Ozone Injury Patterns in the Lake Tahoe Basin

Foliar O_3 injury was evaluated at 25 pre-existing sites in the Lake Tahoe Basin Area. Sites originally were established to contain 15 mature ponderosa pine (*Pinus ponderosa*) trees, but as few as 6 trees remained at some of the locations (Table 7). Evaluations were conducted using the Ozone Injury Index (OII) developed by Miller et al. (1996). Overall 23% of the trees evaluated had foliar O_3 injury present. The average OII was 17.3, which indicates only slight injury is occurring to the pines in this area. Ambient O_3 levels at the sites were largely similar, with seasonal kriged averages generally between 40 and 50 ppb (Fig. 11). No discernable spatial patterns of injury were observed between sites. Differences in the number and severity of O_3 injury between sites are likely due to microsite growing conditions, and genotypic and phenotypic responses of individual trees to O_3 air pollution.

IV.E. Ozone Injury Patterns along the San Joaquin River and Eastside

Foliar O_3 injury was evaluated at 11 sites along a southwest to northeast transect following the San Joaquin River drainage. Foliar evaluations were conducted using the Forest Pest Management (FPM) approach. This approach correlates with the OII at the site level (Arbaugh et al. 1998), but may differ for individual trees. Both percent of trees injured and average FPM were calculated for all sites (Table 7). Sites along the western side of the transect had higher percent of trees with injury, and injured trees had more severe injury (Figure 12) than sites located in the interior the drainage. The most severely injured site was along the western edge (Plot 1), which had an FPM score of 3.15 and over 50% of the trees were injured. Mountain interior and eastside sites generally had few trees injured, and the amount of injury was slight. Values of OII estimated at three other eastside locations were also very low (Figure 12). This pattern indicates that ambient O_3 affects sites well into the interior of the mountains, but had only slight affect on easterly interior and eastside sites, except for a few sensitive genotypes.

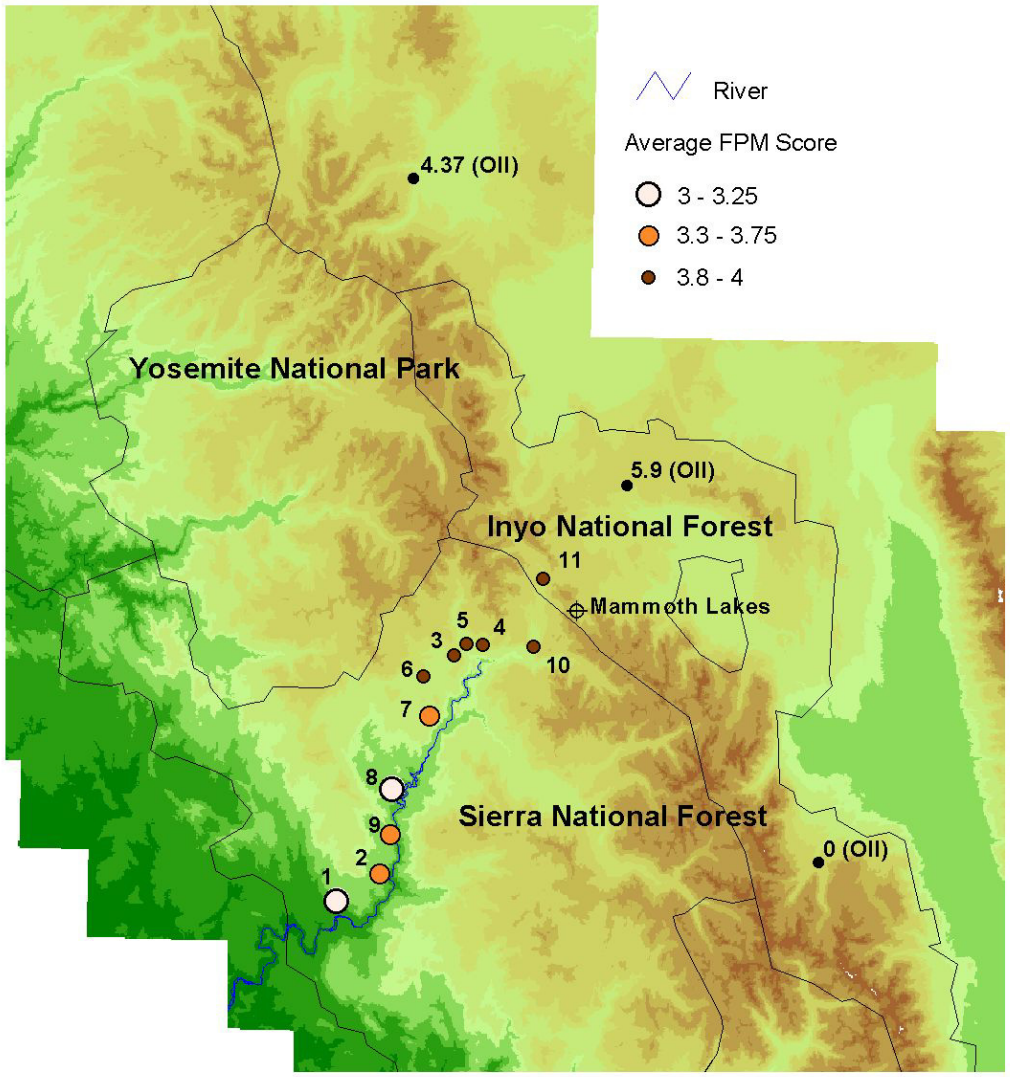

Figure 12. Forest Pest Management (FPM) injury scores along the San Joaquin River Drainage, and OII scores for the Eastern Sierra Nevada.

V. Conclusions

- In the Lake Tahoe area, local pollutant generation appears to be the main cause of increased O_3 and HNO_3 concentrations within the Basin. We postulate that the mountain range west of Lake Tahoe Basin (Desolation Wilderness) creates a barrier that prevents polluted air masses from West (Sacramento Valley and foothills of the Sierra Nevada) from entering the Lake Tahoe Basin.

- The high O_3 concentrations measured along the San Joaquin River Drainage throughout summer-fall 2002 indicate that polluted air masses from the Central Valley can penetrate deep into the Sierra Nevada range. This may be an important contributing factor to elevated O_3 concentrations in the southeastern portion of the Sierra Nevada.

- Nitric acid concentrations are highly elevated near the Central Valley and decrease to background levels found in the Sierra backcountry. The decrease in HNO_3 vapor concentration with elevation is sharper than for O_3 due in large part to its higher deposition velocity.

- Elevated O_3 concentrations during the second half of August at most sites in the San Joaquin River Drainage, eastern and southern Sierra Nevada, were very likely caused by the increased production of pollutant emissions from the McNalley fire. Elevated concentrations of HNO_3 recorded at the same time, at several sites along the San Joaquin River Drainage, could also indicate the effect of the McNalley fire activity.

- In the San Joaquin River Drainage, ammonia concentrations gradually decrease with distance from the San Joaquin Valley. Significantly elevated NH_3 concentrations during the first half of September could be caused by the delayed effects of the McNalley fire.

- No discernable spatial patterns of O_3 injury were observed on ponderosa pines between sites in the Lake Tahoe Basin. Differences in the number and severity of injury between sites are likely due to microsite growing conditions, and genotypic and phenotypic responses of individual trees to O_3.

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Tables

Table 1. Air Pollution Monitoring Sites in the Lake Tahoe Basin and Vicinity[1]

No.	Site	National Forest	Sample ID	Elevation (m)	Latitude (DD)	Longitude (DD)
1	White Cloud	Tahoe	17-5	4,197	39.316	-120.847
2	Kelly Lake	Tahoe	17-6	5,958	39.313	-120.574
3	Serene Lakes	Tahoe	17-7	7,370	39.323	-120.360
4	Hobart Mills	Tahoe	17-8	5,926	39.409	-120.185
5	Forest Hill Seed Orchard	Tahoe	17-10	4,109	39.085	-120.741
6	Cave Rock	LTBMU	19-1	6,171	39.043	-119.948
7	Genoa Peak 7000	LTBMU	19-2	7,071	39.075	-119.929
8	Genoa Peak 8000	LTBMU	19-3	8,035	39.047	-119.909
9	Genoa Peak 8881	LTBMU	19-4	8,881	39.044	-119.883
10	Upper Incline	LTBMU	19-5	8,278	39.285	-119.924
11	Diamond Peak	LTBMU	19-6	8,434	39.257	-119.901
12	Tahoe Regional Park	LTBMU	19-7	6,437	39.252	-120.051
13	64 Acres	LTBMU	19-8	6,235	39.162	-120.141
14	Watson Creek	LTBMU	19-9	7,524	39.229	-120.124
15	Watson Mountain Road	LTBMU	19-10	7,176	39.193	-120.165
16	Barker Pass	LTBMU	19-11	7,149	39.071	-120.230
17	Lower Blackwood Creek	LTBMU	19-12	6,392	39.109	-120.188
18	Upper Blackwood Creek	LTBMU	19-13	7,149	39.078	-120.215
19	Sugar Pine Point State Park	LTBMU	19-14	6,400	39.042	-120.145
20	Valhalla	LTBMU	19-15	6,252	38.936	-120.043
21	Heavenly Gun Barrel	LTBMU	19-16	7,829	38.929	-119.931
22	Heavenly Sky Express	LTBMU	19-17	9,984	38.917	-119.901
23	Heavenly Ridge Bowl	LTBMU	19-18	9,128	38.918	-119.914
24	Little Valley	Toiyabe	19-19	6,417	39.252	-119.877
25	Clear Creek	Toiyabe	19-20	6,886	39.126	-119.883
26	Sly Park	Eldorado	2-Mar	3,500	38.708	-120.593
27	Riverton Ridge	Eldorado	3-Mar	4,024	38.776	-120.440
28	Loon Lake	Eldorado	4-Mar	6,323	38.988	-120.334
29	Echo Summit	Eldorado	5-Mar	7,310	38.811	-120.033
30	Woodford's	Toiyabe	6-Mar	7,014	38.778	-119.834
31	Blodgett	Eldorado	3-10p	4,260	38.897	-120.664

(1) LTBMU = Lake Tahoe Basin Management Unit. "-----" indicates the absence of verified elevation data.

Table 2. Ozone concentrations from active monitors, passive sampler NO_3^- formation rates and conversion factors for calculating O_3 concentrations at three collocated sites of the Lake Tahoe area – 2002 season.

Date	Echo Summit			Cave Rock			White Cloud		
	O_3 (ppb)	NO_3^- formation rate (μg/h)	Conversion factor [ppb O_3/(μg NO_3/h)]	O_3 (ppb)	NO_3^- formation rate (μg/h)	Conversion factor [ppb O_3/(μg NO_3/h)]	O_3 (ppb)	NO_3^- formation rate (μg/h)	Conversion factor [ppb O_3/(μg NO_3/h)]
6/5-21	53.9	0.0755	713.91						
7/2-16				45.6	0.0675	675.56	56.5	0.0880	641.48
7/16-31	48.3	0.0620	779.03	45.1	0.0705	639.72	64.5	0.1000	645.00
7/31-8/12	56.4	0.0795	709.43	51.4	0.0665	772.93	68.4	0.1020	670.59
8/12-26	58.2	0.0765	760.78	56.7	0.0900	630.00	71.2	0.1135	627.31
8/26-9/9	56.2	0.0750	749.33	51.6	0.0825	625.45	61.0	0.0855	713.45
9/9-24	54.1	0.0765	707.19	49.9	0.0770	648.05	60.1	0.8950	671.51
9/24-10/7	45.3	0.0615	736.59	42.4	0.0705	601.42	48.4	0.0725	667.59
10/7-23							56.2	0.0835	673.05
Average	**53.2**	**0.0724**	**736.61**	**49.0**	**0.0749**	**656.16**	**60.8**	**0.0918**	**663.75**
Seasonal average of the conversion factors for 3 collocated sites - **684.5 ppb O_3/(μg NO_3/h)**									

Table 3. Two-week Average Ozone Concentrations (ppb) in the San Joaquin River Drainage Transect: Summer-Fall 2002[1]

Site	---------- Two-week Sampling Period ----------							
	Jun 18 thru Jul 2	Jul 2 thru Jul 16	Jul 16 thru Jul 30	Jul 30 thru Aug 13	Aug 13 thru Aug 28	Aug 28 thru Sep 11	Sep 11 thru Sep 25	Sep 25 thru Oct 9
Auberry	89 (2)	-----	-----	-----	-----	73 (6)	79 (8)	65 (3)
Redinger Lake	80 (1)	88 (1)	89 (0)	94 (2)	98 (3)	75 (1)	74 (2)	62 (2)
Italian Bar	79 (1)	84 (2)	80 (2)	87 (0)	95 (3)	71 (0)	66 (16)	56 (1)
Mammoth Powerhouse	80 (1)	83 (1)	89 (0)	90 (3)	97 (1)	71 (4)	75	62 (0)
Rock Creek	69 (3)	70 (3)	72 (1)	76 (2)	92 (1)	66 (3)	61 (12)	56 (4)
Mammoth Pool	70 (3)	82 (1)	70 (4)	79 (6)	80 (2)	61 (1)	64 (7)	49 (1)
Hells Half Acre	81 (2)	80 (0)	80 (5)	-----	95 (3)	72 (3)	69 (1)	63 (3)
Squaw Dome	85 (6)	70 (1)	76 (2)	87 (3)	186 (2)	70 (1)	66 (5)	60 (3)
Cattle Mountain	89 (1)	74 (1)	80 (5)	79 (1)	94 (1)	67 (3)	60 (16)	60 (1)
Starkweather Lake	67 (2)	61 (0)	61 (2)	41 (9)	88 (15)	61 (7)	60 (1)	57 (9)
Fish Creek	66 (2)	58 (11)	62 (0)	90 (16)	78 (4)	94 (4)	61	59 (7)
Shaver Lake	68 (1)	58 (1)	65 (1)	70 (4)	78 (1)	-----	123 (1)	47 (0)

(1) Mean of two samples ± one standard deviation (in parentheses). Listed values without standard deviations indicate samples in which one of the two replicate filters was invalidated. The site at Shaver Lake is not located on the San Joaquin River Drainage Transect. "-----" = No quality assured data for the sampling period.

Table 4. Two-week Average Ozone Concentrations (ppb) in the Eastern and Southern Sierra Nevada: Summer-Fall 2002

Site	---------- Two-week Sampling Period ----------							
	Jun 16 thru Jul 2	Jul 2 thru Jul 18	Jul 18 thru Jul 31	Jul 31 thru Aug 14	Aug 14 thru Aug 28	Aug 28 thru Sep 11	Sep 11 thru Sep 25	Sep 25 thru Oct 11
Eastern Sierra Nevada								
Chimney Peak	61 (2)	64	67 (1)	50 (1)	80 (2)	62 (0)	61 (2)	51 (1)
Olancha Pass	69 (37)	68 (0)	-----	167 (38)	80 (1)	67	69 (1)	54 (2)
Oak Creek	73 (4)	66 (13)	62 (1)	67 (1)	77 (5)	66 (5)	60 (0)	48 (20)
Sherwin Creek	64 (9)	61 (0)	-----	95 (32)	86	85	75 (7)	70
Bishop Creek	78 (1)	61 (5)	-----	78 (12)	79 (3)	73 (1)	65	58 (2)
395 Lookout	69 (5)	59 (1)	-----	59 (4)	68 (7)	66 (0)	61 (0)	59 (3)
SNARL	62 (50)	46 (2)	58 (3)	63 (1)	76 (0)	58 (1)	64 (17)	41 (2)
Mammoth Mt.	70 (9)	79 (7)	90 (5)	62 (7)	132 (11)	78 (0)	84 (32)	58 (6)
Indiana Smt.	68 (8)	64 (11)	-----	55	75 (1)	63 (1)	64 (7)	43 (2)
Conway Smt.	65	62	-----	100 (21)	78	78	84 (37)	92 (16)
Masonic Mt.	33 (7)	50 (3)	-----	53	63 (1)	67 (2)	59 (3)	40 (1)
Sonora Pass	42 (3)	-----	51 (1)	57	59 (4)	63 (7)	53	41 (4)
Topaz Lake	38 (0)	-----	-----	-----	106 (18)	80 (2)	71	48 (1)
Southern Sierra Nevada								
Breckenridge	80 (0)	84 (1)	85 (0)	85 (4)	95 (2)	73 (0)	79 (2)	61 (1)
Lightner	92 (2)	91 (1)	91 (0)	91 (1)	101 (2)	78 (3)	86 (1)	68 (3)
Kelso	90 (5)	84 (1)	80 (4)	78 (0)	92 (5)	68 (1)	67 (2)	57 (2)
Canebrake	83 (5)	79 (3)	76 (1)	77 (1)	93 (2)	66 (1)	63 (1)	58 (1)

(1) Mean of two samples ± one standard deviation (in parentheses). Listed values without standard deviations indicate samples in which one of the two replicate filters was invalidated. "-----" = No quality assured data for the sampling period.

Table 5. Two-week Average HNO_3 concentrations ($\mu g/m^3$) in the San Joaquin River Drainage Transect: Summer-Fall 2002[1]

Site	---------- Two-week Sampling Period ----------							
	Jun 18 thru Jul 2	Jul 2 thru Jul 16	Jul 16 thru Jul 30	Jul 30 thru Aug 13	Aug 13 thru Aug 28	Aug 28 thru Sep 11	Sep 11 thru Sep 25	Sep 25 thru Oct 9
Auberry	2.7 (1.2)	4.6 (0.3)	4.7 (0.8)	4.5 (0.0)	4.6 (0.3)	3.5 (0.8)	3.9 (0.4)	2.2 (0.4)
Redinger Lake	2.9 (0.6)	3.7 (0.4)	3.8 (0.8)	2.7 (0.9)	4.2 (1.0)	2.8 (0.5)	3.3 (0.6)	2.3 (0.5)
Italian Bar	1.9 (0.2)	2.9 (0.2)	3.1 (0.2)	4.0 (0.7)	2.6 (0.3)	1.9 (0.1)	2.0 (0.3)	1.2 (0.2)
Mammoth Powerhouse	2.2 (0.3)	2.5 (0.3)	3.3 (0.5)	2.3 (0.4)	3.1 (0.3)	2.2 (0.1)	2.3 (0.2)	1.5 (0.0)
Rock Creek	1.5 (0.4)	1.5 (0.5)	1.9 (0.3)	2.8 (0.4)	1.9 (0.5)	1.7 (0.3)	1.3 (0.3)	0.8 (0.2)
Mammoth Pool	1.3 (0.1)	1.5 (0.2)	1.9 (0.3)	2.7 (0.6)	1.6 (0.1)	1.1 (0.1)	1.1 (0.0)	0.6 (0.1)
Hells Half Acre	1.3 (0.1)	1.4 (0.1)	1.6 (0.2)	1.6 (0.1)	1.5 (0.1)	1.2 (0.2)	1.2 (0.0)	0.6 (0.1)
Squaw Dome	1.1 (0.0)	1.2 (0.1)	1.4 (0.0)	1.3 (0.1)	1.4 (0.3)	1.0 (0.1)	1.1 (0.2)	0.5 (0.1)
Cattle Mountain	1.4 (0.2)	0.7 (0.6)	1.0 (0.6)	1.4 (0.2)	1.2 (0.1)	0.9 (0.2)	0.6 (0.2)	0.6 (0.1)
Starkweather Lake	-----	-----	1.3 (0.4)	-----	3.2 (0.4)	1.4 (0.4)	0.9 (0.2)	0.6 (0.1)
Fish Creek	-----	-----	1.8 (0.2)	1.5 (0.3)	1.6 (0.1)	1.8 (0.3)	1.3 (0.4)	0.7 (0.1)
Shaver Lake	-----	1.1 (0.1)	0.3 (0.0)	0.7 (0.1)	1.2 (0.1)	0.8 (0.0)	1.0 (0.1)	0.5 (0.0)

(1) Mean of two samples ± one standard deviation (in parentheses). The site at Shaver Lake is not located on the San Joaquin River Drainage Transect. "-----" = No quality assured data for the sampling period.

Table 6. Two-week Average NH_3 concentrations ($\mu g/m^3$) in the San Joaquin River Drainage Transect: Summer-Fall 2002[1]

Site	---------- Two-week Sampling Period ----------							
	Jun 4 thru Jun 18	Jun 18 thru Jul 2	Jul 2 thru Jul 16	Jul 16 thru Jul 30	Jul 30 thru Aug 13	Aug 13 thru Aug 28	Aug 28 thru Sep 11	Sep 11 thru Sep 25
Auberry	-----	4.5 (0.5)	4.5 (0.0)	5.8 (0.0)	4.3 (0.0)	5.0 (0.2)	7.3 (0.1)	5.2 (0.7)
Redinger Lake	2.4 (0)	3.3 (0.5)	5.5 (0.2)	5.2 (0.1)	3.8 (0.4)	4.5 (0.4)	6.3 (0.1)	4.6 (0.1)
Italian Bar	2.4 (0.1)	2.9 (0.3)	3.5 (0.5)	4.4 (0.5)	3.8	3.3 (0.3)	6.8 (0.8)	4.4 (1.3)
Mammoth Powerhouse	2.0 (0.2)	2.0 (0.1)	2.1 (0.1)	3.6 (0.0)	3.2 (0.7)	3.8 (0.2)	6.9 (0.0)	4.5 (0.1)
Rock Creek	1.8 (0.1)	2.1 (0.5)	2.0 (0.2)	2.9 (0.1)	2.8 (0.4)	3.8 (0.0)	4.7 (0.4)	3.0 (0.2)
Mammoth Pool	1.4 (0.2)	1.9 (0.1)	2.3 (0.2)	2.9 (0.2)	3.0 (0.0)	4.7 (0.2)	4.2 (0.1)	3.3 (0.8)
Hells Half Acre	1.6 (0.1)	2.6 (0.6)	3.1 (0.0)	2.6 (0.0)	3.1 (0.3)	4.4 (0.2)	4.3 (0.1)	3.0 (0.1)
Squaw Dome	0.8 (0.6)	3.2 (0.1)	2.7 (0.3)	2.6 (0.7)	2.2 (0.4)	3.3 (0.3)	4.3 (0.5)	2.4 (0.2)
Cattle Mountain	-----	1.8 (0.2)	3.7 (1.1)	2.2 (0.0)	1.6 (0.3)	3.1 (0.2)	3.7 (0.2)	2.0 (0.2)
Shaver Lake	1.4 (0.1)	2.1 (0.2)	3.2 (1.2)	2.7 (0.0)	2.4 (0.2)	3.7 (0.1)	5.1 (0.1)	3.6 (0.8)

(1) Mean of two samples ± one standard deviation (in parentheses). Listed values without standard deviations indicate samples in which one of the two replicate filters was invalidated. The site at Shaver Lake is not located on the San Joaquin River Drainage Transect. "-----" = No quality assured data for the sampling period.

Table 7. Foliar Injury Sites and Injury Scores

Plot Number	Site Name	Survey Type	Number of Trees	Number Injured	Percent Injured (%)	Average OII or FPM	Crew Leader
Lake Tahoe Basin Region							
1	Slaughterhouse	OII	7	1	14.3	26.4	Duriscoe
2	Rubicon	OII	12	6	50.0	18.0	Duriscoe
3	Ward	OII	9	6	66.7	18.6	Nickerman
4	Upper Blackwood	OII	15	4	26.7	25.1	Nickerman
5	Fallen Leaf	OII	4	0	0.0	0.0	Pronos
6	Grass Lake	OII	13	4	30.8	8.9	Nickerman
7	Lower Blackwood	OII	15	0	0.0	0.0	Pronos
8	Lake Valley	OII	9	2	22.2	17.0	Nickerman
9	Tahoe Mountain	OII	8	0	0.0	0.0	Duriscoe
11	Upper Burton	OII	15	2	13.3	20.6	Duriscoe
12	Brockway	OII	15	0	0.0	0.0	Pronos
13	Angora Creek	OII	8	1	12.5	45.8	Nickerman
14	Angora Lakes	OII	15	8	53.3	7.0	Duriscoe
15	Trout	OII	14	1	7.1	8.9	Nickerman
16	General	OII	9	1	11.1	18.1	Duriscoe
17	Hawley	OII	14	0	0.0	0.0	Duriscoe
18	Sunnyside	OII	11	5	45.5	20.2	Nickerman
19	Kingsbury	OII	13	2	15.4	4.0	Duriscoe
20	Spooner	OII	6	0	0.0	0.0	Duriscoe
21	Marlette	OII	15	8	53.3	16.2	Duriscoe
22	Myers	OII	12	7	58.3	19.5	Nickerman
24	Tunnel	OII	15	3	20.0	11.7	Pronos
25	Luther	OII	15	4	26.7	8.6	Duriscoe
Eastern Sierra Nevada							
1	Bishop Creek	OII	50	0	0.0	0.0	Duriscoe
2	Indiana Summit	OII	50	1	2.0	5.9	Duriscoe
3	Buckeye/Doc&Al's Resort	OII	50	3	6.0	4.4	Duriscoe

Table 7 Continued

Plot Number	Site Name	Survey Type	Number of Trees	Number Injured	Percent Injured (%)	Average OII or FPM	Crew Leader
	San Joaquin Transect						
1	Redinger	FPM	20	11	55	3.15	Duriscoe
2	Mammoth Pool Powerhouse	FPM	20	8	40	3.45	Duriscoe
3	Cattle Mountain	FPM	20	7	35	3.90	Duriscoe
4	Cargyle Creek	FPM	20	4	20	3.95	Duriscoe
5	Near Sheep Crossing	FPM	20	4	20	4.00	Duriscoe
6	Clover Meadow	FPM	20	1	5	3.95	Duriscoe
7	Southfork Trailhead	FPM	20	7	35	3.70	Duriscoe
8	Logan Meadow Trailhead	FPM	20	10	50	3.25	Duriscoe
9	Rock Creek	FPM	20	2	10	3.75	Duriscoe
10	Fish Creek	FPM	20	7	35	3.80	Duriscoe
11	Upper Soda Springs	FPM	20	1	5	4.00	Duriscoe