Spatial and temporal patterns of visibility in Las Vegas, July 2000--July 2001

Arsineh Najjari Hecobian

University of Nevada, Las Vegas

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SPATIAL AND TEMPORAL PATTERNS OF VISIBILITY IN LAS VEGAS

JULY 2000 – JULY 2001

by

Arsineh Najjari Hecobian

Bachelor of Science
University of Nevada, Las Vegas
2000

A thesis submitted in partial fulfillment
of the requirements for the

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Department of Chemistry
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Graduate College
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The Thesis prepared by

Arsineh Najjari Hecobian

Entitled

SPATIAL AND TEMPORAL PATTERNS OF VISIBILITY IN LAS VEGAS

JULY 2000 - JULY 2001

is approved in partial fulfillment of the requirements for the degree of

Master of Science in Chemistry

Vernon Hodge
Examination Committee Chair

Dean of the Graduate College

Examination Committee Member

Examination Committee Member

Graduate College Faculty Representative

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ABSTRACT

Spatial and Temporal Patterns of Visibility in Las Vegas
July 2000 – July 2001

by

Arsineh Najjari Hecobian

Dr. Vernon Hodge, Examination Committee Chair
Professor of Chemistry
University of Nevada, Las Vegas

The Clark County Department of Air Quality Management and the Nevada Department of Motor Vehicles funded a one-year study of visibility trends in Las Vegas. The Desert Research Institute conducted this study from July 2000 to July 2001. The monitoring sites for this study were chosen to represent three areas in Las Vegas, urban, suburban and background/transport. Strong diurnal patterns were found at the urban and suburban sites. The background site had low levels of air pollution, and most of the haze at this site was due to light scattering by particles. The suburban site followed a well-defined diurnal pattern during the cold season, and showed the influences of local activities (such as road construction) during the study. Overall, the urban site had the highest levels of visibility impairment, but during midday the visibility at this site improved and was comparable to that of the suburban site. This thesis presents the data from this study.
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CHAPTER 1

INTRODUCTION

1.1. Atmospheric Visibility Impairment

1.1.1. Atmospheric Visibility

One of the methods used for evaluating the level of atmospheric pollution is visibility. Visibility has been defined as the greatest distance at which a black object may be observed against the horizon sky (Malm, 2000). Visibility of an object observed through the atmosphere is dependent upon many factors, such as the distance of the object from the observer, contrast of the object to the background, eyesight and the vision perception of the observer, the location and the altitude of the observer relative to the object, the light (sunlight) angle, reflection of light from the object to the observer and the weather conditions (Malm 2000). Of all of these factors, the reflected light and its path from the object to the observer play the most important roles. The reflected light must pass through air to reach the observer. Thus, any particles and gases that are present in the atmosphere in the path of light, will reduce the complete reflection of light from the object to the observer. This includes the gases that make up air, such as oxygen, nitrogen, argon, carbon dioxide, neon, helium, krypton, xenon, etc (Air Resource Specialists, 1997a; Spedding, 1974).
These gases and particles will impair visibility by interfering with the correct perception of the color, texture, form and brightness of the object. If a parallel beam of light is transmitted through the atmosphere, its intensity falls exponentially with distance (Spedding, 1974). If the ambient air is free of polluting particles and gases, Rayleigh scattering occurs (Bodhaine, 1979; Bucholtz, 1995). Rayleigh scattering is the scattering of light by particles much smaller than the wavelength of light (Malm, 2000). Absorption and scattering of light are wavelength dependent and the type of pollutants that are present in the atmosphere influences the color of sky. (Bodhaine, 1979).

Gases or particles that are present in the atmosphere cause light scattering. Particles that can cause the greatest reduction in visibility per unit mass, are fine particles (Malm, 2000), fine particles are more efficient in scattering of light than coarse particles per unit mass. The aerodynamic diameter of such particles ranges from 0.1-1.0 μm (Malm, 2000). The U.S. Environmental Protection Agency (EPA) has established National Ambient Air Quality Standards (NAAQS) for particles with a diameter of less than 2.5 μm (United States Environmental Protection Agency, 1998), the PM2.5 standards are under revision as a result of a February 2001 U.S. Supreme Court decision (United States Environmental Protection Agency, 2002). Such standards are also established for particles with a diameter of less than 10 μm (Chow et al, 1993c). Many airborne particles are in the range of 0.1-1.0 μm (National Research Council, 1993).

1.1.2. Light Extinction Coefficient

The value used to quantify visibility impairment is extinction coefficient. The extinction coefficient is a measure of the fraction of light energy dE, lost from a collimated beam of
energy $E$, in traversing a unit thickness of atmosphere, $dx$ (National Research Council, 1993).

$$\frac{dE}{dx} = -B_{\text{ext}} \times E$$  \hspace{1cm} (1)

The extinction coefficient ($B_{\text{ext}}$) is usually calculated in units of $\text{Mm}^{-1}$ (inverse megameters) or $\text{km}^{-1}$ (inverse kilometers). The extinction coefficient in the atmosphere can vary from $10^2 \text{ km}^{-1}$ to $1 \text{ km}^{-1}$ ($10 \text{ Mm}^{-1} - 1000 \text{ Mm}^{-1}$), depending on the location of the measurement and the concentration and type of the pollutants present in the ambient air, (National Research Council, 1993).

Extinction coefficient is also defined as a measure of the ability of particles or gases to absorb and scatter photons from a beam of light (Malm, 2000). This may be expressed as the sum of light scattering and light absorption by gases and light scattering and absorption by particles (Malm 2000).

$$B_{\text{ext}} = B_{\text{scat (gas)}} + B_{\text{scat (part)}} + B_{\text{abs (gas)}} + B_{\text{abs (part)}}$$  \hspace{1cm} (2)

The scattering coefficient is a measure of the ability of particles or gases to scatter photons out of a beam of light (Malm, 2000). The absorption coefficient is a measure of the ability of particles and gases to absorb photons (Malm, 2000). Visibility in kilometers is inversely proportional to the extinction coefficient ($B_{\text{ext}}$) (Malm, 2000).

$$\text{Vis(km)} \propto \frac{1}{B_{\text{ext}}}$$  \hspace{1cm} (3)

Units of deciview (dv) are also used for light extinction measurements. The $B_{\text{ext}}$ unit used in this formula is in $\text{Mm}^{-1}$ (Malm, 2000).

$$dv = 10 \ln \frac{B_{\text{ext}}}{10}$$  \hspace{1cm} (4)
1.1.3 Light Absorption Coefficient

In earth's atmosphere, the only gaseous pollutant that absorbs visible light in any significant levels is nitrogen dioxide (NO\textsubscript{2}) (Watson \textit{et al}, 1988a, 1988b, 1988c). Haze caused by NO\textsubscript{2} is usually observed as a brown atmospheric discoloration (Malm, 2000), because NO\textsubscript{2} absorbs preferentially in the blue-green portion of the visible spectrum. Depending on the angle of light relative to the NO\textsubscript{2} plume and the observer, NO\textsubscript{2} haze may also be observed as a grayish-black plume in the atmosphere (Malm, 2000).

Light absorption by particles is mainly due to black carbon or soot particles (Rosen \textit{et al}, 1978; 1980; Rosen and Hansen, 1984). These particles are formed during combustion of carbonaceous fuels. They are usually small particles with a diameter of less than 1 \(\mu\text{m}\) and have a graphitic crystal structure (Horvath, 1993). These particles are inert and not easily destroyed by atmospheric chemical processes. However, the surface of the black carbon particles is highly porous which results in a larger surface area where toxic compounds bind. In addition atmospheric particles may have surface functional groups that are involved in the binding of toxic materials and organic pollutants (Hansen \textit{et al}, 1984).

1.2. Current Methods of Visibility Measurement

1.2.1. Scattering and Absorption Measurements

Two different sets of measurements are performed for visibility impairment. The first group of these measurements is the ones concerning light scattering and the second group are the ones for light absorption (Chow, 1995; Chow and Watson 2001). Most of the instruments that are used for light scattering measure either the energy scattered from a
short path in the atmosphere or the remaining energy after it (the light beam) has traveled through the atmosphere (National Research Council, 1993). Nephelometers are used for light scattering measurements. They use light detectors to measure the light that is scattered in a closed chamber path, which is filled with ambient air (Ruby and Waggoner, 1981). Transmissometers, on the other hand, focus on the amount of energy detected after it has traveled through the atmosphere over a long path from its point of origin; they measure total light extinction in the atmosphere (Malm, 2000).

The instrument that is most commonly used for direct and real time light absorption measurements by particles is the aethalometer (Anderson et al, 1996; Clarke et al, 1987; Gunter et al, 1993; Hansen et al, 1982; Hansen and Novakov, 1988; Lioussse et al, 1993). This instrument uses the ratio of the intensity of light (at different wavelengths), when it is transmitted through a blank filter compared to when it is transmitted through a filter that has been exposed to ambient air flow for a specified amount of time (Hansen et al, 1984).

There are other instruments that are used for specialized ambient measurements. For example, particle size counters are used to investigate the quantity of particles in different size ranges at any given time. Specialized instruments are also used for quantifying particulate matter measurements in real time or with sampling times of various durations (Air Resource Specialists, 1996b; 1997c; Chan and Lippmann, 1977; Chuang et al, 1990; Eatough et al, 1990; Hawthorne et al, 1988). Filters from some of these instruments may also undergo analytical analysis for chemical speciation (Lee and Ramamurthi, 1993; Tang et al, 1994; Watson et al, 1993). One of the instruments used for particulate matter analysis is the beta attenuation monitor (Clark County Department of Air Quality...
Management, 2002). Beta attenuation monitors (also known as beta gauges) are used for measuring PM$_{10}$ (particulate matter with a diameter of 10 μm) measurements (Clark County Department of Air Quality Management, 2002).

Beta Attenuation Monitors (Met One Instruments, Grants Pass, OR) are used for the monitoring of PM$_{10}$ particles by the Clark County Department of Air Quality management. The Beta Attenuation Monitor (BAM) is U.S. Environmental Protection Agency certified (EPQM-0798-122) as an equivalent method for PM$_{10}$ monitoring. BAM uses beta ray transmission across a filter to determine particulate concentration. At the beginning of the sampling period beta ray transmission is measured across a clean section of the filter tape. This section of the filter tape is then mechanically advanced to the sampling inlet. Ambient air is drawn through the sampling tape and particulate matter is deposited on the filter. The filter tape is then returned to its original location and beta ray transmission through the filter is measured. The difference between the two measurements is used to determine the particulate concentration. The filter tape is placed between the beta source and the detector. As the mass deposited on the filter tape increases the measured beta particle count is reduced according to a known equation. Bam is equipped with self-calibration software for zero and span calibrations. The beta source used in BAM is $^{14}$C, 60 μCi. The resolution of this instrument is $+/-$ 2 μg/m$^3$ (Met One Instruments, 2002).

1.2.2. Nephelometer

A model NGN-2 open air integrating nephelometer was used for light scattering measurements. This nephelometer is built by OPTEC, Inc, Lowell, MI. A block diagram of the nephelometer is shown in Figure 1-1.
The nephelometer measures the light scattering in ambient air by particles (Bsp). Ambient air is pumped into a dark chamber and since ambient air is used directly for the measurements, no significant change is made to its pressure and temperature. Light of a specified intensity is shone through the ambient air in the dark chamber in a horizontal line. A block diagram of the internal arrangement of a nephelometer is shown in Figure 1-2. A 25-volt dichroic reflector halogen lamp is used for this purpose (Grainger, Las Vegas, NV). The nephelometer operates at 550 nm. The wavelength is selected by diffraction grating. A chopper is present immediately in front of the lamp, the chopper motor's rotational speed is precisely held to 2.5 rotations per second. This light is then passed through a heat filter. The heat filter is a heat absorbing glass filter that blocks all radiation longer than 700 nm. There is a light detector (#1) after the heat filter that
measures the intensity of light as a safeguard against low lamp intensity levels. This light
detector produces an output signal that is directly proportional to the chopped light
signal. This means that in case of insufficient lamp intensity a signal is sent by this
detector to the analog port that goes through a feedback loop and stops the sampling. The
operator specifies the lamp intensity levels. There is a photodiode light detector (#2)
located directly above the horizontal ray of light that measures any light scattered by the
particles and gases in the ambient air. This is the main light detector in the nephelometer.
The signal from the light detector is changed into voltage and passed through to the
digital or the analog connection. Both of the photodiodes in the nephelometer are P-N
silicon photodiodes. An electric motor is connected to the ambient air inlet door, so that
the door is automatically sealed during the sampling period to prevent any interference
from outside light. The door is also closed during the clean air and span gas calibrations.
The clean air and span gas calibration inlets are located at the back of the nephelometer.

A clean air filter is connected to the clean air inlet, for the manual or automated clean
air calibrations. The span gas inlet is setup for a connection to span gas container during
the manual span gas calibrations. The type of gas used for span gas calibration depends
on the nature of the measurements and the quality of the ambient air at the location where
the measurements are being taken.

The clean air filters are changed during the measurements, if the ambient air quality of
the site is very poor. For this study, the clean air filter for the nephelometers were only
changed once, and only for one of the nephelometers. The nephelometer was cleaned and
serviced completely and thus the clean air filter was changed.
1.2.3. Aethalometer

Magee Scientific aethalometers (AE30S), (Berkeley, CA) were used for this study. The measurement made by the aethalometer is the optically absorbing portion of carbonaceous particulate emissions (Hansen, 1999). The measurement method used in the aethalometer is the use of optical attenuation. Optical attenuation is defined in the following formula.

\[ \text{ATN} = 100 \times \ln \left( \frac{I_0}{I} \right) \]  

(5)

\( I \) = intensity of light transmitted through the original or blank filter

\( I_0 \) = intensity of light transmitted through a portion of the filter where the aerosol deposit is collected
The wavelength spectrum of the lamps used as the light source affects the black carbon concentration measurements. The black carbon concentrations in the ambient air may be calculated from the following formula (Hansen, 1984).

\[
ATN(\lambda) = \frac{1}{\lambda} \times [BC]
\]  

(6)

The \( \frac{1}{\lambda} \) is the optical absorption cross section, which is wavelength dependent. BC is black carbon concentration in \( \mu g/m^3 \), which are reported by the aethalometer. Equation 6 is rearranged and used by the aethalometer to compute the black carbon concentration in \( \mu g/m^3 \). The rearranged form of equation 6 is presented in equation 7.

\[
[BC] = \frac{1}{\lambda} \times ATN(\lambda)
\]

(7)

A quartz fiber filter (Magee Scientific) is used in the aethalometer. A blank portion of the filter tape is used for the initial light intensity reading and then ambient air flows through the filter in a circle with the area of 0.5 cm\(^2\). After a predetermined volume of air passes through the filter, the light intensity is measured again. This same spot on the filter is used for the second and third readings (after additional ambient air flow), and each time the initial intensity is the final one for the previous reading. This process continues until very low light intensity can be detected and then the tape is automatically advanced to the next spot, unless otherwise specified by the operator. The airflow through the aethalometer is maintained by the use of an external airflow diaphragm pump. The flow rate is set at the inlet connection of the aethalometer and the external pump, using the aethalometer’s internal flow meter. The change in flow is taken into consideration during the black carbon concentration calculations by the aethalometer’s internal computer. A simple block diagram of the inside of the aethalometer is shown in Figure 1-3.

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Filter tape

Figure 1-3: Block Diagram of the Aethalometer

The Magee Scientific aethalometers used in this study measure the black carbon concentrations at seven different wavelengths (350nm, 450nm, 570nm, 590nm, 660nm, 880nm, 950nm). The data from 570 nm wavelength were used in this study, as we are concerned with light absorption in the visible portion of the spectrum. Different components of emissions from different sources show up at different wavelengths (Hansen, 1999). For example, Hematite mineral dust may have a greater influence on the 660nm (red) measurement of black carbon concentration, whereas certain other inorganic compounds show the onset of molecular absorption at 880nm and 950nm, near IR. The aethalometer is equipped with an internal computer and the data are collected on 3.5" floppy disks. The data was archived on an external PC through a serial interface.

1.3 Identification of Sources of Visibility Impairment

Visibility and particulate matter measurements are important for several reasons. One of these reasons is that continuous monitoring and recording of visibility trends help in
the identification of sources responsible for air pollution (Chow et al, 1992; Green and Chow 1997). Visibility measurements combined with chemical speciation of particulate matter samples produce results that help in the recognition of trends of air pollution (Green et al, 2002). Such information is used in source appointment for the air pollutants (Chow et al, 1993a; 1993b; Kahl and Hansen, 1989). However, such measurements alone are not sufficient to present a complete picture of the origin and fate of the pollutants. In order to have a complete understanding of the origin and fate of the atmospheric pollutants that affect visibility, other measurements such as climate history and modeling, climate dynamics, location and the topography of the site of the study, quality and quantity of the polluting sources in operation, and other variables should be taken into consideration (Air Resource Specialists, 1997d; Chow et al, 1996). The first step in complete understanding of pollutants, their sources and their local and regional impact is to have a well-established air pollution and visibility monitoring network (National Research Council, 1993). On the local scale this network may be operated in areas such as Las Vegas Valley, and on a larger scale a network over different states or countries may be established (National Research Council, 1993).

The general distinction between the atmospheric pollutants is that they may be from natural or anthropogenic (man-made) sources. Table 1-1 is a list of anthropogenic and natural sources of the pollutants (Malm, 2000). Some of the pollutants may have both anthropogenic and natural sources. Also, some of the pollutants react with other atmospheric entities and produce new pollutant species. The pollutants that are directly from the source of pollution are called primary pollutants and the pollutants that are a result of the interaction of other pollutants are called secondary pollutants (Malm, 2000).
Table 1-1: Anthropogenic and Natural Pollution Sources

<table>
<thead>
<tr>
<th>Pollution Type</th>
<th>Anthropogenic</th>
<th>Natural</th>
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<tbody>
<tr>
<td>Wind Blown Dust</td>
<td>Roads, Overgrazing, Farming, Mining, Development of Undisturbed Land</td>
<td>Deserts</td>
</tr>
<tr>
<td>Fossil Fuel Combustion</td>
<td>Vehicle Emissions</td>
<td>NA</td>
</tr>
<tr>
<td>Plant Particles</td>
<td>NA</td>
<td>Pollen</td>
</tr>
<tr>
<td>Sea Salt Spray</td>
<td>NA</td>
<td>NaCl</td>
</tr>
</tbody>
</table>

1.4. Effects of Visibility Impairment

1.4.1. Health and Environmental Effects

Particles with a small diameter are mostly responsible for light scattering and haze. These particles have adverse effects on public health (Clark County Department of Air Quality Management, 2002). The presence of pollutant gases and particles in the atmosphere may cause serious health effects to the public (U.S. Environmental Protection Agency, 1998), and as a result the United States Environmental Protection Agency (US EPA) has established National Ambient Air Quality Standards (NAAQS) to protect public health (U.S. Environmental Protection Agency, 1987). Several adverse health
effects are due to particulate matter with small diameter because of their ability to penetrate into lungs and the respiratory system (U.S. Environmental Protection Agency, 1998). Black carbon particles directly affect the respiratory system and may also harbor toxic or carcinogenic chemicals and transfer them to the lungs and aggravate the respiratory system (Hansen, 1999; Lioy et al., 1980).

Particles with small diameter may have local and regional environmental effects (Air Resource Specialists, 1996c; Hansen and Rosen, 1984). These effects are dependent upon atmospheric dispersion scales and other environmental factors (Pandis et al., 1993). On the local scale, fine particles influence the aesthetics of the location, by causing different types of haze (National Research Council, 1993). The different types of haze are layered haze, plume and uniform haze (Malm, 2000). The environmental impact on the regional scale is similar to the local effect depending on the topography of the location and the polluting sources (Fritz and Fontes, 1980). A review of the above-mentioned environmental effects shows that monitoring and controlling the haze causing agents is not a concern restricted to one area or location but resolving it requires the cooperation of states and countries.

1.4.2. Economic Effects

Visibility impairment has had adverse effects on the economy of areas such as national parks and wilderness areas (Watson and Chow, 1994; Watson et al. 1996). Congress has shown its support of efforts to improve visibility in national parks and wilderness areas by the 1977 Clean Air Act (CAA, 42 U.S.C. § 7401-7671q) and later by adding the 1990 amendments to this act (National Research Council, 1993). The Clean Air Act specifies a goal of improving visibility and eliminating anthropogenic (man-
made) haze at these areas. Many programs and studies have been developed to understand, evaluate and prevent haze in such pristine areas. Visitors travel to such areas to enjoy the splendor of nature and see these national and natural monuments. Ultimately, impaired visibility in these regions will reduce tourism to these areas in the near future, adversely affecting local economies (National Research Council, 1993). For example, many of the tourists who are interested in the areas around Las Vegas, such as the Grand Canyon, stay in Las Vegas for part of their visit. Also, the U.S. Environmental Protection Agency (EPA) has specific regulations and penalties for areas that are in non-attainment for NAAQS. For example, remaining an area of non-attainment and failing to take the appropriate actions to reduce the pollutants in the area will cause Environmental Protection Agency to stop the Federal Highway Funds to the state where the non-attainment area is located. This will have adverse effects to the economy of the area (Federal Register, 1991).

1.5. Outline of This Study

1.5.1 Haze in Las Vegas

There are various sources of visibility impairment in Las Vegas. Some of these sources are wind-blown dust and different equipment from construction activities, unpaved roads, agricultural activities and disturbed vacant lands, off road recreational vehicles, motor vehicle emissions, residential wood burning and cooking, wildfire and brush burning, meat cooking and industrial sources (Chow and Watson, 1997; Clark County Department of Comprehensive Planning and Air Quality Management, 2002).
Under the Clean Air Act and its amendments, the U.S. Environmental Protection Agency has established National Ambient Air Quality Standards (NAAQS) for various pollutants. The U.S. Environmental Protection Agency has established NAAQS for some pollutants in the atmosphere. Some of the standards are primary; these standards are set to protect public health. Secondary standards are used to protect the welfare of the public and stop the deterioration of visibility (U.S. Environmental Protection Agency, 1998).

Table 1-2 shows some of these pollutants and their standard limits.

Table 1-2: List of Some Atmospheric Pollutants and Their NAAQS

<table>
<thead>
<tr>
<th>Pollutants</th>
<th>Standard Value</th>
<th>Standard Type</th>
</tr>
</thead>
<tbody>
<tr>
<td>CO</td>
<td>8-hr average</td>
<td>9 ppm (10 mg/m³)</td>
</tr>
<tr>
<td></td>
<td>1-hr average</td>
<td>35 ppm (40 mg/m³)</td>
</tr>
<tr>
<td>NO₂</td>
<td>Annual geometric mean</td>
<td>0.053 ppm (100 μg/m³)</td>
</tr>
<tr>
<td></td>
<td>PM₁₀</td>
<td>50 μg/m³</td>
</tr>
<tr>
<td></td>
<td>Annual geometric mean</td>
<td>150 μg/m³</td>
</tr>
<tr>
<td></td>
<td>24-hour average</td>
<td>50 μg/m³</td>
</tr>
<tr>
<td></td>
<td>3-hour average</td>
<td>150 μg/m³</td>
</tr>
<tr>
<td>SO₂</td>
<td>Annual geometric mean</td>
<td>0.03 ppm (80 μg/m³)</td>
</tr>
<tr>
<td></td>
<td>24-hour average</td>
<td>0.14 ppm (365 μg/m³)</td>
</tr>
<tr>
<td></td>
<td>3-hour average</td>
<td>0.50 ppm (1300 μg/m³)</td>
</tr>
</tbody>
</table>

In 1991, the Las Vegas Valley was classified as a moderate non-attainment area for some pollutants by the U.S. Environmental Protection Agency (Federal Register, 1991). In 1993 Las Vegas Valley was classified as a serious non-attainment area PM₁₀ and carbon monoxide (CO) (Federal Register, 1993). The Clark County Board of Commissioners was designated by the Governor in 1987 as the local responsible entity in the preparation of plans to improve air quality within Las Vegas Valley (Clark County
Department of Air Quality Management, 2002). In 1997 a new State Implementation Plan (SIP) for control of PM₁₀ and CO was submitted by Clark County to the U.S. Environmental Protection Agency for review and approval. The 1997 SIP was withdrawn in December of 2000 and a new plan was set in place that would allow for the attainment of annual NAAQS by 2001 and the 24-hour NAAQS by 2006. Public participation in the State Implementation Plan (SIP) review was initiated on March 6, 2001 when the County Commissioners received the March 2001 draft SIP (Clark County Department of Air Quality Management, 2002).

1.5.2. Visibility Studies

Las Vegas is one of the six serious non-attainment areas for PM₁₀. It is also believed that Las Vegas is a contributor to the regional haze in the Grand Canyon (Chow et al., 1999). Chow et al., (1999) showed that there is a build up of PM₁₀ in locations in the center of Las Vegas. Their data also showed distinct and reproducible PM₁₀ diurnal patterns. Elevated PM₁₀ concentrations were found to be associated with local construction activities, dust from wind and excessive surface loading. Another study conducted in Las Vegas by Chow and Watson (1997) with an emphasis on source contribution, showed that vehicle exhaust is the second largest contributor to air pollution in Las Vegas. The major contributor was found to be fugitive dust particles.

An extensive study of visibility in the United States was conducted by Trijonis et al., (1990). According the data present from 1974-1976, the median visibility in kilometers in Nevada, in suburban and non-urban areas was 50-150 km. The Trijonis et al. (1990) study showed that the 1990 conditions were similar to the data from 1974-1976 (Trijonis et al.,
1988). Visibility was reported to be less than 30 kilometers in California and less than 15 kilometers in the Los Angeles Basin (in suburban and non-urban areas).

According to Trijonis et al. (1990), visibility is worst in the eastern part of the United States. However, in relatively clean areas, small increases in the pollutant concentrations will markedly degrade visibility. The Class I areas of the western United States are such vulnerable areas (National Research Council, 1993). Class I areas are found in national wilderness areas and national parks larger than 5,000 acres, national parks over 6,000 acres and international parks. Any such area must have been in existence on August 7, 1977, the date the Clean Air Act amendments of 1977 were signed into law (National Research Council, 1993). According to a study conducted by Ferman et al. (1981) in the Shenandoah-Blue Mountain Ridge area, 78-86% of the haze is attributed to anthropogenic (man-made) airborne particles. The acquisition of more data on haze in Las Vegas and Nevada is important, because according to National Research Council, (1993), "...Because of data limitations, the modeling exercise does not cover the entire United States. It excludes, ...Nevada.... The excluded area contains important Class I areas..." (National Research Council, 1993).

Other studies such as Gebhart et al. (2001) concentrated on the data from stations all over the United States. They used 34 sites for this study. Nephelometer, aethalometer and transmissometer data were studied. Nephelometers were present at 16 sites, aethalometers were present at 14 sites and both nephelometers and aethalometers were present at 4 sites. They found that on average, during the warm season, the most common diurnal patterns have a midday minimum, and they said that some of this might be related to the relative humidity and heat in midday.
1.5.3. Legislative Background

Visibility impairment or haze is becoming a larger problem as time goes on. This is especially true in areas that have a rapid growth rate and are not prepared to deal with the increase in vehicle emissions, due to the increase in population. The public judges air pollution by how far and how clearly they can see (National Research Council, 1993). Visibility impairment causes social, economic and health problems, either directly or indirectly (National Research Council, 1993). The Congress, the U.S. Environmental Protection Agency and the environmental research community have been exerting more efforts to conduct reliable and standardized studies on visibility impairment. These efforts started to take root in 1990 as a result of the amendments made to the Clean Air Act. In 1997 more organized and cooperative research efforts were started. Also, monitoring networks such as the Interagency Monitoring of Protected Visual Environment (IMPROVE) have been established and expanded for visibility monitoring and research in the Class I areas (Pitchford et al, 1999). Also, in early 1990 the National Research Council established the Committee on Haze in National Parks and Wilderness Areas to address a number of questions related to visibility and its degradation in these pristine areas (National Research Council, 1993).

It is important to have standardized visibility monitoring data not only at the Class I areas, but at the urbanized locations near and around such areas (National Research Council, 1993). This is especially important if the location influencing the Class I area is a rapidly growing and expanding city like Las Vegas.

Las Vegas Valley is an area with the potential for high atmospheric pollution and visibility impairment. This is due to the topography of Las Vegas and the fast rate of...
growth in the Valley (U.S. Census Bureau, 2001). Thus, it is important for the public health and a continuous healthy economy to have a clear understanding of haze and air pollution in Las Vegas.

1.5.4. The Goals of This Study

The goals of this study were to setup appropriate visibility monitoring equipment to investigate and record patterns of visibility impairment in Las Vegas. This data will be used in the development of more effective measures and regulations for the high haze time periods in Las Vegas. Also, the information gained from this study will help in the development of future sampling methods and site selection and will establish a basis for the comparison of current visibility data to any future studies. The data and conclusions from this study were made available to Clark County Department of Air Quality Management in a report by the Desert Research Institute and will be accessible to the public in a less technical context.

The goals of this thesis are to present the visibility impairment data from the Desert Research Institute study to show current visibility trends at three sites in and around Las Vegas, and to compare the data from the three sites. A third goal is to evaluate the visibility monitoring equipment used at each of these sites for future studies.
CHAPTER 2

EXPERIMENTAL

2.1. Sites of Study

The Clark County Department of Air Quality Management has twenty-two air pollution monitoring stations. These include stations in and around Las Vegas. These stations and the pollutants measured at each station may be found in the Table A-3 of the Appendix. (Clark County Department of Air Quality Management, 2001)

Three sites were chosen in this study in and around Las Vegas. Each site was selected to represent a specific level of air pollution, population and urbanization in and around Las Vegas, using data from other studies such as Air Resource Specialists (1997b) and Watson and Chow (2001). The first site was chosen near the center of the city of Las Vegas to represent a heavily populated, urbanized area. The second site was chosen to monitor visibility in a residential suburban area, and the third site was chosen to represent a transport/background area. Locations of these sites are shown in Figure 2.3. There were other sites in and around Las Vegas that have the required levels of pollution and traffic; however, due to budgetary restrictions only three sites were set up for the study.
The site that was chosen to represent the urban area in Las Vegas, with high traffic and pollution levels was the East Charleston site (ECh). This station was located at 2801 East Charleston Boulevard, in Las Vegas. The elevation of this site is 567 meters above mean sea level. This is a residential and commercial site located at the eastern part of the Valley. The site is about 200 meters east of the junction of Eastern Avenue and East Charleston Boulevard. This area has been in non-attainment for carbon monoxide levels (Bowen and Egami, 1994). The traffic around the site is moderate to heavy with relatively short durations of high volume traffic around the morning and afternoon rush hours, at about 7:30am and 5:00pm. There are several stores located around this station.
Across the street from the station, there is a large parking lot for a furniture store (The Furniture Store) and a department store. A Mexican fast food store is located on the east side of the station and there are several small car repair shops and residential complexes to the west of the station. A nephelometer, an aethalometer, a laser particle spectrometer, a sequential gas sampler with a PM$_{2.5}$ cyclone and another one with a PM$_{10}$ cyclone were operated at this site during this study.

The second site was the Palo Verde (PV) station. The Palo Verde station is located on the parking lot of the Palo Verde high school at 333 Pavillion Drive, in Las Vegas, near the junction of Pavillon Dr. and Greenmoore St. The elevation of this site is 909 meters above mean sea level. This monitoring site was chosen so that it represented a suburban and residential setting. This station is near the exit of the parking lot of Palo Verde High School (PVHS) and there are high volumes of traffic at this area at about 6:30-7:00 am and 12:30-1:30 pm every weekday during the school year. There is also a recreational center that shares the parking lot with PVHS. This area has been known to have very high ozone concentrations. The building used for this station belongs to Clark County Department of Air Quality Management for their air pollution monitoring studies. A nephelometer, and aethalometer, and a sequential gas sampler with a PM$_{2.5}$ cyclone were operated at this site during the time of this study.

The third site, Jean (JN), was chosen as the background/transport site. This station is located about 25 km southwest of Las Vegas. The elevation of this site is 979 meters above mean sea level. The building that was used for the set up of this study is surrounded by desert land from all directions for at least 2 miles. The building belongs to the Las Vegas Valley Water District and was utilized by CCDAQM at the beginning of
the study. A new building was constructed by CCDAQM during this study a few meters north of the original building. The Jean (JN) site is located a few kilometers east of Interstate 15 (I-15). There are two large casinos located on I-15, a few kilometers west of this station. Table 2-1 shows the stations designations and their abbreviations.

Table 2-1: Site Designation and Abbreviations

<table>
<thead>
<tr>
<th>Site Designation</th>
<th>Site Name</th>
<th>Site Abbreviation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Urban</td>
<td>East Charleston</td>
<td>ECh</td>
</tr>
<tr>
<td>Suburban</td>
<td>Palo Verde</td>
<td>PV</td>
</tr>
<tr>
<td>Transport/Background</td>
<td>Jean</td>
<td>JN</td>
</tr>
</tbody>
</table>

2.2. Instrument Set Up

The nephelometers were set up on the roof of each sampling station. Each nephelometer was secured in place by a pole, which has a small rain shelter above the nephelometer. The nephelometers use an external power supply for DC power; so each one was connected to an AC/DC power converter inside the building. Each nephelometer was connected to a computer through serial COM port connections. One computer was operated at each site for data collection.

Clean air and span gas calibrations are conducted at specified intervals to compensate for the drift due to change of temperature from one season to another or accumulation of dirt. The clean air and span gas calibration are also used as a quality control tool for the data acquired from the nephelometer. The clean air measurements are conducted...
automatically by the nephelometer at the operator specified intervals. A clean air filter connected directly to the nephelometer is used for this purpose. However, if required the nephelometer accepts commands from a computer connection for clean air measurements. The span gas calibration may also be done in operator-specified intervals, automatically; or manually by the operator. Different gases are used for span gas calibration. The choice of gas is dependent upon the nature of the study and the level of the pollution of the site where the nephelometer is operated.

A simple linear formula may be used for the response of the nephelometer to light scattering. (Optec, 1999)

\[ Y = mx + b \]  

\( Y = \text{normalized nephelometer reading in counts} \)

\( m = \text{slope of calibration line} \)

\( x = \text{multiple of Rayleigh scattering} \)

\( b = \text{the intercept (nephelometer wall scattering in counts)} \)

\( m \) and \( b \) are calculated using the following formulas:

\[ m = \frac{C_{\text{span}} - C_{\text{zero}}}{S_{\text{span}} - S_{\text{zero}}} \]  

\[ b = C_{\text{zero}} - (m \times S_{\text{zero}}) \]

\( C_{\text{span}} = \text{nephelometer counts during upscale span calibration (counts)} \)

\( C_{\text{zero}} = \text{nephelometer counts during clean air calibration (counts)} \)

\( S_{\text{span}} = \text{span gas multiple of Rayleigh scattering (dependent upon the span gas used)} \)

\( S_{\text{zero}} = \text{clean air multiple of Rayleigh scattering (always equals one)} \)
If equations 8, 9 and 10 are combined, the equation used for the calculation of multiple of Rayleigh scatterings (MRS) as follows:

\[
MRS = \left( \frac{C_{\text{span}} - C_{\text{zero}}}{S_{\text{zero}}} \times X \right) + \left( C_{\text{zero}} - C_{\text{span}} - C_{\text{zero}} \right) \left( \frac{C_{\text{span}} - C_{\text{zero}}}{S_{\text{zero}}} \right)
\]  

(11)

The $y$ in this equation is the light scattering counts from the nephelometer. The multiple of Rayleigh scattering and the Rayleigh coefficient may be used to calculate the scattering coefficient ($B_{\text{scat}}$), using equation 12. The Rayleigh coefficient ($B_{\text{ray}}$) is dependent upon the elevation of the site and was acquired from the Rayleigh scatter as a function of altitude table in the nephelometer manual (Optec, 1999).

\[
B_{\text{scat}} = MRS \times B_{\text{ray}}
\]  

(12)

For the purposes of this study, the multiple of Rayleigh scattering used is listed in Table 2-2 (Optec, 1999).

<table>
<thead>
<tr>
<th>Site Abbreviation</th>
<th>Rayleigh Scattering at Each Site (Mm$^{-1}$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>ECh</td>
<td>10.98</td>
</tr>
<tr>
<td>JN</td>
<td>10.66</td>
</tr>
<tr>
<td>PV</td>
<td>10.66</td>
</tr>
</tbody>
</table>

Span gas calibrations were conducted at each site, for each nephelometer, every 15 days or more often if required, by the operator. Clean air samples were taken every six hours for most of the duration of the study and the ambient air measurements were made every two minutes, automatically by the nephelometer. Each new clean air value was
used with the latest span gas reading to calculate the slope and the light scattering coefficient.

The span gas that was used, for calibration purposes, during this study was Genetron (SUVA) 134a or 1,1,1,2-Tetrafluoroethane. This is a liquid refrigerant. The Material Safety Data Sheet (MSDS) number for this gas is GTRN-0011. The parameters for each nephelometer were set identically. A copy of these parameters may be found in the Appendix, in Table A-2. The rain sensors for all of the nephelometers were disabled in the middle of the study, due to malfunction.

Sampling times were set for 5 minutes at each site, for the aethalometers. This is the recommended time-base for data collection for the study of local impact in areas of high black carbon concentrations. The aethalometer is capable of collecting and presenting data for a sampling period of 2 seconds to 60 minutes. The valid values for any measurement of black carbon concentration by the aethalometers are 1-1000 µg/m³ (Hansen et al., 1984). The aethalometer algorithm uses a wavelength dependent absorption efficiency of 10 m²/g to convert the initial attenuation readings to black carbon concentrations in ng/m³. Thus, the black carbon concentrations from the aethalometer are multiplied by 0.01 to calculate the absorption coefficient (Babs) in Mm⁻¹ (Hansen, 1999). This is shown in equation 13.

\[ B_{\text{abs}} = 0.01 \times [BC] \]  

(13)

The aethalometers were set up inside the buildings at each site and the ambient air was directed to the aethalometers through a teflon tube from the roof of the building. The length of the air inlet connection at each site was less than 5 feet. A typical sample of a setup file for the aethalometers may be found in the Appendix in Table A-3. The airflow
rates for the aethalometers were set to 2.5 liters per minute (lpm) for the East Charleston site and 5.0 lpm for the Palo Verde and Jean site. The reason for the difference of the flow rate is the higher air pollution rate at the East Charleston site.

2.3. Data Analysis

2.3.1. Data Acquisition

The nephelometers and the aethalometers at the three sites were connected to a site computer (RS232 serial port connections) and the data was collected in text format on the computers located at the monitoring site. Each site computer was in turn connected to one office computer via a telephone line. A diagram of this setup is shown in Figure 2-2.

![Data Acquisition Flow Chart](image)

All of the computers used for this study (on site or in the office) were generic computers purchased from Apex Systems with an Intel Pentium III 500EMHZ CPU on a Super Micro motherboard, a master Western Digital 10.1GB Ultra-DMA/66 IDE – 5400RPM hard drive loaded with the Windows 98 operating system. The computer in the
office was connected to each of the site computers through a phone line. Using the
PCAnywhere communication software, the office computer would connect to each site
computer (one at a time) and collect the hourly data files from the site computers. These
files were transferred to the Visibility folder in the office computer. This method of
collecting data allowed for fast response time to any problems with each instrument at
each site. The operator would check the data collected in the office computer each day
and respond to any difficulties in the data collection process at each site. Logbooks were
placed at each site so that the operator was able to report each site visit and the activities
that took place during each site inspection.

The data were imported from text format to Microsoft Access 2000® version 9.0.270
(Troy, NY) for database building purposes. The tables in MS Access® are shown in a
bulleted list below.

- ECh Neph
- ECh Aeth
- JN Neph
- JN Aeth
- PV Neph
- PV Aeth

The data were then put into Microsoft Excel 2000® version 9.0.270 (Troy, NY)
format for quality control and analysis purposes. The name of each Microsoft Excel®
2000 file corresponded to the MS Access® table from which the data were acquired.
2.3.2. Data Analysis and QA

Each text file was checked for invalid representation of data. The text files were closed and saved automatically at each site every hour, sometimes the last part of a data set was cut off (truncated), because at the time of the closing of the file the data was being written into the file by the instruments. The data were then imported into Microsoft Access 2000® and a program written by the operator in MS Access® checked the data to verify the site and instrument type for each part of the data, to catch any file name errors that might have occurred during the transfer of the files from the site computers to the office computer. Each line of the data was then given an ID, which included the site, the instrument type and the date and time of data collection. Data quality control measures were taken when the data were transferred to MS Excel® format. First the nephelometer light scattering coefficient was calculated. These values were then checked for any extremely low or extremely high values, using two standard deviation from the mean for each hour as suggested by Bevington (1969). The inconsistent values were flagged to be checked at a later time. The aethalometer black carbon concentrations were converted to light absorption coefficient, using a wavelength dependent absorption efficiency of 10 m²/g at 570 nm. These values were then processed like the light scattering coefficient values for any extreme highs or lows.

The next step was to check the flagged data. For the nephelometer data, the clean air values were checked to see if there was any inconsistency in those values. If problems were present, then the data were flagged at the time and date that the clean air values were suspect. At the last checkpoint, the flagged aethalometer and nephelometer data were compared with each other; if there were any spikes that were present in both data
sets, a flag was set at that point of the database. If the high or low value was present in only one of the instruments, that data point was given a final flag and was discarded. If the high or low value was present in both the aethalometer and the nephelometer, then the beta attenuation monitors' (beta gauge) data at each site were studied for similar spikes. A beta gauge was present at or near each site, operated by CCDAQM. If the high or low point was present in the beta gauge data, then the aethalometer and nephelometer data point was accepted as valid. If the high or low point was not present in the beta gauge data, then the data point was flagged and discarded. Figure 2-3 is a diagram of the data validation process.

Figure 2-3: Flow Chart of the Data Validation Process
A sample of the flags used for data validation is shown in Table 2-3.

Table 2-3: A List of QC Flags and Their Description

<table>
<thead>
<tr>
<th>Flag abbreviation</th>
<th>Flag description</th>
</tr>
</thead>
<tbody>
<tr>
<td>B</td>
<td>Instrument malfunction</td>
</tr>
<tr>
<td>H</td>
<td>Extremely high value</td>
</tr>
<tr>
<td>L</td>
<td>Extremely low value</td>
</tr>
<tr>
<td>NC</td>
<td>Inconsistencies in nephelometer clean air values</td>
</tr>
<tr>
<td>N</td>
<td>Consistent spikes in nephelometer and aethalometer values</td>
</tr>
<tr>
<td>DD</td>
<td>Data point discarded as invalid</td>
</tr>
</tbody>
</table>

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CHAPTER 3

RESULTS AND DISCUSSION

3.1. Data and Instrument Quality Control

Collocated tests of the nephelometers and aethalometers were conducted at the beginning and the end of the study. The results in the beginning of the study were consistent with the results at the end of the study. Figures 3-1, 3-2, 3-3 show the results of the data comparison of collocated studies of the nephelometers.

Figure 3-1: Comparison of the Collocated Data for E. Charleston & Jean Nephelometer

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Comparison of Nephelometer Bscat Values

**JN and PV**

\[ y = 1.3433x \]

\[ R^2 = 0.9123 \]

Figure 3-2: Comparison of the Collocated Data for Palo Verde and Jean Nephelometers

Comparison of Nephelometer Bscat Values

**ECh and PV**

\[ y = 0.9135x \]

\[ R^2 = 0.9137 \]

Figure 3-3: Comparison of the Collocated Data for Palo Verde and East Charleston Nephelometers

The regression for the collocated data was calculated using MS Excel® spreadsheets, and the intercepts were forced through zero for each set of data. The data presented in
Figures 3-1, 3-2, 3-3 are from collocated studies conducted at the end of the study. The nephelometers were operated at the Desert Research Institute, in a lab. Figures 3-1 and 3-2 show that the Jean nephelometer underestimated the light scattering values compared to Palo Verde and East Charleston. The average slope of this data was used to correct the data for this site.

The quality of the data from the nephelometers was also checked by comparing the span gas and clean air values of the nephelometer. Figures 3-4, 3-5 and 3-6 show the data for span gas calibration and clean air values reported at each site from the beginning to the end of the study.

![Comparison of Span Gas and Clean Air Drift (ECh)](image)

Figure 3-4: Span Gas and Clean Air Values at the East Charleston Site
Comparison of Span Gas and Clean Air Drift (JN)

Figure 3-5: Span Gas and Clean Air Values at the Jean Site

Comparison of Span Gas and Clean Air Drift (PV)

Figure 3-6: Span Gas and Clean Air Values at the Palo Verde Site
Clean air values of the nephelometer were checked regularly to make sure that the instrument was functioning correctly. Span gas calibration values at different points of the study were compared with the clean air values to make sure that the drift was consistent in both numbers. The span gas and clean air values should be correlated. If any of the above mentioned values showed inconsistencies, the nephelometer was physically checked and cleaned. This was also done every month for each nephelometer at each site. For example, during the month of January at the Palo Verde site the clean air values increased, whereas the span gas values stayed the same. As a result, the Palo Verde nephelometer was taken to the office for service, which included a complete cleaning and change of lamp.

An example of the check sheet used for the nephelometer may be found in the Appendix A. These sheets were kept in the office logbooks for reference. The lamp intensity level was set at 1000 and due to the continuous use of the nephelometers the lamps were changed almost every month, because of low lamp intensity levels. The nephelometer is equipped with a self-check process every time that it is turned off and on. The results from these checks were kept in computer files for reference.

The accuracy of the flow rate of the aethalometers was checked and appropriate measures were taken where the flow rate displayed by the aethalometer did not match the measured flow rate. The flow rate check was conducted using an LPMAIR Dwyer flow meter (the flow meter was readable to two points after the decimal). The $R^2$ and slope values for each of these comparisons are shown in Figures 3-7, 3-8, 3-9 and the results are summarized in Table 3-1. The aethalometer data were multiplied by the slope value
corresponding to each site. The measured flow rate, compared to the displayed flow rate was very consistent in all sites except for the Jean site.

Figure 3-7: Comparison of the Aethalometer's Measured and Displayed Flow Rates, ECh

Figure 3-8: Comparison of the Aethalometer's Measured and Displayed Flow Rates, JN
Collocated studies were also conducted for the aethalometers. The primary and final collocated studies of the aethalometers were consistent with each other. For this test, the aethalometers were operated for 2-5 hours side by side in a lab at the Desert Research Institute, in Las Vegas. Figures 3-10, 3-11 and 3-12 show the results of these collocated studies for the aethalometers. The results from the collocated studies were used to correct the nephelometer and aethalometer values.
Figure 3-10: Comparison of Collocated Aethalometer Data from Each Site, East Charleston and Jean

Figure 3-11: Comparison of Collocated Aethalometer Data from Each Site, Palo Verde and Jean

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3.2. Processing and Conversion of Instrument Data

3.2.1. Aethalometer Data Processing

The aethalometer data were converted to black carbon (μg/m³) concentration and stored, every five minutes. Figures 3-13, 3-14, and 3-15 present typical raw aethalometer data acquired from each site.

The highest data point for the Jean site is lower than that of the Palo Verde and East Charleston sites. The difference between the lowest black carbon concentration and the highest one is very high at the Palo Verde site, compared to the Jean and East Charleston. This may be due to the proximity of Palo Verde High School's parking lot to the monitoring station.
Figure 3-13: 5-minute Raw Aethalometer Values, East Charleston

Figure 3-14: 5-minute Raw Aethalometer Values, Jean
Data are shown for a Monday morning in November (11/6/00 5:00 to 9:00 am). At the Jean site the values fluctuate more than the other two sites, but they are much lower and the scale of fluctuation is small when compared to the other two sites. A steady rise in black carbon concentrations is observed at the East Charleston site. The large peak in the earlier part of the morning at the Palo Verde site is attributed to construction activities taking place near the site. The rise of black carbon concentrations is from about 5:30 am to 7:00 am may be because of the arrival of the Palo Verde High School students for class.

The black carbon concentrations (ng/m$^3$) were multiplied by 0.01 m$^2$/g to acquire light absorption (Babs Mm$^{-1}$) values. Figures 3-16, 3-17, and 3-18 present the same data as Figures 3-13, 3-14, and 3-15; however, the data have been processed and the Babs values are presented.
Figure 3-16: 5-minute Processed Aethalometer Data, East Charleston

Figure 3-17: 5-minute Processed Aethalometer Data, Jean
3.2.2. Nephelometer Data Processing

Nephelometer data were collected as normalized light scattering counts at two-minute intervals. The nephelometer measures the light scattering by particles (Bsp). The scattering count data were processed using the clean air and span gas values, to calculate Bsp and then Bscat, which is the sum of scattering by particles (Bsp) and scattering by gases (Bsg). The following formulas were used to calculate the Bscat values. Slope was calculated using the span gas (span), clean air (clean) and Rayleigh scattering (RL) values. Rayleigh is different at each site and is dependent upon the site elevation. The Rayleigh values for each site may be found in Table 2-2.

\[
\text{Slope} = \frac{6.1 \times RL}{\text{span} - \text{clean}}
\]  
(14)

\[
\text{Bscat} = \text{Slope} \times (\text{scattering counts} - \text{clean}) + RL
\]  
(15)

Figures 3-19, 3-20, and 3-21 present the 2-minute raw data collected from the nephelometers at each site, for a period of four hours.
Figure 3-19: 2-minute Raw Nephelometer Values, East Charleston

Figure 3-20: 2-minute Raw Nephelometer Values, Jean
These values are from a Monday morning in November (11/6/00 5:00 to 9:00am). At the East Charleston site an early morning peak is followed by the peak corresponding to the rush hour traffic. Data at the Jean site are stable with no specific patterns. At the Palo Verde site, a rise in the normalized scattering values is observed which may be due to the early morning traffic for Palo Verde High School.

The nephelometer data in raw form are not comparable for the different sites; because the span gas and clean air values have not been used to calculate the Bscat values for each site.

The data were converted to Bscat values that are shown in Figures 3-22, 3-23, and 3-24.
Figure 3-22: 2-minute Processed Nephelometer Data, East Charleston

Figure 3-23: 2-minute Processed Nephelometer Data, Jean
A steady rise in the Bscat values is observed at the East Charleston site. This early morning peak may be due to rush hour traffic at this site. At the Palo Verde site two peaks are observed in the morning. The first peak starts at about 5:30 am until 7:00 am, and the second peak starts at around 8:00 am until about 9:00 am. At the Jean site the Bscat values are steady and comparable to the Babs values. The Bscat values at the Palo Verde site have a higher range when compared to the Jean and East Charleston site.

3.2.3. Hourly Average Data for Bscat and Babs

After Babs and Bscat are calculated and the data have gone through quality control checks as described in Chapter 2, hourly averages of the data are computed and plotted for each day. The hourly averages for each day, presented in charts for each month may be found in Appendix B. Figures 3-25 to 3-30 present typical daily averages of Bscat for a period of 48 hours at each site. Two charts are present for each site. One chart presents
the data for a typical weekend (Saturday and Sunday) and another chart presents the data for weekdays (Monday and Tuesday).

Figure 3-25: Hourly Averages of Bscat for a Typical Weekend (East Charleston)

Figure 3-26: Hourly Averages of Bscat for Two Typical Weekdays (East Charleston)
Figure 3-27: Hourly Averages of Bscat for a Typical Weekend (Jean)

Figure 3-28: Hourly Averages of Bscat for Two Typical Weekdays (Jean)
Figure 3-29: Hourly Averages of Bscat for a Typical Weekend (Palo Verde)

Figure 3-30: Hourly Averages of Bscat for Two Typical Weekdays (Palo Verde)
At the East Charleston site (Figures 3-25 and 3-26) the data show a clear diurnal pattern for the weekend and the weekdays. However, the Bscat values are at a much lower level at midday on the weekends, and the maximum value during the weekend is lower than that of the weekdays. The Bscat values stay higher at the end of the day at the East Charleston site. At the Jean site (Figures 3-27 and 3-28), the Bscat values are stable during the weekend and weekday, except for a peak at about noon on Tuesday, where the Bscat values are elevated by about 10 Mm⁻¹ and stay high for the rest of the day. It was later found out that this elevation in Bscat was caused by particulate emissions from construction activities by CCDAQM at this site. At the Palo Verde site a peak is observed almost every day (weekday and weekend) at about one in the afternoon. The peak is higher during the weekdays due to the vehicle traffic from the Palo Verde High School (PVHS). The high levels of Bscat descend later in the day, however, during the weekend the descent is steeper than during the weekdays.

Figures 3-31 through 3-36 present the data for hourly averages of Babs for typical weekends and weekdays at each site. A diurnal pattern is observed at the East Charleston site for the weekdays and the weekend (Figures 3-31 and 3-32). However, during the weekends at midday the levels of Babs are so low at this site that they are comparable to the Jean (background/transport) site. Also the Babs levels stay high at the end of the day during the weekdays. The Babs levels are very low at the Jean site and no specific patterns are observed (Figures 3-33 and 3-34). At the Palo Verde site afternoon Babs peaks are observed (Figure 3-35 and 3-36) that correspond to the afternoon Bscat peaks (Figures 3-29 and 3-30). During the weekday, the peak Babs levels are much higher (typically 50 Mm⁻¹) than during the weekends (typically 8 Mm⁻¹).
Figure 3-31: Hourly Averages of Babs for a Typical Weekend (East Charleston)

Figure 3-32: Hourly Averages of Babs for Two Typical Weekdays (East Charleston)
Figure 3-33: Hourly Averages of Babs for a Typical Weekend (Jean)

Figure 3-34: Hourly Averages of Babs for Two Typical Weekdays (Jean)
Figure 3-35: Hourly Averages of Babs for a Typical Weekend (Palo Verde)

Figure 3-36: Hourly Averages of Babs for Two Typical Weekdays (Palo Verde)
3.2.4. Warm and Cold Seasonal Patterns

Hourly data were analyzed in search of similar trends in spatial and temporal patterns of visibility in Las Vegas. The hourly averages of light absorption and light extinction were plotted for each month. Charts of a typical cold month (Figures 3-37 and 3-39) and a typical warm month (Figures 3-38 and 3-40) for the East Charleston site are presented next. Similar charts for each month at each station may be found in Appendix B. The bars presented for each data point are the computed standard deviation values for that hour (+/- Std Dev).

![Hourly Averages of Bscat (ECh-Nov00)](image)

Figure 3-37: Hourly Averages of Bscat at the East Charleston Site for the Month of November (representing a cold season month)

The Bscat values are on average 9 times higher than the Babs values at the East Charleston during the warm season. The Bscat values are on average 12 times higher than the Babs values during the cold season at the East Charleston site. The highest ratio of Bscat to Babs at the East Charleston site is 66 during the warm month, whereas the Bscat
to Babs ratio is 150 during the cold month. These ratios were calculated using the data shown in Figures 3-37 through 3-40. The range of values during the cold month is wider for Bscat and Babs at the East Charleston site, when compared to the warm month. The minimum Bscat values of the cold month at East Charleston (Figure 3-37) are lower than the minimum Bscat values of the warm month at the East Charleston site (Figure 3-38). Diurnal peaks are present for the Bscat values during the cold month for the East Charleston site (Figures 3-37 and 3-38). These patterns are also present for the Babs values (Figures 3-39 and 3-40).

![Hourly Averages of Bscat (ECH-June01)](image)

Figure 3-38: Hourly Averages of Bscat at the East Charleston Site for the Month of June (representing a warm season month)
Figure 3-39: Hourly Averages of Babs at the East Charleston Site for the Month of November (representing a cold season month)

Figure 3-40: Hourly Averages of Babs at the East Charleston Site for the Month of June (representing a warm season month)
The hourly averages were used to show similar patterns for the cold and warm months. The months were grouped into two sections according to consistent patterns that the data showed, the cold season months and the warm season months. The cold months are October, November, December of 2000 and January of 2001; and the warm months are April, May, June and July of 2001. The months of August and September were not used at this stage of the analysis due to insufficient data from several sites. The data were incomplete at the Jean site for the month of August and the data were incomplete at the East Charleston site for the month of September.

Seasonal effects were observed in the database. Figure 3-41 compares the 50-th percentile Babs values during the cold season for all three sites. The East Charleston site shows the most distinct diurnal pattern in this chart. The Palo Verde (suburban) site has a less well-defined diurnal pattern that is the inverse of the East Charleston site. The East Charleston site in the middle of the day is cleaner than the Palo Verde site on average. This is an interesting point and may be due to either the heating patterns at the East Charleston site or due to differences in traffic counts in the two sites. The heat of the sun is strong enough in the middle of the day that it can heat the air near the ground. The heated air is light so it rises, and the pollutants in the warm air rise also and are diluted in the atmosphere.

For the cold season 50-th percentile of cold season Bscat (Figure 3-42), the East Charleston site shows the distinct diurnal pattern again. An inverse diurnal pattern for Palo Verde is present, but is even less obvious than the pattern observed at Palo Verde for Babs (Figure 3-41).
Figure 3-41: Comparison of the 50-th percentile Cold Season Babs

Figure 3-42: Comparison of the 50-th percentile Cold Season Bscat
During the warm season, the 50-th percentile Babs still shows a diurnal pattern at the East Charleston site (Figure 3-43). However, the warm season peaks are less sharp and the pattern smoother than during the cold season (Figure 3-41). The Palo Verde site shows a very high peak in early morning during the warm season (Figure 3-43). This may have been due to some construction activity that was taking place near this site during the first part of the study.

Figure 3-44 shows the 50-th percentile Bscat for the warm season. All three sites show an early morning peak at about 5:00 am. A diurnal pattern is present at the East Charleston site. The Bscat values are low at the East Charleston site at mid-day, they are close to the Jean site Bscat values which is the background/transport site. The Bscat values at the Palo Verde site are lower than both the East Charleston and Jean site for the warm season.

![Comparison of Babs (Apr, May, Jun, Jul)](image)

**Figure 3-43: Comparison of the 50-th percentile Warm Season Babs**

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3.2.5. Monthly Average Patterns

Monthly averages were computed for each month, from the beginning of the study until the end and are plotted in Figures 3-45 and 3-46. The East Charleston site shows similar patterns for both the Bscat and Babs values. Bscat and Babs exhibit lower values during the warmer months and higher values during the cold months. The Palo Verde site shows a higher than expected Babs value during the August, 2000. This anomaly may be attributed to construction activities going on at the site at that time. If August, 2000 is disregarded, then Palo Verde shows patterns similar to that of East Charleston for Babs. Palo Verde Bscat values are unusually low during the last months of the study which may be because of instrument malfunctions.

The Jean site does not show any specific pattern for the Babs values except that they are very low as is to be expected. The Bscat values at the Jean site also do not show any specific pattern. The average monthly Bscat is highest on January 2001 at the Jean site. The average monthly Babs is highest on November 2000 at the Jean site.
Comparison of Monthly Babs

Figure 3-45: Comparison of monthly averages in all sites (Babs)

Comparison of Monthly Bscat

Figure 3-46: Comparison of monthly averages in all sites (Bscat)

3.2.6. Statistical Characteristics of the Warm and Cold Season Data

Tables 3-2, 3-3, 3-4 and 3-5 present statistical summaries of the warm and cold season hourly average data. Overall, the maximum values of Babs and Bscat are typically higher during the cold season. This is evident at Jean and East Charleston, but due to some
construction activities in the beginning of the study at Palo Verde, not very distinct at this site. The standard deviation is interesting to note at the Jean site during the cold and warm season for the Bscat values. The standard deviation is much higher during the cold season. This may be due to high winds at this site during the cold months. Due to instrument malfunction the Bscat values at the Palo Verde site do not cover the entire cold season and so should be compared to the East Charleston and Jean site with caution.

Table 3-2 Statistical Data for Cold Season Babs

<table>
<thead>
<tr>
<th>Site</th>
<th>Babs Mean (Mm⁻¹)</th>
<th>Babs Median (Mm⁻¹)</th>
<th>Babs Max. (Mm⁻¹)</th>
<th>Babs Min. (Mm⁻¹)</th>
<th>Babs Std. Dev. (Mm⁻¹)</th>
<th>Babs Skew</th>
<th>Babs Count</th>
</tr>
</thead>
<tbody>
<tr>
<td>ECh</td>
<td>19.0</td>
<td>11.6</td>
<td>86.8</td>
<td>0.330</td>
<td>3.29</td>
<td>1.14</td>
<td>7473</td>
</tr>
<tr>
<td>JN</td>
<td>1.15</td>
<td>0.700</td>
<td>5.33</td>
<td>0.130</td>
<td>1.15</td>
<td>1.66</td>
<td>6196</td>
</tr>
<tr>
<td>PV</td>
<td>5.87</td>
<td>3.53</td>
<td>43.1</td>
<td>0.210</td>
<td>2.06</td>
<td>3.49</td>
<td>4535</td>
</tr>
</tbody>
</table>

Table 3-3 Statistical Data for Warm Season Babs

<table>
<thead>
<tr>
<th>Site</th>
<th>Babs Mean (Mm⁻¹)</th>
<th>Babs Median (Mm⁻¹)</th>
<th>Babs Max. (Mm⁻¹)</th>
<th>Babs Min. (Mm⁻¹)</th>
<th>Babs Std. Dev. (Mm⁻¹)</th>
<th>Babs Skew</th>
<th>Babs Count</th>
</tr>
</thead>
<tbody>
<tr>
<td>ECh</td>
<td>6.48</td>
<td>3.79</td>
<td>36.6</td>
<td>0.810</td>
<td>1.68</td>
<td>2.17</td>
<td>4551</td>
</tr>
<tr>
<td>JN</td>
<td>0.930</td>
<td>0.850</td>
<td>2.82</td>
<td>0.140</td>
<td>0.200</td>
<td>0.950</td>
<td>5843</td>
</tr>
<tr>
<td>PV</td>
<td>4.59</td>
<td>2.86</td>
<td>38.5</td>
<td>0.450</td>
<td>1.64</td>
<td>2.97</td>
<td>4527</td>
</tr>
</tbody>
</table>
Table 3-4 Statistical Data for Cold Season Bscat

<table>
<thead>
<tr>
<th>Site</th>
<th>Bscat Mean (Mm⁻¹)</th>
<th>Bscat Median (Mm⁻¹)</th>
<th>Bscat Max. (Mm⁻¹)</th>
<th>Bscat Min. (Mm⁻¹)</th>
<th>Bscat Std. Dev. (Mm⁻¹)</th>
<th>Bscat Skew</th>
<th>Bscat Count</th>
</tr>
</thead>
<tbody>
<tr>
<td>ECh</td>
<td>69.0</td>
<td>57.1</td>
<td>256</td>
<td>13.9</td>
<td>9.27</td>
<td>1.24</td>
<td>11265</td>
</tr>
<tr>
<td>JN</td>
<td>29.4</td>
<td>21.0</td>
<td>185</td>
<td>10.6</td>
<td>3.05</td>
<td>3.28</td>
<td>11302</td>
</tr>
<tr>
<td>PV</td>
<td>28.1</td>
<td>21.4</td>
<td>136</td>
<td>9.36</td>
<td>4.19</td>
<td>2.22</td>
<td>11242</td>
</tr>
</tbody>
</table>

Table 3-5 Statistical Data for Warm Season Bscat

<table>
<thead>
<tr>
<th>Site</th>
<th>Bscat Mean (Mm⁻¹)</th>
<th>Bscat Median (Mm⁻¹)</th>
<th>Bscat Max. (Mm⁻¹)</th>
<th>Bscat Min. (Mm⁻¹)</th>
<th>Bscat Std. Dev. (Mm⁻¹)</th>
<th>Bscat Skew</th>
<th>Bscat Count</th>
</tr>
</thead>
<tbody>
<tr>
<td>ECh</td>
<td>37.5</td>
<td>33.6</td>
<td>105</td>
<td>10.5</td>
<td>4.81</td>
<td>1.33</td>
<td>10365</td>
</tr>
<tr>
<td>JN</td>
<td>29.6</td>
<td>26.4</td>
<td>91.9</td>
<td>10.9</td>
<td>2.99</td>
<td>1.35</td>
<td>9633</td>
</tr>
<tr>
<td>PV</td>
<td>17.1</td>
<td>15.7</td>
<td>45.2</td>
<td>6.10</td>
<td>2.66</td>
<td>1.54</td>
<td>11186</td>
</tr>
</tbody>
</table>

3.2.7. Seasonal Effects on Relative Contributions to Bext

Relative contributions to Bext were computed from the seasonal average Bscat and Babs data. The following methodology was used for these calculations. Babs is the light absorption coefficient, Bsg is light scattering coefficient due to gases and Bsp is light scattering coefficient due to particles. Bscat is the sum of Bsp and Bsg. Bsg is the same as Rayleigh scattering. So, Bsp can be calculated using the following formula, where Rayleigh scattering is obtained from Table 2-2.

\[
Bsp = Bscat - \text{Rayleigh scattering} \tag{16}
\]

The percentages of Bsp, Babs and Bsg are calculated using the following formula.
\[
\%Bsp = \left( \frac{Bsp}{Bscat + Babs} \right) \times 100 \tag{17}
\]

\[
\%Bsg = \left( \frac{Bsg}{Bscat + Babs} \right) \times 100 \tag{18}
\]

\[
\%Babs = \left( \frac{Babs}{Bscat + Babs} \right) \times 100 \tag{19}
\]

Results are plotted as pie charts in Figures 3-47 and 3-48 for the East Charleston site, Figures 3-49 and 3-50 for the Jean site and Figures 3-51 and 3-52 for the Palo Verde site. The warm season data for the Palo Verde site are incomplete due to instrument malfunction. Only the data from the two months of April and May are used for the warm season averages at this site.

At the Palo Verde site the \%Babs is higher during the cold months (Table 3-6). This may have several reasons; one of them may be the temperature inversion, which takes place in the valley during the cold season. Also more schools are open during the cold season and the buses and the traffic from them may be a contributor to Babs at the Palo Verde site. Relative high levels of Bsg or Rayleigh scattering are indicative of cleaner air and this takes place during the warm season at the East Charleston site (Table 3-7). It should be noted that Figures 3-47 to 3-52 and Tables 3-6 to 3-8 indicate relative contributions but not absolute magnitudes of Bext. Overall extinction values at the Jean site are much lower than that of the East Charleston site (Table 3-9). The Bext values were obtained by adding 50-th percentile Babs and Bscat for the cold and warm months. Table 3-9 shows the 50-th percentile values of light extinction for each of the three study sites.
Table 3-6: Percentage of Babs Contribution to Bext at All Sites

<table>
<thead>
<tr>
<th>Site</th>
<th>%Babs Warm</th>
<th>%Babs Cold</th>
</tr>
</thead>
<tbody>
<tr>
<td>ECh</td>
<td>12%</td>
<td>18%</td>
</tr>
<tr>
<td>JN</td>
<td>3%</td>
<td>4%</td>
</tr>
<tr>
<td>PV</td>
<td>18%</td>
<td>16%</td>
</tr>
</tbody>
</table>

Table 3-7: Percentage of Bsg Contribution to Bext at All Sites

<table>
<thead>
<tr>
<th>Site</th>
<th>%Bsg Warm</th>
<th>%Bsg Cold</th>
</tr>
</thead>
<tbody>
<tr>
<td>ECh</td>
<td>29%</td>
<td>18%</td>
</tr>
<tr>
<td>JN</td>
<td>37%</td>
<td>50%</td>
</tr>
<tr>
<td>PV</td>
<td>56%</td>
<td>42%</td>
</tr>
</tbody>
</table>

Table 3-8: Percentage of Bsp Contribution to Bext at All Sites

<table>
<thead>
<tr>
<th>Site</th>
<th>%Bsp Warm</th>
<th>%Bsp Cold</th>
</tr>
</thead>
<tbody>
<tr>
<td>ECh</td>
<td>59%</td>
<td>64%</td>
</tr>
<tr>
<td>JN</td>
<td>60%</td>
<td>46%</td>
</tr>
<tr>
<td>PV</td>
<td>26%</td>
<td>42%</td>
</tr>
</tbody>
</table>
Table 3-9: 50-th Percentile Light Extinction Values Warm and Cold Season

<table>
<thead>
<tr>
<th>Site</th>
<th>Bext Warm (Mm⁻¹)</th>
<th>Bext Cold (Mm⁻¹)</th>
</tr>
</thead>
<tbody>
<tr>
<td>ECh</td>
<td>44.0</td>
<td>88.0</td>
</tr>
<tr>
<td>JN</td>
<td>30.5</td>
<td>30.5</td>
</tr>
<tr>
<td>PV</td>
<td>21.7</td>
<td>34.0</td>
</tr>
</tbody>
</table>

As expected at the Jean site the Babs is a very small portion of the light extinction coefficient (Figures 3-49, 3-50 and Table 3-6). This is due to the remote location of the site, as black carbon in the atmosphere is mostly due to urban sources such as diesel exhaust. However, it is very interesting to see the large percentage of particulate light scattering at this site especially during the warm season. As was mentioned before the Jean site is surrounded by desert land, so dust from wind or off road driving plays a major role in the light scattering at this area.

Figure 3-47: ECh Warm Season Estimated Proportional Contributions to Bext
Figure 3-48: ECh Cold Season Estimated Proportional Contributions to $B_{ext}$

Figure 3-49: JN Warm Season Estimated Proportional Contributions to $B_{ext}$
Figure 3-50: JN Cold Season Estimated Proportional Contributions to Bext

Figure 3-51: PV Warm Season Estimated Proportional Contributions to Bext
3.3. Comparison of Data From the Three Sites

Figures 3-53 and 3-54 are the 50-th percentile of the hourly averages for all data acquired during this study. Figure 3-53 shows that the Babs levels are the highest at the East Charleston site, and a diurnal pattern is apparent. Since East Charleston is located in a low lying area with low winds and high levels of rush hour traffic in the morning and afternoon, a diurnal pattern is expected. At the Palo Verde site the Babs levels have a sharp peak in the morning and then decline slowly. The high peak early in the morning may be due to the construction near this site or the inflow of traffic to the Palo Verde High School parking lot before 7:00 am. Also, Palo Verde High School lets the students leave at around 12:30pm; there are about 200 cars going out of the parking lot at this time. The exit that is used by about 80% of these cars is the one that is located near the Palo Verde station.

Figure 3-52: PV Cold Season Estimated Proportional Contributions to Bext
When comparing Bscat values at the different stations, the diurnal pattern of East Charleston is smoother but still the dominant pattern when comparing the Bscat hourly averages (Figure 3-54). However, unlike the Babs values the Bscat values at East Charleston always stay higher than those at the Palo Verde site. The Palo Verde site sometimes has lower values of Bscat at some hours than the Jean site.
The 90-th percentile data for Bscat are included next to show that even at the highest point some of the Bscat values for Palo Verde are lower than that of the Jean site (Figure 3-55). This discrepancy may have occurred because of some instrument malfunction at the Palo Verde site near the end of the study.

The 90-th percentile data for Babs are shown in Figure 3-56. A diurnal pattern is observed for the East Charleston site. Palo Verde site 90-th percentile Babs has an early morning peak that is extended until early afternoon. The Babs values at the Jean site do not show any diurnal patterns. The 90-th percentile Babs values is very low at the Jean site compared to the Palo Verde and East Charleston site. The range of Babs values at the Jean site are 1.6 Mm$^{-1}$ to 3.1 Mm$^{-1}$.

![Bscat 90-th Percentile (Jul00-Jul01)](image)

Figure 3-55: Comparison of Bscat for all sites (90th percentile)
3.4. Weekday/Weekend Comparison

3.4.1. Urban Site

Figure 3-57 shows the hourly averages of seven days of a typical week in the month of October. The starting day is a Monday and the ending day is a Sunday. The values compared in the chart are Babs and Bsp. A secondary axis was used for the Babs values. The difference between the first days and the last two days (Saturday and Sunday) is very distinctive. This may be due to the high traffic volume at this site during the weekday rush hours. The data present in the following figures start on Monday and end on Sunday.
3.4.2. Suburban Site

Figures 3-58 and 3-59 are examples of cold and warm season weekday and weekend patterns. The suburban area has very distinctive weekday and weekend patterns for the cold and warm seasons alike. In both warm and cold seasons, there are distinctive weekday early morning peaks (Figures 3-58 and 3-59). Early morning peaks are much weaker or absent on the weekends. Some of this difference may be due to the proximity of the station to the parking lot of Palo Verde High School.
Figure 3-58: Weekday Weekend Comparison of Babs and Bsp at PV (October)

Figure 3-59: Weekday Weekend Comparison of Babs and Bsp at PV (April)
3.4.3. Background/Transport Site

The Background/Transport site did not exhibit any recognizable difference in weekday/weekend patterns for the Bscat values, as can be observed in Figure 3-60. However, a very small difference is observed for the Babs values. Since the Babs values are very low at this site, the pattern may be due to background noise.

![Figure 3-60: Weekday Weekend Comparison of Babs and Bsp at JN (May)](reproduced_with_permission)
CHAPTER 4

CONCLUSIONS AND FUTURE WORK

4.1 Conclusions

Weekly diurnal light scattering and light absorption patterns were observed at the urban and suburban sites, but not at the background/transport site. Light extinction at the urban and transport/background site are mostly due to scattering by particles both during the cold and warm season. The percentage of light scattering at the background/transport site was much higher than the light absorption at this site; this may be due to the surrounding desert around the site. At the urban site at midday, both light absorption and light scattering have very low values when compared to light absorption and light scattering at the beginning of the day. Local sources, such as the construction and parking lot near the suburban area may have caused high values of scattering and absorption at this site. The percentage of scattering at the suburban site is lower than the percentage of absorption. There is a lot of diesel buses and construction equipment around this site, which may have caused high values of light absorption. There are not many sources of dust around this site, which may explain the low values of light scattering.
4.2 Recommended Future Work

Obviously local factors such as construction, motor vehicle emissions, off road driving and disturbed land have a very strong influence on visibility impairment in Las Vegas. One of the first recommended steps is a continuation of this study. An extended study would show more complete seasonal patterns in light scattering and light absorption. Data from such a study could be incorporated into the visibility monitoring networks that are already in place to give a clearer understanding of the local and regional sources of haze in Las Vegas, and the effects of Las Vegas's haze to the surrounding areas. The number of sites should be expanded and special care should be taken not to place the sites near high traffic areas or local polluting sources. Although these sources contribute to the overall pollution, if a site is too near a local source, the scattering and absorption results will be unduly influenced by the local source. For example, the Palo Verde station would be moved to the other side of the street, across from the Palo Verde High school parking lot.

The next step would be to relate the aethalometer and nephelometer data to chemical composition of the aerosols. Such a study was conducted by the Desert Research Institute and the results were presented in a report to the Clark County Department of Air Quality Management. Also, an attempt should be made to present the light scattering and light absorption data as actual visibility impairment data.
## Table A-1: Nephelometer Quality Control Sheet

<table>
<thead>
<tr>
<th>Nephelometer Span Gas Calibration and QC Data Sheet</th>
<th>Operator</th>
</tr>
</thead>
<tbody>
<tr>
<td>Date</td>
<td>Site</td>
</tr>
<tr>
<td>Door Open Close</td>
<td></td>
</tr>
<tr>
<td>Insect Screen</td>
<td></td>
</tr>
<tr>
<td>Clean Air Filter</td>
<td></td>
</tr>
<tr>
<td>Light Trap</td>
<td></td>
</tr>
<tr>
<td>Ambient Span Clean</td>
<td></td>
</tr>
<tr>
<td>Lamp Intensity</td>
<td></td>
</tr>
<tr>
<td>Lamp Change Yes No</td>
<td></td>
</tr>
<tr>
<td>Comments</td>
<td></td>
</tr>
</tbody>
</table>
Table A-2: Set of Parameters for the Nephelometer

<table>
<thead>
<tr>
<th>Nephelometer Parameter</th>
<th>Parameter Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>RUN Mode 1</td>
<td>Different sampling modes</td>
</tr>
<tr>
<td>SN 11</td>
<td>Serial number</td>
</tr>
<tr>
<td>Intervals 72</td>
<td>Ambient sampling intervals</td>
</tr>
<tr>
<td>Auto span 1=off</td>
<td>Auto span calibration option</td>
</tr>
<tr>
<td>Baud rate 9600</td>
<td>Rate of data transmission 9600 bits per second</td>
</tr>
<tr>
<td>Auto test 1=on</td>
<td>Auto test before every restart</td>
</tr>
<tr>
<td>Total run time 4613 hours</td>
<td>Total run time</td>
</tr>
<tr>
<td>Low lamp limit 1000</td>
<td>Lamp intensity minimum</td>
</tr>
<tr>
<td>Fog limit 1500</td>
<td>Rain sensor minimum</td>
</tr>
</tbody>
</table>
Table A-3: Setup File Sample for the Aethalometer

<table>
<thead>
<tr>
<th>--- AE-SETUP.TXT ---</th>
</tr>
</thead>
<tbody>
<tr>
<td>Created: 05-jun-00</td>
</tr>
<tr>
<td>12:12:16</td>
</tr>
<tr>
<td>SN: 217</td>
</tr>
<tr>
<td>Instrument type (0.U (1X), 1.UV+LED (2X), 2.7xLED (3X)): 2</td>
</tr>
<tr>
<td>Date format (0=US, 1=EU): 0</td>
</tr>
<tr>
<td>Tape saver: 0</td>
</tr>
<tr>
<td>Spots per advance: 1</td>
</tr>
<tr>
<td>Gesytec parameters:</td>
</tr>
<tr>
<td>Volumetric unit settings:</td>
</tr>
<tr>
<td>Volumetric units (0.Standard, 1.Volumetric): 0</td>
</tr>
<tr>
<td>Air Pressure (mbars): 1017</td>
</tr>
<tr>
<td>Temperature: 20</td>
</tr>
</tbody>
</table>
### Table A-4: List of the Air Pollution Monitoring Sites in Las Vegas, CCDAQM

O$_3$ = ozone, PM$_{10}$ = Particulate matter with a diameter of 10 μm, CO = carbon monoxide

<table>
<thead>
<tr>
<th>Site Code</th>
<th>Site Name</th>
<th>Site Address</th>
<th>Pollutants Measured</th>
</tr>
</thead>
<tbody>
<tr>
<td>AP</td>
<td>Apex</td>
<td>Township 18S, R. 63 E., Section 14</td>
<td>O$<em>3$, PM$</em>{10}$</td>
</tr>
<tr>
<td>BC</td>
<td>Boulder City</td>
<td>1005 Industrial Rd.</td>
<td>CO, O$<em>3$, PM$</em>{10}$</td>
</tr>
<tr>
<td>BS</td>
<td>Craig Rd.</td>
<td>4701 Mitchell St.</td>
<td>CO, O$<em>3$, PM$</em>{10}$</td>
</tr>
<tr>
<td>CC</td>
<td>City Center</td>
<td>559 North 7th St.</td>
<td>CO, O$<em>3$, PM$</em>{10}$</td>
</tr>
<tr>
<td>FL</td>
<td>E. Flamingo</td>
<td>584 E. Flamingo Rd.</td>
<td>CO, PM$_{10}$</td>
</tr>
<tr>
<td>FP</td>
<td>Freedom Park</td>
<td>650 N. Mojave Rd.</td>
<td>CO</td>
</tr>
<tr>
<td>GV</td>
<td>Green Valley</td>
<td>248 Arroyo Grande Blvd.</td>
<td>CO, PM$_{10}$</td>
</tr>
<tr>
<td>JD</td>
<td>J.D. Smith</td>
<td>1301B E Tonopah Ave</td>
<td>CO, O$<em>3$, PM$</em>{10}$</td>
</tr>
<tr>
<td>JN</td>
<td>Jean</td>
<td>Township 25S, R. 59E.</td>
<td>O$<em>3$, PM$</em>{10}$</td>
</tr>
<tr>
<td>JO</td>
<td>Joe Neal</td>
<td>6651 W. Azure Ave.</td>
<td>O$<em>3$, PM$</em>{10}$</td>
</tr>
<tr>
<td>LO</td>
<td>Lone Mountain</td>
<td>3525 N. Valdez Ave.</td>
<td>O$<em>3$, PM$</em>{10}$</td>
</tr>
<tr>
<td>MC</td>
<td>E. Sahara</td>
<td>4001 E. Sahara Ave</td>
<td>CO, PM$_{10}$</td>
</tr>
<tr>
<td>MG</td>
<td>S. Las Vegas Blvd.</td>
<td>3799 S. Las Vegas Blvd.</td>
<td>CO</td>
</tr>
<tr>
<td>MQ</td>
<td>Mesquite</td>
<td>Old Mill Rd. / Mimosa Valley</td>
<td>O$<em>3$, PM$</em>{10}$</td>
</tr>
<tr>
<td>MS</td>
<td>Microscale</td>
<td>2801 E. Charleston Blvd.</td>
<td>PM$_{10}$</td>
</tr>
<tr>
<td>--------</td>
<td>------------------</td>
<td>--------------------------</td>
<td>-----------</td>
</tr>
<tr>
<td>PL</td>
<td>Henderson</td>
<td>545 W. Lake Mead Dr.</td>
<td>CO, O$<em>3$, PM$</em>{10}$</td>
</tr>
<tr>
<td>PM</td>
<td>Paul Meyer Park</td>
<td>4525 New Forest Dr.</td>
<td>CO, O$<em>3$, PM$</em>{10}$</td>
</tr>
<tr>
<td>PV</td>
<td>Palo Verde</td>
<td>333 Pavilion Center Dr.</td>
<td>O$<em>3$, PM$</em>{10}$</td>
</tr>
<tr>
<td>SA</td>
<td>Sunrise Acres</td>
<td>2501 S. Sunrise Ave.</td>
<td>Not Available</td>
</tr>
<tr>
<td>ST</td>
<td>Searchlight</td>
<td>103 Highway 95 Rd.</td>
<td>O$_3$</td>
</tr>
<tr>
<td>WJ</td>
<td>Walter Johnson</td>
<td>7701 Ducharme Ave.</td>
<td>O$<em>3$, PM$</em>{10}$</td>
</tr>
<tr>
<td>WW</td>
<td>Winterwood</td>
<td>5483 Club House Dr.</td>
<td>CO, O$_3$</td>
</tr>
</tbody>
</table>

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APPENDIX II

The hourly averages of Babs and Bscat are presented in this section, for each site. The Bscat data for the months of June 2001 and July 2001 are not present for the Palo Verde site, due to instrument malfunction. The bars for each data point present the standard deviation for the hourly average of that data point.

![Hourly Averages of Bscat (ECh-July00)](image-url)
Hourly averages of Bscat (ECh-Oct00)

<table>
<thead>
<tr>
<th>Date &amp; Time</th>
<th>Bscat (Mm⁻¹)</th>
</tr>
</thead>
<tbody>
<tr>
<td>10/2/00</td>
<td>0</td>
</tr>
<tr>
<td>10/7/00</td>
<td>0</td>
</tr>
<tr>
<td>10/12/00</td>
<td>0</td>
</tr>
<tr>
<td>10/17/00</td>
<td>0</td>
</tr>
<tr>
<td>10/22/00</td>
<td>0</td>
</tr>
<tr>
<td>10/27/00</td>
<td>0</td>
</tr>
<tr>
<td>11/1/00</td>
<td>0</td>
</tr>
</tbody>
</table>

Hourly Averages of Bscat (ECh-Nov00)

<table>
<thead>
<tr>
<th>Date &amp; Time</th>
<th>Bscat (Mm⁻¹)</th>
</tr>
</thead>
<tbody>
<tr>
<td>10/31/00</td>
<td>0</td>
</tr>
<tr>
<td>11/5/00</td>
<td>0</td>
</tr>
<tr>
<td>11/10/00</td>
<td>0</td>
</tr>
<tr>
<td>11/15/00</td>
<td>0</td>
</tr>
<tr>
<td>11/20/00</td>
<td>0</td>
</tr>
<tr>
<td>11/25/00</td>
<td>0</td>
</tr>
<tr>
<td>11/30/00</td>
<td>0</td>
</tr>
</tbody>
</table>

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Hourly Averages of Bscat (ECh-Feb01)

Date & Time

Hourly Averages of Bscat (ECh-March01)

Date & Time

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Hourly Averages of Babs (ECh-July00)

Date & Time

Hourly Averages of Babs (ECh-Aug00)

Date & Time

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Hourly Averages of Babs (ECh-Sep00)

Date & Time

Hourly Averages of Babs (ECh-Oct00)

Date & Time
Hourly Averages of Babs (ECh-Nov00)

Hourly Averages of Babs (ECh-Dec00)
Hourly Averages of Babs (ECH-July01)

Hourly Averages of Bscat (JN-July00)
Hourly Averages of Bscat (JN-June01)

Date & Time

Hourly Averages of Bscat (JN-July01)

Date & Time

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Hourly Averages of Bscat (PV-Aug00)

Hourly Averages of Bscat (PV-Sep00)
Hourly Averages of Bscat (PV-April01)

Hourly Averages of Bscat (PV-May01)

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Hourly Averages of Babs (PV-Sep00)

Hourly Averages of Babs (PV-Oct00)
Hourly Averages of Babs (PV-July01)

Date & Time

6/30/01 12:00 7/5/01 12:00 7/10/01 12:00 7/15/01 12:00

Babs (Mm⁻¹)
REFERENCES


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Federal Register, (1993), Reclassification of moderate PM10 non-attainment areas to serious areas, 40 CFR, Part 81, Federal Register, 58:3334, January 8, 1993


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United States Environmental Protection Agency, (1987), Revisions to the National Ambient Air Quality Standards; 40 CFR, parts 51 and 52; Federal Register 52 (July 1): 24634-3071


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July 2000 – July 2001

Thesis Examination Committee:
Chairperson, Dr. Vernon Hodge, Ph.D.
Co-advisor, Dr. Mark Green, Ph.D.
Committee Member, Dr. David James, Ph.D.
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