Vehicle Emissions Containing Ultrafine Particulate:

Are We Living Too Close to Major Roadways.

By

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"The views expressed in this paper are those of the author and do not necessarily reflect the official policy, position or views of BCIT, the Environmental Health Program or its faculty."

ABSTRACT

Background

Ultrafine particulate is classified as particulate matter that is 0.1 micron in diameter and smaller. According to the BC Ministry of Health (2000), air-borne particulate matter generated by combustion is the dominant air pollution problem in British Columbia from a public health perspective. Vehicle exhaust is a major contributor of ultrafine particulate (UFP) in the atmosphere (Zhu, Hinds, Kim, Shen & Sioutas, 2005). Studies have linked high levels of ultrafine particulate matter to increases in emergency room visits, hospitalizations, and days lost from school and work (B.C. Ministry of Health, 2000). The purpose of the study was to examine the horizontal distance from Highway No. 1 where exposure to elevated concentrations of ultrafine particulate was likely due to vehicle emissions on this major roadway.

Methods

A portable P-TRAK manufactured by TSI was used to collect the data for this project as it provided real time data and was able to datalog (TSI, n.d). The P-Trak measures ultrafine particles by condensation counting technology in units of particles per cubic centimeter (cm^3). The sampling was conducted in Burnaby at the Burnaby Lake Regional District Park. A background sample was collected at a greater distance from Highway #1 and compared to the subsequent samples that were collected at distances of 50, 100, and 250 meters in the park.

Results

Thirty samples were collected at each location for a total of 120 data points. The Analysis of Variance (ANOVA) indicated that the data was not normally distributed and that there was a significant difference of UFP concentrations at all of the locations. Correlation/regression determined that there was moderate relationship between UFP concentrations and distance from the highway and that with each meter traveled from the 50 meter start point next to the highway there was a 120 particles/cm^3 decrease.

Discussion

The results of this study indicated that traffic on Highway No. 1 is responsible for elevated UFP concentrations in the vicinity of the Highway. Furthermore, it was determined that UFP concentrations exceeded background levels at an offset of at least 250 meters from the roadway. Finally, it was determined that UFP levels decreased as the distance from the freeway increased. These results indicate further research should be conducted to determine the influence of UFP concentrations on human health and establish an acceptable exposure limit. The findings of this study should be considered during planning for land use next to major roadways. For example, commercial/industrial buildings could be placed closest to roadways where public buildings that serve the most vulnerable including daycares and hospitals should be located at greater distances.

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INTRODUCTION

According to the BC Ministry of Health (2000), air-borne particulate matter generated by combustion is the dominant air pollution problem in British Columbia from a public health perspective. Vehicle exhaust is a major contributor of ultrafine particulate (UFP) in the atmosphere (Zhu, Hinds, Kim, Shen & Sioutas, 2005). Studies have linked high levels of ultrafine particulate matter to increases in emergency room visits, hospitalizations, and days lost from school and work (B.C. Ministry of Health, 2000). Recent studies report that there is a "consistent relationship between increases in particulate matter (PM) exposure and contemporary increases in mortality and morbidity" (Zhu et al., 2002. p. 4323). At present, there are no regulatory requirements for acceptable levels of UFPs in the environment. Further research needs to be conducted to determine the influence of highways on concentration of UFPs.

LITERATURE REVIEW

PM is the suspension of fine, solid, or liquid particles in air (Plog, Niland, Quinlan, 1996). It typically consists of a mixture of inorganic and organic chemicals, including carbon, sulfates, nitrates, metals, acids, and semi-volatile compounds (Minnesota Department of Health, n.d.). PM is generated by natural mechanisms such as wind erosion, breaking ocean waves, and volcanic eruptions and by anthropogenic activities including combustion, industrial processes and vegetative burning (Environment Canada, 2002). PM varies in shape and size and typically ranges from approximately 0.005 to 100 micrometers (μm) in diameter (Minnesota Department of Health, n.d.). According to the U.S. Environmental Protection Agency (2005) PM is commonly classified into three size categories:

- Coarse (PM_{10}), ranging from 2.5 to 10 micrometers in diameter;
- Fine ($PM_{2.5}$) 2.5 micrometers in diameter and smaller;
- Ultrafine Particulate (UFP) 0.1 micrometer in diameter and smaller.

Figure 1, below, shows the relative size of PM_{10}, $PM_{2.5}$ and UFP.

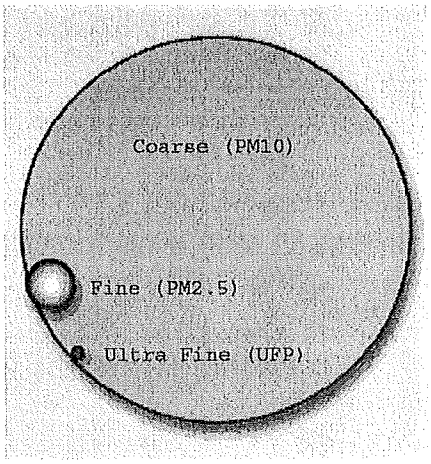


Figure 1. Particle Size Comparisons (EPA, 2005)

Interestingly, the surface area of particulate matter increases as the diameter decreases. (Plog, et al., 1996).

PM_{10} are coarse particles that originate from sources such as windblown dust, vehicles traveling on unpaved roads, and crushing and grinding operations (Wisconsin Department of Natural Resources, 1998). PM_{10} particles settle from the air within hours because of their relatively large size. (Sioutas, Delfino, Singh, 2005). Historically, research and controls have focused primarily on PM_{10}, because researchers believed that PM_{10} caused significant human health problems. It is now known that these particles are usually trapped in the upper respiratory system. PM_{10} particles generally attach to the moist surfaces inside the nasal passages and throat. They are expelled from the body by sneezing and coughing, or they are swallowed into the digestive system (Plog et al., 1996).

$PM_{2.5}$ is usually generated by combustion sources such as vehicles exhaust, industrial processes, fireplaces and chemical reactions involving gases and other particles in the air (Environment Canada, 2002; EPA, 2005). $PM_{2.5}$ is the most important contributor to visibility impairment (GVRD, 2005). $PM_{2.5}$ particles settle quite slowly from the air relative to PM_{10}. Meteorological conditions and

wind patterns are able to transport $PM_{2.5}$ particles long distances (hundreds of miles) and keep them airborne for days. $PM_{2.5}$ has not been studied to the extent of PM_{10}, but in 2000 a Canadian Wide Standard was developed based on research findings which indicate that exposure to $PM_{2.5}$ is detrimental to human health (GVRD, 2005). $PM_{2.5}$ particles are able to enter deep into the lungs and cause health problems because the body is unable to defend itself against such small particles (EPA, 2005). In addition, the chemical makeup of $PM_{2.5}$ particles is quite different than for PM_{10}. EPA (2005) data indicates that $PM_{2.5}$ particles are composed primarily of sulfates, nitrates, organic compounds, and ammonium compounds and also contain acidic materials, metals and other contaminants that cause adverse health affects. $PM_{2.5}$ can also be a Hazardous Air Pollutant as the surface of the particles can be contaminated with other potentially harmful substances (B.C. Ministry of Environment, 2002).

Vehicle exhaust from gasoline and diesel powered vehicles are the major source of UFPs in the urban environment (Sioutas, et al., 2005; Zhu et al., 2002). UFPs have large surface areas that are capable of carrying considerable amounts of other air toxins. Sulphates are one such toxin that can be carried on UPFs; they are acidic in nature and can damage lung tissue when inhaled (BC Ministry of Environment, 2002). Organic carbon and other carbon containing compounds such as polycyclic aromatic hydrocarbons (PAHs) can be carcinogenic and also be carried on UFPs (Sioutas, et al., 2005). Lastly, UFPs can transport trace metals such as lead and cadmium which can cause varying health effects (BC Ministry of Environment, 2002).

It was not until the last decade that research attention has been focused on ultrafine particulate and their affect on human health. This was mainly due to equipment limitations that allowed these particles to go largely undetected (Vitallo, 2005). Measuring UFPs is complex and requires sophisticated equipment. In the past, gravimetric and chemical analysis were the primary methods used for measuring particulate (Plog et al., 1996). The gravimetric method weighs the total mass which is ineffective for UFPs because of their small

size. Currently, there is limited equipment to measure long term UFPs, which is partly why limited research has been done on the background levels of UFPs in outdoor environments. The United Kingdom uses Tapered Element Oscillating Microbalance techniques but such methods underestimate the mass of UFPs. (Environmental & Occupational Health, 2003). The P-TRAK is a new piece of equipment that counts UFP by condensation particle technology. It provides real time data and is able to datalog (TSI, n.d.).

Since UFPs are so small they are able to enters the body through inhalation. It was previously believed that UFPs were also exhaled, and therefore did not cause harm to humans. It is now known that UFPs settle in large numbers in the lower respiratory tract on the pulmonary tissues (Salvatore, 1997). As reported in the Plog et al. (1996) lung tissue efficiently captures and absorbs airborne contaminants. Furthermore, body fluid soluble particulates can enter the blood stream from the lungs. The chemical makeup of UFPs can cause severe and fatal injuries to humans despite the fact that they represent only a small total mass. (Salvatore, 1997). Recent studies have demonstrated that UFP's are more toxic than larger particles with identical chemical composition and mass concentration" (Zhu et al. 2002).

The adverse health affects of UFP's are becoming more apparent as research in the field advances. The BC Ministry of Health (2000) reported that exposure to UFPs has been shown to aggravate existing heart and lung conditions. Also, a consistent relationship between PM exposure and increased occurrences of disease and death was demonstrated by epidemiological data from air pollution studies. Other research highlights significant increases in the population death rate due to prolonged exposure to PM pollution (B.C. Ministry of Environment, 2002).

Sioutas, et al., (2005) suggest that new epidemiological evidence links exposure to UFPs and respiratory problems. They indicate that the small size of UFPs enable them to avoid phagocytosis and enter the pulmonary interstitial

sites where they can cause inflammation. They also note that studies have shown a stronger "association between respiratory health in asthmatic adults and exposure to UFPs compared with fine or coarse particles" (Sioutas et al., 2005, p.948). Other studies indicate that UFPs are more likely to lower lung function than other fine particles (Kim, & Jaques, 2005).

Growing evidence suggests that pollutants from traffic are responsible for the increase in prevalence of childhood asthma (Oyana, & Rivers, 2005). Furthermore, studies of asthmatic children have shown links between UFP exposure and shortfalls in peak expiratory flow (Sioutas, et al., 2005). The occurrence of asthma in children is a significant public health problem in the United States and elsewhere. In the United States, it affects approximately 15 million children and results in a staggering 2 million emergency room visits and more than 5000 deaths every year (Oyana, & Rivers, 2005).

UFPs are able to enter the circulation system and travel to other areas of the body including the cardiovascular system where they may cause serious cardiac events, such as cardiac arrhythmias and myocardial infarction (Minnesota Department of Health. (n.d.). Currently, the actual mechanism of how UFPs causes cardiovascular problems is unclear. Theories include UFPs causing blood clotting or altering the autonomic control of the heart (Hartog et al., 2003). Numerous studies have found correlations between elevated levels of PM and increased heart arrhythmias and heart rates (Hartog et al., 2003). Relationships between ambient air pollution and cardiovascular mortality have also been found (Delfino, Sioutas, Malik, 2005). A crossover study conducted in England found that exposure to traffic was linked to the onset of myocardial infarctions. Another study reported that "the risk of death from cardiopulmonary causes was twice as high among persons living close to a major road or highway" (Peters, et al. 2004, p. 1721). Although the last two studies do not directly implicate UFPs as the cause of the cardiopulmonary complications, it is apparent that UFPs are a major component of vehicle exhaust.

UFPs have been shown to be detrimental to human health, however, not all persons are equally susceptible. The BC Ministry of Health (2000) identifies children and senior citizens as being most vulnerable to PM exposure. Children are more susceptible since their lungs are still developing. They can experience episodes of coughing, difficulty breathing, and decreased lung function due to increased exposure to PM. Senior citizens are also more susceptible to PM exposure because they are more likely to have preexisting lung and heart conditions. Asthmatics, people with other respiratory diseases, and smokers are also affected at low levels of exposure to PM which can result in breathing difficulty, asthma attacks, and respiratory mortality. Finally, people with cardiovascular disease may encounter shortness of breath, chest tightness, heart attacks, and cardiovascular mortality due to increased PM exposure (EPA, 2005).

To determine an individuals actual exposure to UFPs, concentrations need to be measured from all daily activities. Since UFPs are ubiquitous in the environment, almost all areas need to be considered. In many cases, exposure to outdoor pollutants is limited since the average person spends only 10% of their time outdoors (CHMC, n.d). Unfortunately, the characteristics of UFPs allow them to penetrate building exteriors and migrate indoors (Sioutas, et al., 2005). Therefore, exposure during time spent indoors, outdoors, driving, working etc. should be measured and weighted appropriately. On their website, the GVRD (2005) indicates that health research has not yet established a maximum safe exposure for PM, and points out that current findings suggests that there may not be a safe level.

It is evident that further research needs to be conducted to fully understand the health affects related to UFP exposure. However, the results from current studies indicate that it would be wise to control human exposure to this type of PM. Researches are already looking at UFP controls for gasoline and diesel powered vehicles as they predict emissions regulations will be implemented in the future (Rubino, et al., 2005). Other controls might involve

locating daycares, senior homes, and hospitals at specific distances from major UFP generating sources such as freeways.

Sioutas, et al., (2005) report that "despite the increasing concerns about the health impacts of UFPs, very little information is available on their concentrations or physical/chemical properties in places where people live and work..."(p. 953). "It is anticipated that ultrafine particulate matter will become a standard parameter in particulate monitoring" (Environmental & Occupational Health, 2003). Before standards can be made research needs to be conducted to determine background levels of UFPs in outdoor air and to determine the amount vehicles and industry that affects the ambient levels.

PURPOSE OF THE STUDY

The purpose of this study was to determine at what horizontal distance from Highway No. 1 exposure to elevated concentrations of ultrafine particulate likely existed from vehicle emissions due to the proximity of this major roadway.

METHODS

Currently, there is limited equipment available to measure airborne UFP concentrations. There are also no regulatory limits or guidelines on the acceptable concentrations of UFPs at this time as more research on the health effects and peoples exposure needs to be conducted. In the past, methods such as gravitational settling and centrifugal collection were used to measure particulate concentrations of large particulates (>1um in diameter), but this method is not suitable for UFPs (Brown, Colllings, Harrison, Maynard, & Maynard, 2003). Efficient methods of detecting UFP concentrations are still developing and at this time (Brown et al., 2003). In the United Kingdom, tapered element oscillating microbalance (TEOM) instruments are used to measure UFPs, but this method underestimates the mass (Environmental & Occupational Health, 2003). Another instrument, a scanning mobility particle sizer (SMPS) is an electrostatic classifier and a condensation particle counter which has been used in other

studies to measure the volume and concentration of airborne UFPs (Hitchins, Morawska, Wolff, & Gilbert, 2000). This instrument, however, is expensive and not available to the researcher for this project.

Instead, a portable P-Trak™ Ultrafine Particle Counter manufactured by TSI was used for this project. The P-Trak measured the concentration of ultrafine particles in units of particles per cubic centimeter (cm^3) by condensation particle counting technology. It provided real time data and measured particles in the size range of 0.1 to 0.02 micrometers in diameter.

The P-Trak datalogged the measured concentrations, and the data was later downloaded and viewed using TRAKPRO™ software. The P-Trak logging interval was set for a 10 second averaging period. The averaged readings were desirable to filter out instantaneous particle concentration fluctuations and thus providing more reliable results.

The P-Trak can be configured to suit the purpose of the sampling. For this project the P-Trak was set up to sample through the inlet screen assembly only, rather than utilizing the sampling tube and probe (see Figure 2 below). This configuration set up was chosen because it produced the most valid results for area sampling (TSI, 2002).

Figure 2. P-Trak set up with inlet screen only and shoulder strap attached (TSI, 2002).

The P-Trak was selected to collect data for this project, because of its ability to measure ultrafine particles (<0.1um), the ease of its use and its availability (BCIT Environmental Health owns one P-Trak).

Pilot Tests

Pilot tests of the sampling strategy took place during late December 2005 and early January 2006. The pilot tests identified that location and method adjustments were needed to improve the reliability of the results.

It was discovered during the numerous pilot tests that the original sample location at the Douglas Road overpass was less than ideal. The Douglas Road overpass experienced low traffic volumes which was desirable, but was frequented by large diesel semi trucks that were found to greatly influence the concentration of UFP. The UFP concentration measurements were less representative of the highways influence and more related to truck volume on Douglas Road. For this reason, a new location at Burnaby Lake Regional Park was chosen to better control the arterial road variable and to isolate the impact of highway.

The pilot test also revealed problems in the original methodology. The original method involved collecting a background sample up wind of the highway and collecting the remaining samples downwind. However, the predominant wind direction was parallel to the highway which made it difficult to clearly define the upwind or downwind side. Furthermore, Burnaby is a densely populated urban area with many busy collector arterial roads. This made it difficult to find background sample locations that were not impacted by surrounding roads. Therefore, the background samples were also collected in Burnaby Lake Regional Park but at a greater horizontal distance from the highway than the other samples.

Lastly, the pilot test uncovered the P-Traks inability to operate in wet conditions. As a result, sampling was only conducted during dry to light rain weather conditions.

Sampling Location

Burnaby Lake Regional Park was chosen for the new testing location because of the lack of nearby roads that might influence the results. The park is located on the north side of Highway #1, just east of the Kensington interchange, as seen in Figure 3.

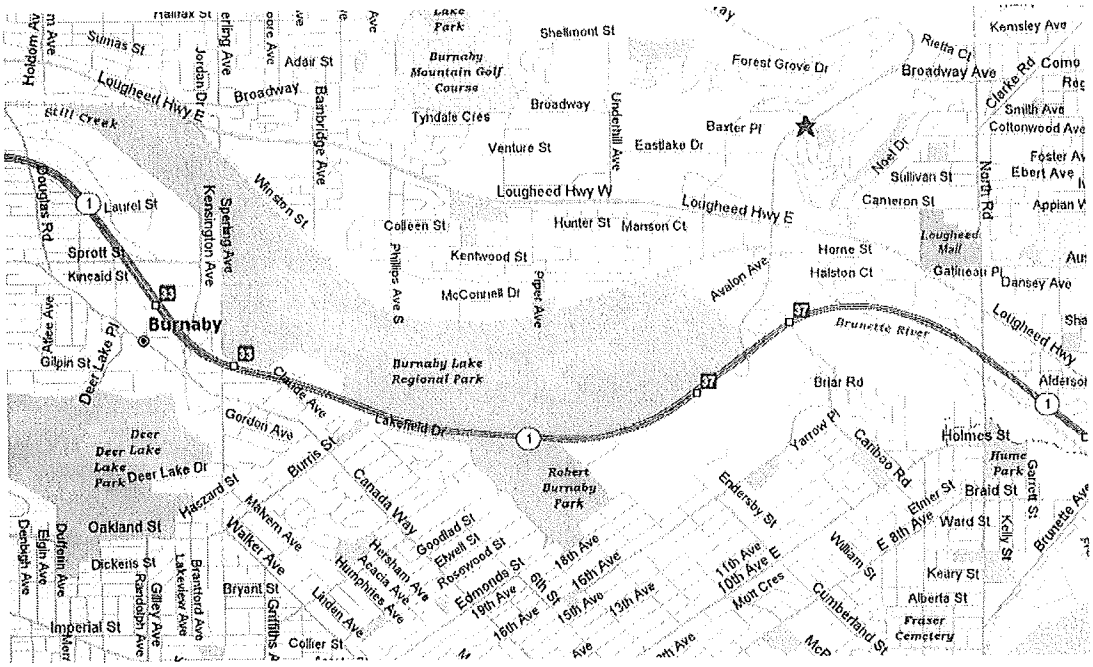


Figure 3. Map of Burnaby Lake Regional Park and Highway #1 in Burnaby (Mapquest, 2005).

UFP samples were collected along a north-south oriented trail that runs roughly perpendicular to Highway #1. Samples were collected at horizontal distances of 50 meters, 100 meters, and 250 meters from Highway #1. Samples were not collected at 0 meters from the highway due to access restrictions and safety concerns.

Sampling Strategy

First, the P-Trak was prepared for operation by filling the alcohol cartridge and ensuring it was free from leaks (see Appendix A for a detailed description). The P-Trak was zeroed with a zero filter assembly to ensure correct operation of the instrument before each use (refer to Appendix B for detailed zero description). At the first sampling point (50 meters), the P-Trak was turned on and put into log mode 2 and a 2 minute sample was recorded. The process was repeated at the second (100 meters) and third (250 meters) locations. Lastly, a background sample was collected deeper in Burnaby Lake Park at a further distance from the Highway (approximately 400m). After samples were collected the P-Trak was connected to a computer and the logged data was downloaded into TrakPro software. A total of 30 rounds of sampling was conducted.

Accuracy

Calibration of the P-Trak can only be performed at the factory. The manufacturer recommends that the P-Trak be sent for calibration annually. Fred Shaw, BCIT Environmental Health Technician reported that the P-Trak is sent for calibration only when the instrument is malfunctioning, or if it cannot be zeroed. (personal communication, November 8, 2005). Since the instrument was zeroed successfully it was presumed to be operating correctly and giving accurate results.

Validity of Measures

The results from this project can be generalized to not only the area closely surrounding Burnaby Lake Park, but also to other areas in Burnaby that are located in close proximity to Highway #1 since traffic volumes, traffic make up, and topography are similar. The results may represent other areas that are close to a major roadways, but not as clearly since traffic patterns, traffic density, traffic make up (more diesel powered compared to gas powered engines etc.) and topography may differ. However, it should be noted that some areas likely

experience higher concentrations of UFP than measured in the park because of the additional contribution of UFP from arterial roads in the area, not just the impact from the Highway.

STATISTICAL ANALYSIS

A quantitative study was performed to evaluate the collected numerical data set. A complete printout of the data is located in Appendix C. The Number Crunching Statistical System (NCSS) software program was used as the statistical package to assist with manipulating the data and determining both the descriptive and inferential statistics (NCSS, 2000). Thirty samples were collected at each location for a total of 120 data points. Since this research project compared more than two locations of results the Analysis of Variance (ANOVA) was the statisitical method used (Heacock & Chiodo, 2005) to compare the different locations of UFP concentrations. Correlation/regression was used to determine the relationship between the distance from the highway and UFP concentrations.

Hypothesis:

ANOVA

H_o: There is no difference between the mean levels of UFP concentrations, and 50, 100 and 250 meter distances from the highway.

H_a: There is a difference between the mean levels of UFP concentrations, and 50, 100 and 250 meter distances from the highway.

Regression

H_o: There is no association between distance and levels of UFP concentrations, and 50, 100 and 250 meter distances from the highway.

H_a: There is an association between distance and levels of UFP concentrations, and 50, 100 and 250 meter distances from the highway.

Alpha and Beta Errors

Alpha was set at 0.01 for this study to reduce the likelihood that the results were due to chance. Lowering the alpha value reduced the potential for Type I errors that would indicate that there was a difference between the locations UFP concentrations when there really was no difference. Therefore, chance was unlikely to have affected the results. The analysis of the study shows the power to be 100 percent. Therefore, Beta errors need not be considered to have affected the results.

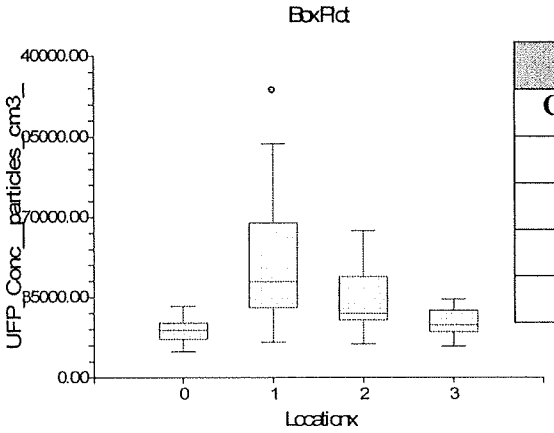
RESULTS

Descriptive Results

Measures of central tendency were determined for each location for each sampling period (see Appendix D). Specifically, the mean and median were calculated. Standard deviation and range were also determined in order to analyze the spread of the data (see Table 1 and Figure 4, below).

Table 1. Summary of Descriptive Statistics

Location	Mean	Standard Deviation	Median	Range
50 meters	51370.27	25799.9	42123	109517
100 meters	33318.8	12921.54	28197.5	49538
250 meters	23878.17	5513.387	23294	20438
Background	20634.57	5126.97	21013.5	19687



Box Plot Key	
Chart	**Location**
0	Background
1	50 meters from highway
2	100 meters from highway
3	250 meters from highway

Figure 4. Box Plot Showing the Spread of the Data at Each Sampling Location

Inferential Results

ANOVA Results

According to the Test of Assumptions, all assumptions were rejected ($p<0.05$) therefore the data was not normally distributed and the results from a non-parametric test were examined (refer to Appendix E for complete results). The non-parametric Kruskal-Wallis One-Way ANOVA on Ranks procedure was used to test the hypotheses. The test indicated H_0 should be rejected since $p = 0.00$. The results indicate that there was a statistically significant difference between the concentrations of UFPs measured at all of the locations. To reduce the alpha error, alpha was set at 0.01. The post hoc Scheffe's Multiple Comparison Test shows UFP data collected at 50 meters from the highway are different from all of the sampling locations (H., Heacock, personal communication, March 2, 2005).

Kruskal-Wallis One-Way ANOVA on Ranks

Hypotheses

Ho: All medians are equal.

Ha: At least two medians are different.

Test Results

Method	DF	Chi-Square (H)	Prob Level	Decision(0.01)
Not Corrected for Ties	3	50.83047	0.000000	Reject Ho
Corrected for Ties	3	50.83065	0.000000	Reject Ho
Number Sets of Ties	1			
Multiplicity Factor	6			

Figure 5. Kruskal-Wallis One-Way ANOVA on Ranks Results

Correlation/Regression Results

A Linear Regression evaluation of the data determined that there was moderate relationship between UFP concentrations and distance from the highway as the "r" value was found to be -0.51 (see Appendix G for complete results). The regression equation is y= mx+b; in these results the y= (-120.26) (x)+52 224. So this means the y intercept, which is the estimated value of UFP concentration when location 50 meters from the highway is 52 224 particles/cm^3. The slope, the estimated change in UFP concentration in unit change in location was -120.26 particles/cm^3. The t-test for intercept and slope are significant (p=0.00). The intercept does not equal 0, therefore reject H_0. The slope was statistically significantly different from 0, therefore the Ho was rejected and it was concluded that with each meter traveled from the 50 meter start point next to the highway there was a 120 particles/cm^3 decrease (see Figure 6, below and Appendix F).

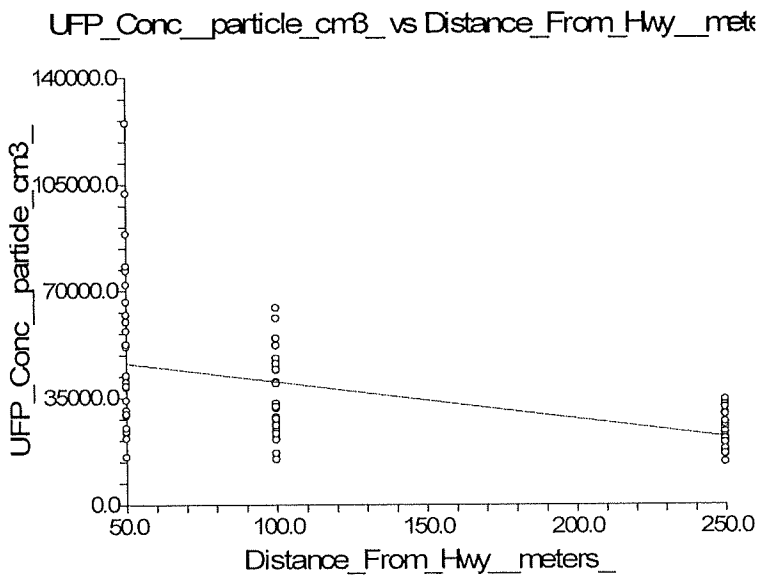


Figure 6. Correlation/Regression Results

DISCUSSION

The purpose of this study was to determine the horizontal distance from Highway No. 1 where elevated concentrations of ultrafine particulate exist from vehicle emissions. It was found that the concentrations of UFP measured nearest to the highway were the highest and as the distance from the highway increased the UFP concentrations decreased. The ANOVA test indicated that there was a statistically significant difference between the concentrations of UFPs measured at all of the locations. The results show that the UFP concentrations decrease fairly rapidly from the 50 meter location to the 250 meter location, where they had fallen to near background levels. The background was arbitrarily selected at 400 meters due to space constraints in the park. To find the "true" background it would have been necessary to take samples at progressively greater distances from the highway until the difference in the results was no longer statistically significant. However, the small range of results at the 400 m location and the reasonably small difference between the means of the 250m and the 400m locations would suggest that a background level was being approached.

The data set had a large range, particularly at 50 and 100 meters from the highway. This was likely due to variations in traffic volume and makeup on the highway. For example, it was noted that UFP concentrations were temporarily elevated when diesel powered tractor-trailers drove by. Surprisingly, no consistent correlation was observed between degree of highway congestion and UFP concentrations. The variations may also have been due to changes in meteorological conditions. The wind direction was generally parallel to the freeway during testing, however, wind speeds and weather conditions varied greatly from test to test. Although the degree of congestion and meteorological conditions were recorded at the time of sampling, their effects were not considered in the statistical analysis.

Correlation/regression analysis of the data indicated that a moderately linear relationship existed between UFP concentration and distance from the highway. A correlation such as this might be used to estimate UFP concentrations at intermediate points within the test range. Since the relationship is only moderate, caution should be exercised while using this relationship to estimate UFP concentrations outside of the test range.

The results from this study are consistent with previous research that vehicle exhaust is the major contributor to UFP concentration in the urban environment (Sioutas, et al., 2005; Zhu el al., 2002). Since there is limited research on the impact of major roadways on the surrounding UFP concentration in the environment it is difficult to determine if the results are consistent with other studies. Previous research indicates that elevated concentrations of UFPs have negative health affects on the exposed population including respiratory and cardiovascular complications. Therefore it is likely that the increased concentrations from major roadways, as observed in this study, would negatively impact these people.

Limitations

Limitations that may have played a role in this study, include:

- A short sample period of 2 minutes was used due to time constraints of conducting the project. If time was not a factor and equipment could be safely left unattended it would be advantageous to monitor for much longer periods such as entire days or weeks.
- Measurements were not made at the edge of the roadway due to safety concerns. UFP concentrations are likely significantly higher at the edge of the highway.
- Measurements were made sequentially at each of the sampling locations rather than simultaneously. The data was gathered in this manner because only one monitor was available. This may have affected results since it would take approximately 20 minutes to complete a round of sampling. In this time, traffic conditions on the highway may have changed.
- Samples were not collected during rainy weather conditions, since the monitor would not function in these conditions.
- Measurements were only collected in the geographic region of Burnaby Lake Park, which limited the generalizability to other locations especially those outside of Burnaby.

Conclusions

The results of this study indicated that traffic on Highway No. 1 was responsible for elevated UFP concentrations in the vicinity of the Highway. Furthermore, it was determined that UFP concentrations exceeded background levels at an offset of at least 250 meters from the roadway. Finally, it was determined that UFP levels decreased as the distance from the freeway increased.

Observations during the study showed that there are houses located within 250 meters of the highway in Burnaby. Therefore, it is likely that the occupants of

these houses are exposed to elevated concentrations of UFP and may experience health complications as a result.

Recommendations

Based on the results of this study, the following recommendations are suggested:

- Carry out more studies to determine the influence of UFP concentrations on human health and establish an acceptable exposure limit.
- Incorporate the findings into future planning for land use next to major roadways. For example, commercial/industrial buildings could be placed closest to roadways where public buildings that serve the most vulnerable including daycares and hospitals should be located at greater distances.
- Educate public on the health effects of UFP.
- Develop strategies to lower UFP emissions to reduce health impacts.

Future Research

- Determine the influence of arterial roads and major intersections on UFP concentrations.
- Assess the concentrations of ambient UFP that is present on a neighbourhood level.
- Measure UFP concentrations during daily activities such as in homes, riding the bus, driving a car, etc.
- Determine different vehicle output of UFP concentrations (ie. Diesel engines, gas engines, new cars, old cars etc.)
- Simultaneously collect UFP concentrations at various distances from Highway No. 1 for an extended time period and correlate to readily available traffic data. This model could be used to estimate UFP concentrations for future developments, etc.

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APPENDIX A

Locating and Identifying Components

To add alcohol to the P-TRAK you must first identify and locate the alcohol related components and accessories that are included with the instrument (refer to Figure 1-2, for more information). You will need the following items:

- Isopropyl Alcohol
- Alcohol Fill Capsule
- Storage Cap
- Alcohol Cartridge

Isopropyl alcohol is supplied by TSI in 30 ml plastic bottles. The alcohol fill capsule is located in the P-TRAK carrying case. The alcohol cartridge will also be either in the P-TRAK cartridge cavity or in the alcohol fill capsule, whichever one is **not** holding the storage cap. The storage cap should be either sealing the alcohol fill capsule or inserted into the P-TRAK cartridge cavity.

Filling the Alcohol Fill Capsule

1. Turn the P-TRAK off.
2. Open the alcohol fill capsule by twisting the storage cap (or alcohol cartridge) ⅛ turn counter-clockwise. Set the storage cap (or alcohol cartridge) down on a clean surface, with the end standing up, as shown in Figure 2-3.

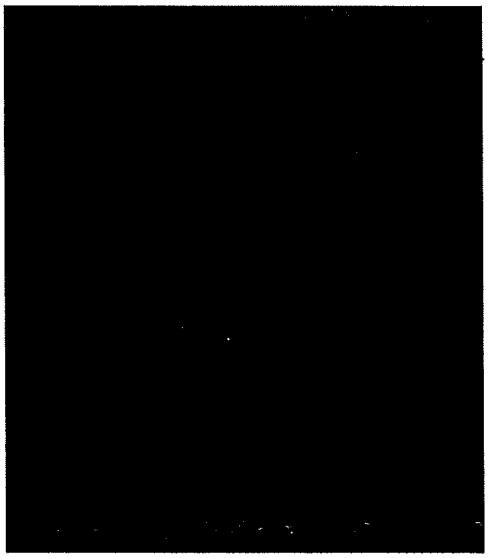


Figure 2-3: Alcohol Cartridge and Storage Cap

3. Open a bottle of alcohol. Invert the bottle and insert the nozzle end into the alcohol fill capsule as far as possible to make certain that you cannot inadvertently spray alcohol anywhere except down into the capsule.

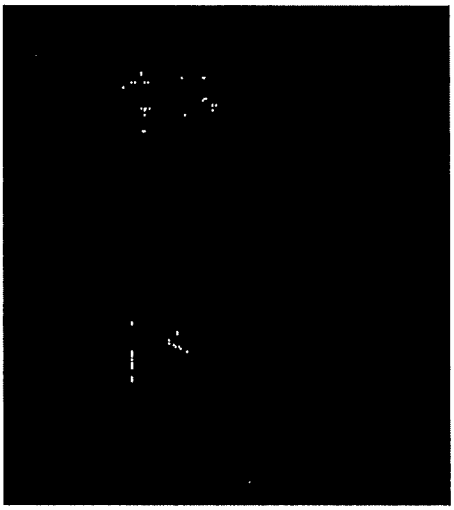


Figure 2-4: Alcohol Fill Capsule

4. Squeeze alcohol into the alcohol fill capsule until the liquid level is even with the scribed fill-line near the base (Figure 2-4). Recap the alcohol bottle.
5. *Make certain the alcohol cartridge is clean!* Insert the alcohol cartridge into the alcohol fill capsule by aligning the groove with the pin and turning ⅛ turn (clockwise) until it locks into place (Figure 2-5).

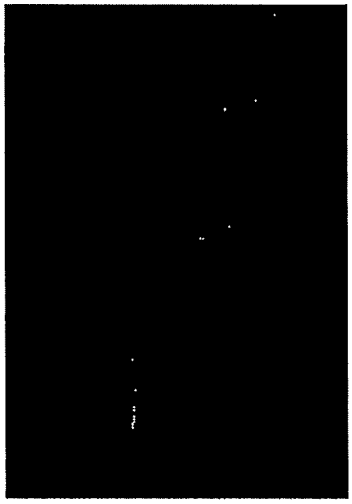


Figure 2-5: Insert Alcohol Cartridge into Fill Capsule

6. Set the alcohol fill capsule down and wait a few minutes while the wick inside the cartridge soaks up alcohol.

Installing the Cartridge into the P-TRAK

1. Remove the alcohol cartridge from the fill capsule and gently shake it to allow excess alcohol to drain back into the capsule. Stop when excess alcohol is no longer dripping. It is not necessary to wait until the outside surface of the alcohol cartridge is dry.
2. Insert the cartridge into the cartridge cavity on the P-TRAK. It should slide in easily with little effort. **Do not force it!** Align the tab on the alcohol cartridge with the corresponding tab on the P-TRAK, located just above the cartridge cavity.
3. As you approach full insertion, firmly twist the alcohol cartridge clockwise about ⅛ turn. It should snap into position.

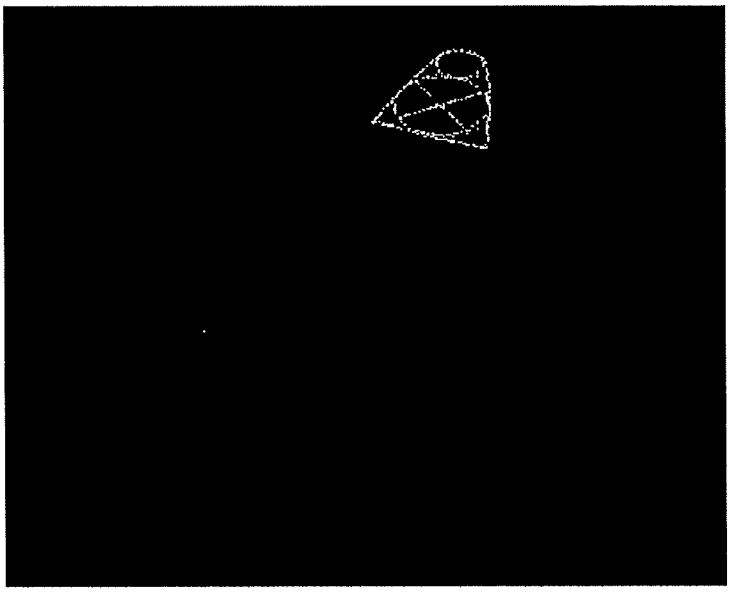


Figure 2-6: Insert Alcohol Cartridge into P-TRAK

Cleaning Up and Final Cautions

1. Recap the alcohol fill capsule using the storage cap.

Note: *Always recap the alcohol fill capsule and other containers immediately to prevent absorption of moisture and the escape of fumes. Dispose of any alcohol that is visibly contaminated.*

2. When the P-TRAK is stored in the carrying case, you should store the alcohol cartridge in the alcohol fill capsule. The alcohol fill capsule is designed to be a safe transportation and storage container for alcohol. The alcohol cartridge can be left soaking in alcohol indefinitely. Also, install the storage cap into the cartridge cavity to prevent dirt or lint from getting inside the P-TRAK.
3. **Never** transport or store the P-TRAK with the alcohol cartridge inside it. Flooding of the optics could occur.
4. **Always** keep the alcohol cartridge clean.
5. **Never** leave the cartridge cavity open longer than necessary. Use the storage cap to cover the cartridge cavity when the P-TRAK is transported or stored.

6. Keep the storage cap and alcohol cartridge clean. Always set them down with the end standing up. These precautions prevent dirt or debris from entering the instrument and causing operational problems.

Attaching the Inlet Screen Assembly, Sample Tube, and Telescoping Probe to the Instrument

The normal sampling configuration for the P-TRAK Ultrafine Particle Counter consists of the inlet screen assembly, sample tube, and telescoping probe (see Chapter 3, "Operation," for information on other sampling options).

The inlet screen assembly helps to prevent large particles and fibers from entering the instrument and plugging the internal fittings. *Do **not** operate the P-TRAK without the inlet screen assembly in place.* To attach the sampling assembly:

1. Make sure the quick-connect fitting is in the "unlocked" position. If the fitting is locked, the sampling tube will not be able to be inserted into the instrument. To unlock the fitting, press up on the tab under the fitting.
2. Insert the inlet screen assembly into the fitting and press it firmly until it snaps into place (see Figure 2-7). It may help to rotate the inlet screen while inserting.
3. Attach one end of the sample tube to the inlet screen assembly barbed fitting.
4. Attach the other end of the sample tube to the barbed fitting on the telescoping probe.

APPENDIX B

Daily Zero Check

Before beginning to sample with the P-TRAK , it is important to verify that the instrument is operating normally. This Daily Zero Check should be performed at least once a day.

1. Turn on the instrument and let it warm up (approximately 60 seconds).
2. Remove the sample tube from the inlet screen assembly (if attached).
3. Attach the supplied zero filter assembly (item #4, Figure 1-3) to the inlet screen assembly.
4. The particle concentration should go to zero in approximately 5 to 10 seconds. Leave the zero filter attached to the instrument for 30 seconds, to make sure the zero reading is stable.

***Note**: If the instrument does not go to zero, please refer to Chapter 5, Troubleshooting, for more information.*

The Daily Zero Check cannot be performed when the telescoping sample probe is attached to the instrument. The telescoping joints will cause a small number of particles to be sampled and will invalidate the zero check.

5. Remove the zero filter. Attach the sample tube and telescoping sample probe, as desired. The instrument is now ready for operation.

P-TRAK Keypad

The P-TRAK is controlled using a simple, 4-way keypad, with Up, Down, Left, and Right keys along with an Enter key. These keys are used to move between menu items, to increase or decrease selected values and to select the desired item/value. When pressing the keys on the front panel, the P-TRAK beeps to confirm the function. See Figure 3-1.

APPENDIX C

UFP Conc particles cm3	Locationx	C	C4	UFP Conc particle cm3	Distance
21753	0			15506	50
24146	0			51524	50
17528	0			42107	50
20789	0			71843	50
17332	0		Background=0	56680	50
13754	0		50 m away=1	41793	50
14468	0		150 m away=2	52311	50
12514	0		300 m away=3	61991	50
11313	0			66233	50
17084	0			59701	50
21047	0			59701	50
28033	0			77119	50
25447	0			88563	50
20980	0			101983	50
21491	0			39927	50
29751	0			30775	50
28878	0			34007	50
23629	0			28932	50
21988	0			42139	50
24438	0			29491	50
20807	0			38245	50
22713	0			23353	50
22208	0			23875	50
21455	0			38555	50
20436	0			76491	50
13351	0			21575	50
15259	0			78000	50
31000	0			25000	50
15700	0			125023	50
19745	0			38665	50
15506	1			40035	100
51524	1			25550	100
42107	1			43887	100
71843	1			25497	100
56680	1			27338	100
41793	1			21103	100
52311	1			31331	100
61991	1			39491	100
66233	1			54185	100
59701	1			60793	100
59701	1			47636	100
77119	1			45895	100
88563	1			51893	100
101983	1			44038	100
39927	1			28417	100
30775	1			28558	100
34007	1			27468	100
28932	1			23946	100
42139	1			25698	100

APPENDIX D

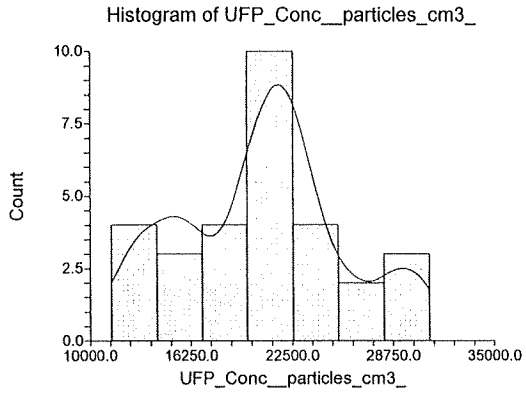
Descriptive Statistics Report

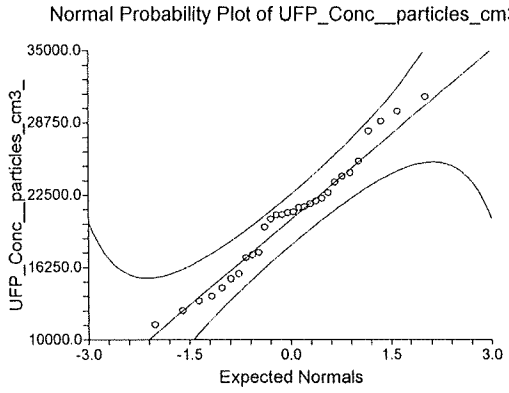
Page/Date/Time 1 4/30/2006 10:36:23 AM
Database C:\Documents and Settings\Shannon\Desktop\UFP DATA\realdata.S0

Summary Section of UFP_Conc__particles_cm3_ when Locationx=0

Count	Mean	Standard Deviation	Standard Error	Minimum	Maximum	Range
30	20634.57	5126.97	936.0524	11313	31000	19687

Plots Section of UFP_Conc__particles_cm3_ when Locationx=0

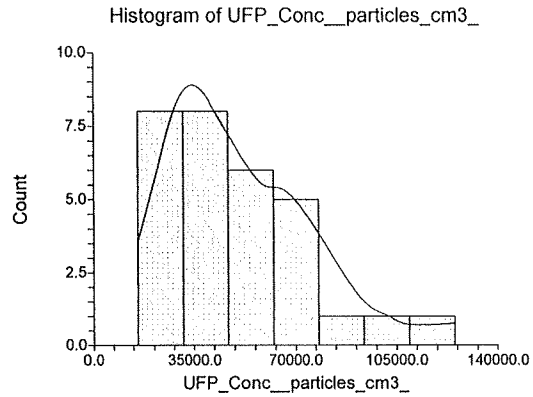


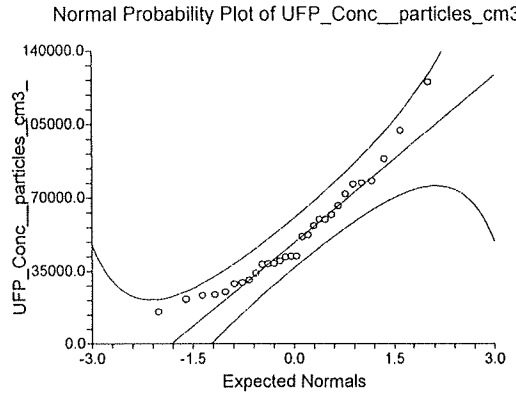


Summary Section of UFP_Conc__particles_cm3_ when Locationx=1

Count	Mean	Standard Deviation	Standard Error	Minimum	Maximum	Range
30	51370.27	25799.9	4710.395	15506	125023	109517

Plots Section of UFP_Conc__particles_cm3_ when Locationx=1





Summary Section of UFP_Conc__particles_cm3_ when Locationx=2

Count	Mean	Standard Deviation	Standard Error	Minimum	Maximum	Range
30	33318.8	12921.54	2359.14	14662	64200	49538

APPENDIX E

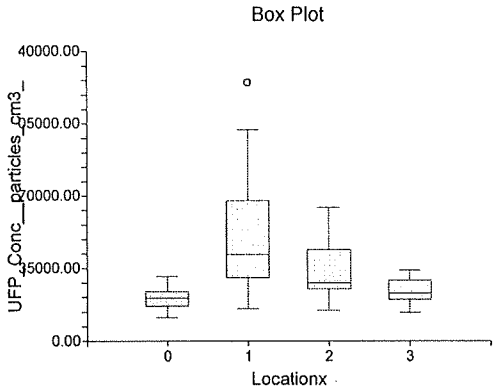
Analysis of Variance Report

Page/Date/Time 1 4/30/2006 10:31:11 AM
Database C:\Documents and Settings\Shannon\Desktop\UFP DATA\realdata.S0
Response UFP_Conc__particles_cm3_

Tests of Assumptions Section

Assumption	Test Value	Prob Level	Decision (0.01)
Skewness Normality of Residuals	5.1297	0.000000	Reject
Kurtosis Normality of Residuals	4.7301	0.000002	Reject
Omnibus Normality of Residuals	48.6875	0.000000	Reject
Modified-Levene Equal-Variance Test	14.2997	0.000000	Reject

Box Plot Section



Expected Mean Squares Section

Source Term	DF	Term Fixed?	Denominator Term	Expected Mean Square
A: Locationx	3	Yes	S(A)	S+sA
S(A)	116	No		S(A)

Note: Expected Mean Squares are for the balanced cell-frequency case.

Analysis of Variance Table

Source Term	DF	Sum of Squares	Mean Square	F-Ratio	Prob Level	Power (Alpha=0.01)
A: Locationx	3	1.715168E+10	5.717226E+09	25.72	0.000000*	1.000000
S(A)	116	2.578924E+10	2.22321E+08			
Total (Adjusted)	119	4.294092E+10				
Total	120					

* Term significant at alpha = 0.01

Analysis of Variance Report

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Database C:\Documents and Settings\Shannon\Desktop\UFP DATA\realdata.S0
Response UFP_Conc__particles_cm3_

Kruskal-Wallis One-Way ANOVA on Ranks
Hypotheses
Ho: All medians are equal.
Ha: At least two medians are different.

Test Results

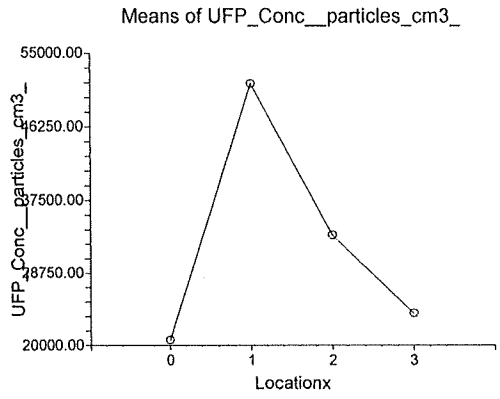
Method	DF	Chi-Square (H)	Prob Level	Decision(0.01)
Not Corrected for Ties	3	50.83047	0.000000	Reject Ho
Corrected for Ties	3	50.83065	0.000000	Reject Ho

Number Sets of Ties	1
Multiplicity Factor	6

Group Detail

Group	Count	Sum of Ranks	Mean Rank	Z-Value	Median
0	30	975.00	32.50	-5.0909	21013.5
1	30	2746.00	91.53	5.6424	42123
2	30	2136.00	71.20	1.9455	28197.5
3	30	1403.00	46.77	-2.4970	23294

Plots of Means Section



Scheffe's Multiple-Comparison Test

Response: UFP_Conc__particles_cm3_
Term A: Locationx

Alpha=0.010 Error Term=S(A) DF=116 MSE=2.22321E+08 Critical Value=3.4446

Group	Count	Mean	Different From Groups
0	30	20634.57	1
3	30	23878.17	1
2	30	33318.8	1
1	30	51370.27	0, 3, 2

Notes:
This report provides multiple comparison tests for all possible contrasts among the the means. These contrasts may involve more groups than just each pair, so the method is much stricter than need be. The Tukey-Kramer method provides more accurate results when only pairwise comparisons are needed.

Tukey-Kramer Multiple-Comparison Test

Response: UFP_Conc__particles_cm3_
Term A: Locationx

Alpha=0.010 Error Term=S(A) DF=116 MSE=2.22321E+08 Critical Value=4.5004

Group	Count	Mean	Different From Groups
0	30	20634.57	2, 1
3	30	23878.17	1
2	30	33318.8	0, 1
1	30	51370.27	0, 3, 2

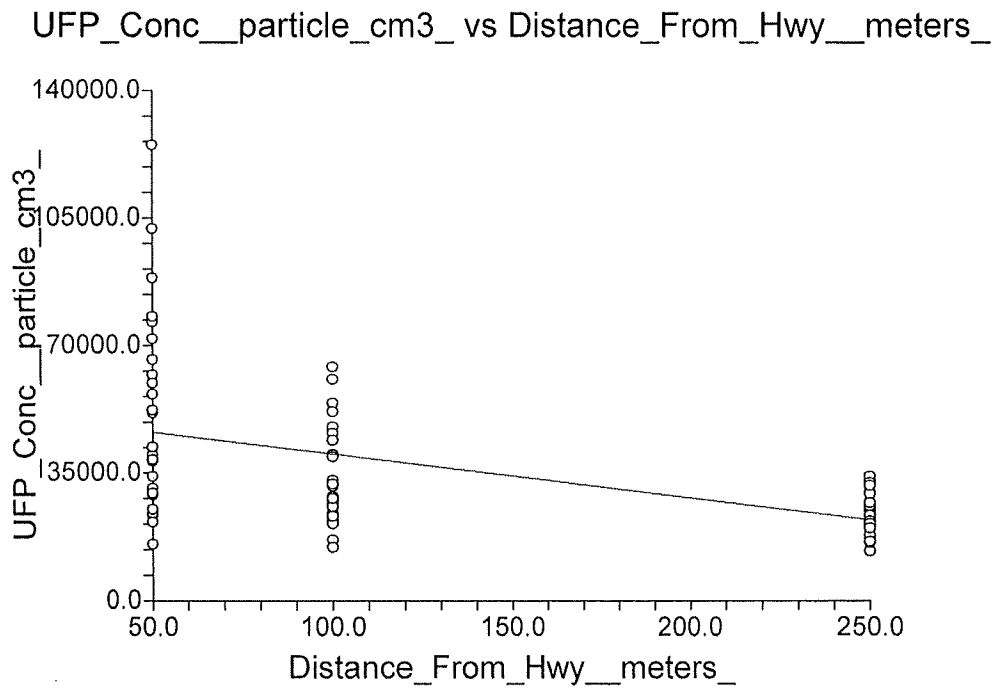
Notes:
This report provides multiple comparison tests for all pairwise differences between the means.

APPENDIX F

Linear Regression Report

Page/Date/Time 1 4/30/2006 10:34:45 AM
Database C:\Documents and Settings\Shannon\Desktop\UFP DATA\realdata.S0
Y = UFP_Conc__particle_cm3_ X = Distance_From_Hwy__meters_

Linear Regression Plot Section



Run Summary Section

Parameter	Value	Parameter	Value
Dependent Variable	UFP_Conc__particle_cm3_	Rows Processed	120
Independent Variable	Distance_From_Hwy__meters_	Rows Used in Estimation	90
Frequency Variable	None	Rows with X Missing	30
Weight Variable	None	Rows with Freq Missing	0
Intercept	52224.1308	Rows Prediction Only	0
Slope	-120.2629	Sum of Frequencies	90
R-Squared	0.2559	Sum of Weights	90.0000
Correlation	-0.5059	Coefficient of Variation	0.4870
Mean Square Error	3.10612E+08	Square Root of MSE	17624.19

Summary Statement

The equation of the straight line relating UFP_Conc__particle_cm3_ and Distance_From_Hwy__meters_ is estimated as: UFP_Conc__particle_cm3_ = (52224.1308) + (-120.2629) Distance_From_Hwy__meters_ using the 90 observations in this dataset. The y-intercept, the estimated value of UFP_Conc__particle_cm3_ when Distance_From_Hwy__meters_ is zero, is 52224.1308 with a standard error of 3456.3878. The slope, the estimated change in UFP_Conc__particle_cm3_ per unit change in Distance_From_Hwy__meters_, is -120.2629 with a standard error of 21.8601. The value of R-Squared, the proportion of the variation in UFP_Conc__particle_cm3_ that can be accounted for by variation in Distance_From_Hwy__meters_, is 0.2559. The correlation between UFP_Conc__particle_cm3_ and Distance_From_Hwy__meters_ is -0.5059.

A significance test that the slope is zero resulted in a t-value of -5.5015. The significance level of this t-test is 0.0000. Since 0.0000 < 0.0500, the hypothesis that the slope is zero is rejected.

The estimated slope is -120.2629. The lower limit of the 95% confidence interval for the slope is -163.7053 and the upper limit is -76.8205. The estimated intercept is 52224.1308. The lower limit of the 95% confidence interval for the intercept is 45355.2862 and the upper limit is 59092.9753.

Descriptive Statistics Section

Parameter	Dependent	Independent
Variable	UFP_Conc__particle_cm3_	Distance_From_Hwy__meters_
Count	90	90
Mean	36189.0778	133.3333
Standard Deviation	20316.2957	85.4598
Minimum	13617.0000	50.0000
Maximum	125023.0000	250.0000

Linear Regression Report

Page/Date/Time 3 4/30/2006 10:34:45 AM
Database C:\Documents and Settings\Shannon\Desktop\UFP DATA\realdata.S0
Y = UFP_Conc__particle_cm3_ X = Distance_From_Hwy__meters_

Regression Estimation Section

Parameter	Intercept B(0)	Slope B(1)
Regression Coefficients	52224.1308	-120.2629
Lower 95% Confidence Limit	45355.2862	-163.7053
Upper 95% Confidence Limit	59092.9753	-76.8205
Standard Error	3456.3878	21.8601
Standardized Coefficient	0.0000	-0.5059
T Value	15.1095	-5.5015
Prob Level (T Test)	0.0000	0.0000
Reject H0 (Alpha = 0.0500)	Yes	Yes
Power (Alpha = 0.0500)	1.0000	0.9997
Regression of Y on X	52224.1308	-120.2629
Inverse Regression from X on Y	98846.5360	-469.9309
Orthogonal Regression of Y and X	98845.7111	-469.9247

Notes:
The above report shows the least-squares estimates of the intercept and slope followed by the corresponding standard errors, confidence intervals, and hypothesis tests. Note that these results are based on several assumptions that should be validated before they are used.

Estimated Model
(52224.1307692308) + (-120.262897435897) * (Distance_From_Hwy__meters_)

Linear Regression Report

Page/Date/Time 4 4/30/2006 10:34:45 AM
Database C:\Documents and Settings\Shannon\Desktop\UFP DATA\realdata.S0
Y = UFP_Conc__particle_cm3_ X = Distance_From_Hwy__meters_

Tests of Assumptions Section

Assumption/Test	Test Value	Prob Level	Is the Assumption Reasonable at the 0.2000 Level of Significance?
Residuals follow Normal Distribution?			
Shapiro Wilk	0.9042	0.000006	No
Anderson Darling	1.5481	0.000553	No
D'Agostino Skewness	4.8367	0.000001	No
D'Agostino Kurtosis	3.9051	0.000094	No
D'Agostino Omnibus	38.6431	0.000000	No
Constant Residual Variance?			
Modified Levene Test	9.5083	0.002732	No
Relationship is a Straight Line?			
Lack of Linear Fit F(1, 87) Test	8.0194	0.005749	No

No Serial Correlation?
Evaluate the Serial-Correlation report and the Durbin-Watson test if you have equal-spaced, time series data.

Notes:
A 'Yes' means there is not enough evidence to make this assumption seem unreasonable. This lack of evidence may be because the sample size is too small, the assumptions of the test itself are not met, or the assumption is valid.
A 'No' means the that the assumption is not reasonable. However, since these tests are related to sample size, you should assess the role of sample size in the tests by also evaluating the appropriate plots and graphs. A large dataset (say N > 500) will often fail at least one of the normality tests because it is hard to find a large dataset that is perfectly normal.

Normality and Constant Residual Variance:
Possible remedies for the failure of these assumptions include using a transformation of Y such as the log or square root, correcting data-recording errors found by looking into outliers, adding additional independent variables, using robust regression, or using bootstrap methods.

Straight-Line:
Possible remedies for the failure of this assumption include using nonlinear regression or polynomial regression.

Linear Regression Report

Page/Date/Time 5 4/30/2006 10:34:45 AM
Database C:\Documents and Settings\Shannon\Desktop\UFP DATA\realdata.S0
Y = UFP_Conc__particle_cm3_ X = Distance_From_Hwy__meters_

Residual Plots Section

Residuals of UFP_Conc__particle_cm3_ vs Distance_From_Hwy__meters_