Assessing Fine Particulate Matter Concentrations Across Dalhousie University's Studley Campus

ENVS/SUST 3502
Campus As A Living Lab
Group 5
Dr. Greene

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Executive Summary

This report aims to provide an assessment of the air quality across Dalhousie's Studley campus; primarily focusing on a group of aerosols with an aerodynamic diameter ranging from 1 µm to 10 µm, known as particulate matter. Particulate matter is of interest due to the risk it introduces to respiratory and cardiovascular systems in individuals exposed to elevated concentrations on both a short-term and long-term scale (WHO, 2017).

Measurements were taken using two instruments manufactured by TSI. Inc and were lent to the team by the Health and Environment Research Centre (HERC) Laboratory at Dalhousie University . The first instrument being the DustTrak DRX (model no. 8533), which continuously monitors mass and size fractions for particles in the air, specifically PM_1, $PM_{2.5}$, PM_{10} and total PM. In addition, the Condensation Particle Counter (model no. 3007) was used to measure total particle counts, specifically particles <1 µm in size.

Using the aforementioned devices, 8 different sites across the Studley Campus were measured at two different times during the day, 11:15 AM and 7:00 PM to observe if changes in pedestrian and vehicular traffic had an effect on particulate matter concentrations.

Overall, 16 unique combinations of location and time were sampled each with 5 replicates due to sampling each time period once per day for 5 days. Data was analyzed using a one-way analysis of variance (ANOVA), with a 95% confidence interval using Minitab 17. ANOVA was used to test significance between two factors; time and location to provide data on pedestrian/traffic effects on particulate matter concentrations, as well as significance between locations on Studley campus.

Particulate matter concentrations across campus are homogenous when comparing 11:15 AM concentrations against 7:00 PM concentrations, suggesting that higher pedestrian and vehicular traffic does not have a significant impact on particulate matter concentrations.

Particulate matter concentrations between locations also appeared to be homogenous and there was no significant difference in concentrations aside from the Dalplex entrance area, which appeared to have significantly higher $PM_{2.5}$ and PM_{10} concentrations - likely due to the ongoing construction in the area.

Due to the brevity of the sampling period, it is difficult to ascertain whether or not the elevated concentrations at the Dalplex pose a risk to the health and safety of students in faculty, but suggests that further data should be collected to better characterize the air quality within Studley campus.

Introduction

This research project was undertaken to collect and analyze data on Dalhousie University's Studley campus in regards to the concentration of particulate matter (PM_1, $PM_{2.5}$, PM_{10}) during both morning and evening times. The project aims to identify the concentrations of particulate matter at several locations around campus where students often walk or spend time, such as at bus stops or busy intersections on campus.

Our team used data collection tools consisting of a condensation particle counter (TSI CPC Model 3007) and an aerosol monitor (TSI DustTrak DRX) to collect data on nanoparticle counts (0.1 nm – 1 µm) and PM_1, $PM_{2.5}$, and PM_{10} at designated areas around Studley campus. The sampling will consist of ~5 minute samples at these locations with the data then being logged from the instruments for statistical analysis to determine any significant concentrations and areas of concern.

The group would like to thank Dr. Jong Sung Kim and Jacqueline Yakobi-Hancock, along with the rest of the Health & Environments Research Centre (HERC) Laboratory for the use of their equipment, training, and for providing feedback and comments on our project.

Air quality is a major environmental factor affecting human health; areas with low levels of air pollution tend to have populations with better respiratory and cardiovascular health, both in the short-term and the long-term (WHO, 2016). Particulate matter (PM) is a designation of particles with aerodynamic diameters <10 µm and is often attributed as a measurement of air quality; the risk that PM provides to human health is in its size (US EPA, 2016). As the size of a particle decreases, its penetration into the respiratory system increases; for $PM_{2.5}$ and below, particles can reach from the secondary bronchi to the alveoli where they can cross membranes and enter the bloodstream leading to negative cardiovascular responses (ACRD, 2017).

In addition to affecting human health, particulate matter can be environmentally damaging (US EPA, 2016). These particles are small enough to be carried great distances by wind and then settle on the ground or in water; depending on chemical composition, these particles can have adverse effects such as: acidification of water bodies/water courses, changes in nutrient loading of regional basins, depleting soil nutrients, damaging forests/crops, and acid rain (US EPA, 2016).

The Canadian Ambient Air Quality Standards (CAAQS) are a set of health-based air quality objectives used to characterize concentrations of $PM_{2.5}$ and ozone in outdoor air, these values are summarized in Table 1 below and are established by the Canadian Council of Ministers of the Environment.

Table 1 $PM_{2.5}$ and Ozone CAAQS (CCME, 2012)

Pollutant	**Averaging time**	**Standards** (concentration)	
		2015	**2020**
$PM_{2.5}$	24-hour (calendar day)	28 µg/m^3	27 µg/m^3
$PM_{2.5}$	annual (calendar year)	10.0 µg/m^3	8.8 µg/m^3
Ozone	8-hour	63 ppb	62 ppb

Due to Dalhousie University's relatively centralized location in an urban environment and its proximity to several major roadways and transit routes, it is important to ascertain if concentrations of $PM_{2.5}$ exceed air-quality objectives set by CAAQS.

Research indicates that fine particles are well mixed and fairly evenly distributed spatially due to mixing in the troposphere (Brook et al., 2011). As noted by Guigliano et al. (2005), ambient fine particulates are slightly greater in a central urban environment away from roads, rather than near trafficked roads.

Atmospheric mixing from a variety of fine particulate sources produces a greater concentration of fine particulates than emissions straight from a point source; however, particles can accumulate in an area if there is not adequate mixing. As fine particulates are spatially homogenous, individuals that are located further from a source of emission can still be impacted with a severity seen by those closer to the emission source (Guigliano et al., 2005).

Though fine particulates are expected to be spatially homogenous over time, current literature shows that fine particulates are higher during winter than summer for background urban environments (Brook et al., (2011), Guigliano et al., (2005)). Increased anthropogenic activity near point sources increases the ambient air fine particulate concentrations for the area due to tropospheric mixing causing spatial homogeneity; the entire urban area is affected by increased point source production of particulates increasing the health risk to individuals in that area (Guigliano et al., 2005). Atmospheric conditions that are not conducive to tropospheric mixing during winter allows for the accumulation of particulates until they leave the system via wet fall or are blown away by wind (Guigliano et al., 2005).

Total particulate material concentrations within ambient air has been declining in Canada since the 1970's, resulting in the cessation of monitoring for this factor in air quality (Wood, 2002). Incomplete data in relation to this important aspect of air quality may put individuals at risk if PM concentrations regularly exceed the CAAQS.

Dalhousie University's Environmental Health and Safety Policy intends to comply with regulatory guidelines to create a safe and healthy campus environment (Dalhousie University, 2016). Our research work aims to identify if policy adjustments are required to mitigate PM concentrations on campus. As members of the Dalhousie community it is important to ensure the campus environment is in line with supporting community health by identifying campus environment compliance with the CAAQS.

Methods

<u>Data Collection</u>

The purpose of this project is to collect data as a means of characterizing air quality in areas where students frequent on Studley campus. To test for this, air quality will be measured twice daily at eight specified locations throughout the campus, shown in Appendix E. Testing will occur once during high traffic times, at approximately 11:15 am, and once during low traffic times at approximately 7:00 pm, a further breakdown of the schedule can be seen in Table 1 below. These time frames were chosen to provide a representation of the range of movement that exists across campus on a regular basis. The specified times were chosen because one will give a representation of air quality during high traffic, and the other during low traffic. The high traffic data collection time was determined to take place at approximately 11:15 am. This is a time when a substantial portion of students are finishing classes or are going to their class, and it is also during lunchtime. As well, many students and faculty are leaving or coming to campus through different methods of transportation (walking, personal or public transport, biking etc.). The low traffic data collection time was determined to take place at approximately 7:00 pm, as the vast majority of students and faculty have left campus. Furthermore, data will not be collected on weekends since traffic is likely to be significantly lower at this time, which may negatively skew the results.

Air quality will be tested using two monitors provided by Dr. Kim in the Health and Environment Research Center (HERC); the TSI CPC monitors model 3007 (Appendix B) and the TSI DustTrak-Drx monitor model 8533 (Appendix A). CPC stands for condensation particle counter and measures particulate matter concentration as particles/cm3. The device is handheld and will allow data to be collected every 1 second. The range in size of these particulates are 1 nm to > 1.0 µm. Unfortunately, data collected using the CPC monitor could not be extracted and was lost. Subsequently, the study was narrowed in focus to PM10 and PM2.5 concentrations which were extracted from the DustTrak monitor.

The condensation particle counter works by pulling sample air in and mixing it with vaporized alcohol, 3-propanol. The condensed mixture passes through a laser light which has a reflection and light sensor in the unit. The laser is able to determine how many particles are present at that moment by the amount of light absorbed by the photodetector. For a diagram of operation please visit Appendix D. The DustTrak will collect particulate matter that ranges in size from 0.1 to > 15 µm. Specifically, it counts particles in mg/m3 every 10 seconds, for a diagram of operation please visit Appendix C. However, it is important to note out that both monitors will not identify the type of particulate matter found. In sum, the approximate concentration of the particulate matter will be collected at each location twice per day.

The airborne particles (aerosols) that were counted range in size from 1 nm to > 1.0 µm. The specified size range is considered fine particulate matter and has severe negative impacts on health (Song et al., 2016). The concentration of fine particulate matter found in this study will be compared to the pre-existing set air quality standards set out by the CAAQ, as well as primary literature. This comparison will provide evidence of whether or not air quality levels at the Studley campus are appropriate. Once determined, the next step will be to then decide whether air quality should be improved on Studley campus.

Data Collection Locations

Data was collected at various locations on campus. These locations were chosen specifically because they are along routes in which students are highly concentrated. It is understood that prevailing winds and weather patterns may skew data, regardless the samples were chosen to represent accurate depictions of different location types across the campus. Eight locations on Studley campus were chosen and are displayed on a Geographic Information Systems (GIS) map in Appendix E. The process of sampling along the designated route took no longer than 20 minutes. Non-probabilistic sampling, specifically representative sampling, was used (Palys & Atchison, 2013). This is because our purpose for picking the locations is to represent those which show the highest or lowest level of air quality. For this reason, random sampling was not chosen because an appropriate amount of samples could not be collected due to limiting factors such as available equipment and time constraints. Therefore, samples cannot be used to apply to the entire population on Studley campus.

Data Analysis

Data was collected over a one-week period; therefore, there were 16 unique combinations of location and time as well as 5 replicates of those combinations (data collected once per day for 5 days). Originally, two weeks was chosen as the time frame for data collection, however, due to adverse weather conditions this was limited to 5 days of data. Air quality is not able to be effectively measured on days directly after or during periods of precipitation as particulate matter settles on the ground. Furthermore, the data collection could not be extended, due to deadline constraints. However, each combination type was tested at least once per day. Therefore, completeness of data was not affected, only number of replicates was reduced.

The data was analyzed using a one-way analysis of variance (ANOVA) test with interaction, using the software Minitab 17. The test used a 95% confidence level. The factor being tested was time. This test calculated whether there is a significant difference in the average particulate matter concentration among the different combinations of location and time. It also tested to determine if there is any interaction between location and time (e.g. a location may only have high particulate matter concentration during high traffic times). If a significant difference between locations was found, multiple comparisons would then be conducted to assess specifically, which location and time combinations significantly differed from each other. Overall, understanding whether the means of the different locations and times significantly differ from each other gave a broader characterization of how and if, air quality changes around campus.

Table 2 Data Collection Schedule

	Monday	Tuesday	Wednesday	Thursday	Friday
11:15 am	Heba	Jenna	Nathan	Jenna	Stu
7:00 pm	Dylan	Nathan	Dylan	Heba	Stu

Results

The results from this experiment indicate that all campus locations are fairly homogenous in PM2.5 and P10 concentrations in both busy and calm periods of traffic, excluding the Dalplex which has higher concentrations of both particulate matter sizes than all other locations and the CAAQS guidelines.

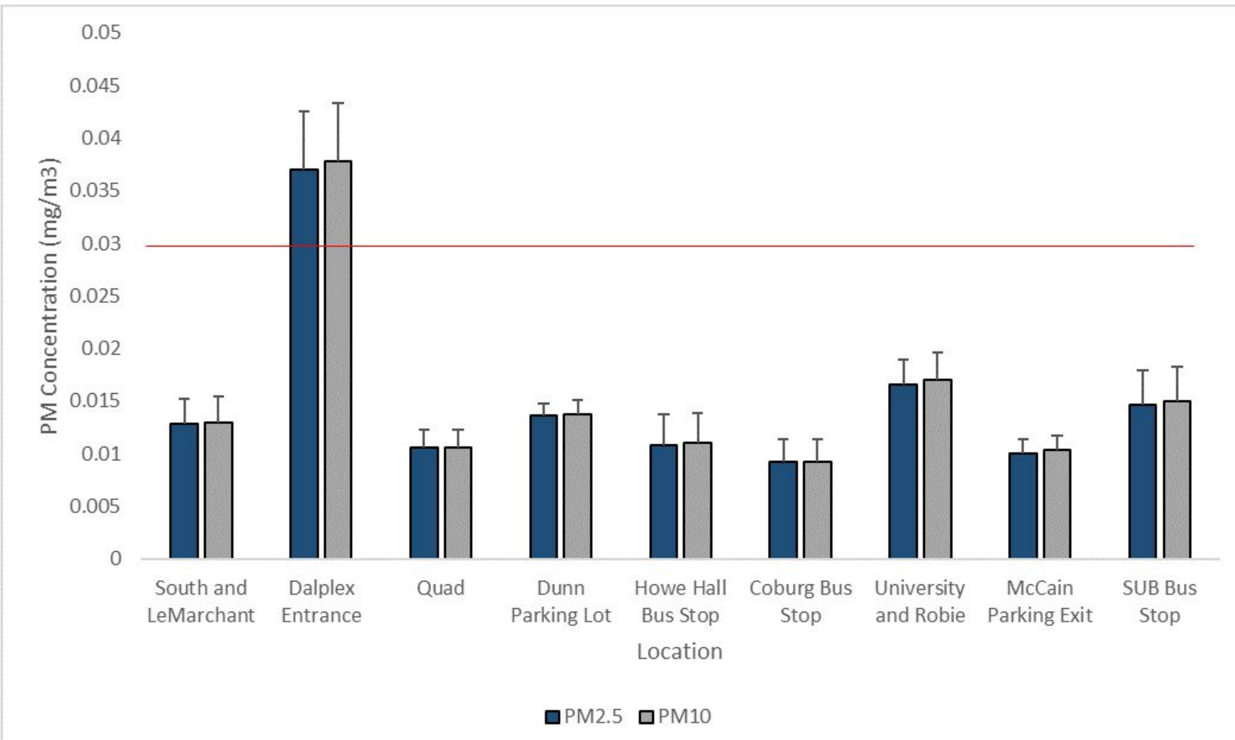

Figure 1 Total average PM10 and PM2.5 concentrations (mg/m^3) across various Dalhousie Studley Campus locations with SE bars and line indicating the acceptable 24 hour PM2.5 concentration

Figure 1 above expresses the total average particulate matter over the entire study for each location with the red line delineating the acceptable 24 hour PM2.5 concentration according to the CAAQ. As evidence by the graph, the Dalplex has noticeably higher PM2.5 and PM10 concentrations than all other locations. The Dalplex also exceeds the 24 hour CAAQ guidelines for PM2.5. When statistically analyzed, the Dalplex is statistically significant from all other groups at the PM2.5 concentration (f_8=9.22, p<0.001) and at the PM10 concentration (f_8=9.57, p<0.001). Following the same tests, no other location is statistically significant from each other. Both PM2.5 and PM10 have fairly similar values in all locations with a slight increase in PM10 concentrations at the Dalplex, Dunn Parking Lot, and at the corner of University Avenue and Robie Street.

Figure 1 explains the total averages over the course of the entire experiment and the following Figures 2 and 3 explain the differences between the busy (morning) and calm (evening) periods of traffic between all locations and at both particulate matter sizes.

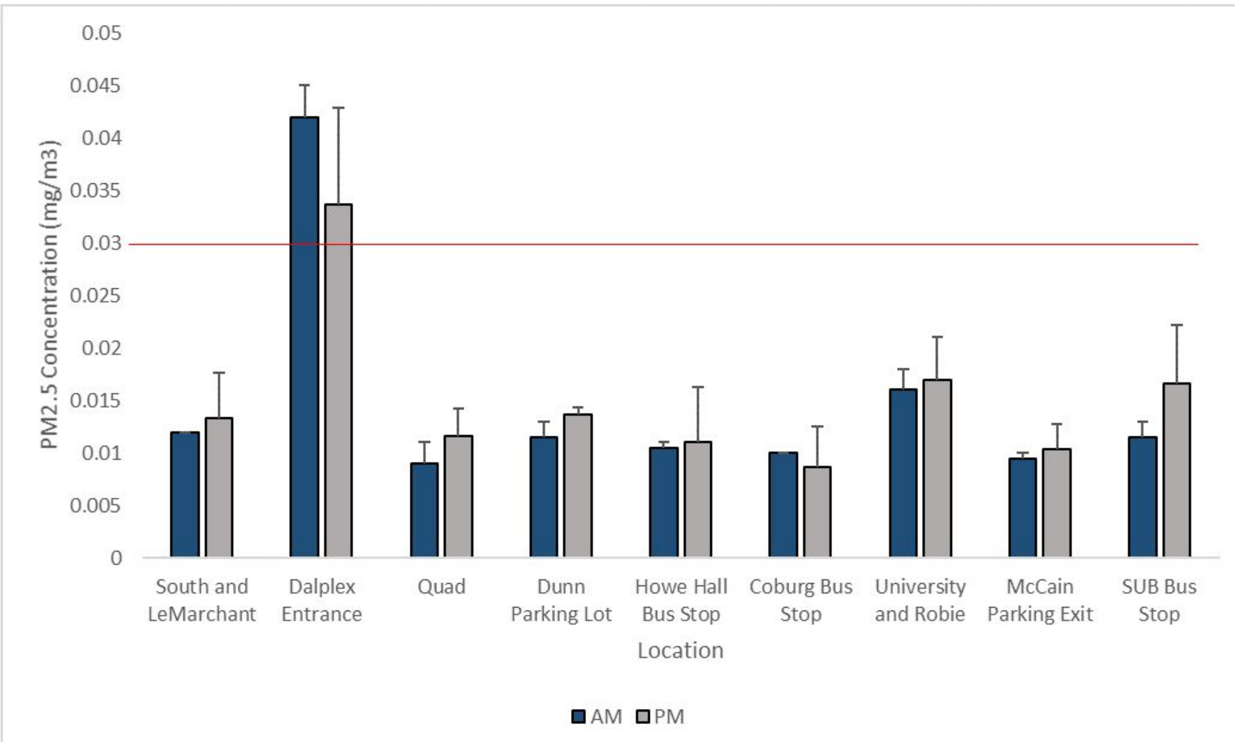

Figure 2 Average PM2.5 concentration (mg/m^3) across various Dalhousie's Studley Campus locations with SE bars and line indicating the acceptable 24 hour PM2.5 concentration

The PM2.5 concentrations between morning and evening hold similar trends to the total averages in Figure 1 with slight discrepancies; overall the Dalplex has a greater PM2.5 concentration than all other values than CAAQ guidelines, with all other locations being fairly homogenous to each other. After statistical analysis, the Dalplex differs significantly from all other locations in both the morning (f_8=44.69, p<0.001), but only differed significantly from the Coburg Bus Stop in the evening (f_8=2.46, p=0.054). This difference is likely due to the large amount of variation in the evening sample at the Dalplex and further samples may help to minimize this discrepancy. The concentration of PM2.5 particles differs noticeably between the morning and evening in some cases, particularly in the Dalplex, in the Quad, the Coburg bus stop, and the Student Union Building Bus Stop.

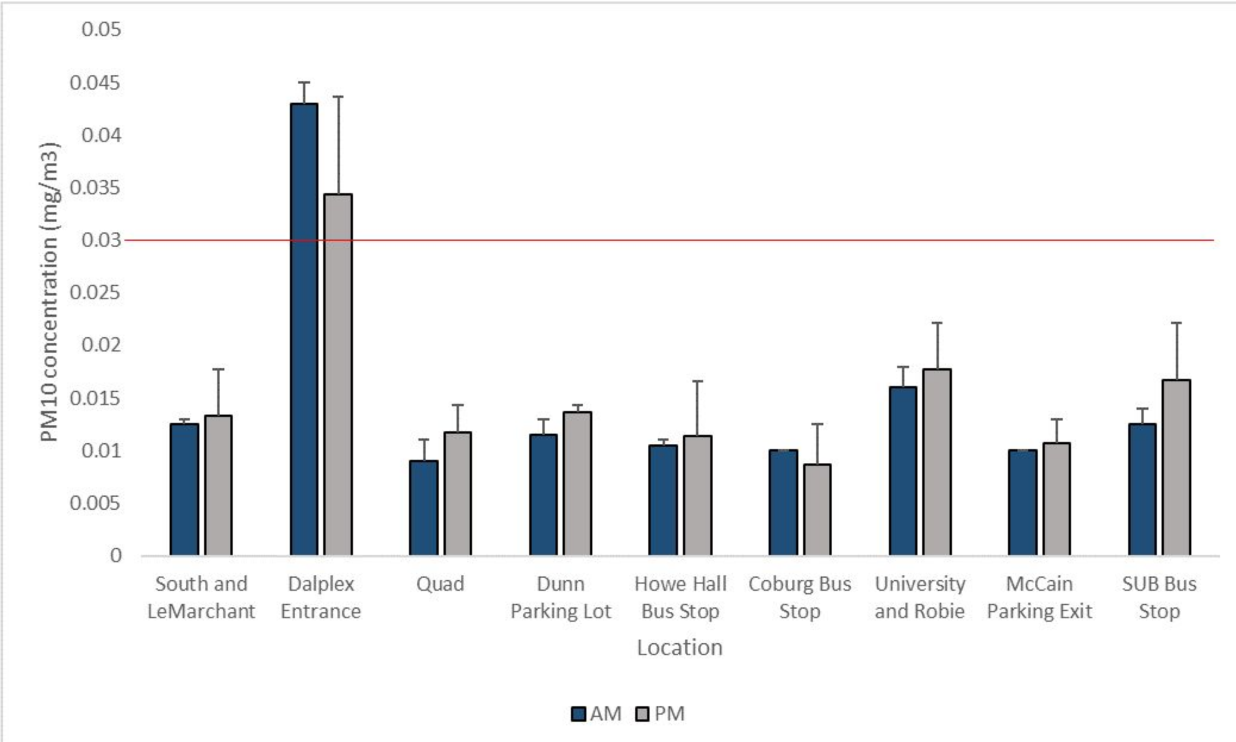

Figure 3 Average PM10 concentration (mg/m^3) across various Dalhousie Studley Campus locations with SE bars and line indicating the acceptable 24 hour PM2.5 concentration

The PM10 concentration, as displayed in Figure 3, between morning and evening keeps a near identical trend to the PM2.5 concentration in Figure 2. The Dalplex exceeds all other locations in the morning and evening as well as the CAAQ guidelines at 0.03 mg/m^3. When analyzed, the morning PM10 concentration differs significantly at the Dalplex from all other locations (f_8=60.6, p<0.001), but only differs significantly from the Coburg Bus Stop rather than all other locations in the evening (f_8=2.51, p=0.05). Similar to the PM2.5 concentration, this discrepancy is likely due to the large amount of variation within the evening PM10 sample. Differences between the morning and evening are less pronounced than in the PM2.5 concentration, but are still present especially in the Dalplex, Quad, Dunn Parking Lot, Coburg Bus Stop, Sub Bus Stop, and the corner of University and Robie.

Discussion

There were significantly higher concentrations of PM2.5 and PM10 in the Dalplex, compared to all other locations tested (f_8=9.22, p<0.001 and f_8=9.57, p<0.001, respectively). All other locations did not significantly differ from each other. It is interesting to note that areas that were expected to have higher air quality (i.e. lower PM2.5 and PM10 concentration), such as in the Studley Quad, did not differ in comparison to areas that were predicted as having worse air quality, such as the bus stops (Figure 1).

There were spatial factors that were expected to influence the results, but did not. Factors such as being near to streets did not appear to have a large effect on air quality. This can be seen when comparing the locations located near streets. The concentration of PM10 has been found to be high near streets that experience high traffic compared to other city locations (Boogaard et al. 2010). There were 6 locations located on main streets, only one of which, the Dalplex, had significantly higher PM concentrations. This could mean that vehicular emissions and movement did not influence air quality. Alternatively, it could mean that high traffic times were not accurately represented. Overall, nearness to street did not appear to impact particulate matter concentration as expected.

Another factor which was expected to influence PM2.5 and PM10 concentrations was vegetation cover. The Studley Quad (Appendix E), is surrounded by more vegetation than the other locations. Therefore, it was expected to have lower particulate matter. This is supported by previous literature which found that areas with more vegetation had lower particulate matter concentrations (Irga et al. 2015). In summary, locations and vegetation did not appear to influence particulate matter concentrations.

There were no drastic differences between traffic times in all locations except for the Dalplex (Figures 2 and 3). The PM2.5 and PM10 concentrations were significantly higher near the Dalplex during the morning than all other locations (f_8=44.69, p<0.001 and f_8=60.6, p<0.001, respectively). Slightly different results were found in the evening (Figures 2 and 3). Though the Dalplex appeared to have higher PM2.5 and PM10 concentrations, it was only significantly higher when compared to the Coburg Bus Stop (f_8=2.46, p=0.054 and f_8=2.51, p=0.05). This difference may be attributed to the small sample size, where the large variation found near the Dalplex evening concentrations may have skewed the data.

There did not appear to be a difference between PM2.5 and PM10 concentrations in the morning or evening. In addition, there was a lack of significant difference between all other locations, except for the Dalplex in the morning. This means traffic may not have played a huge role in determining air quality even though traffic has been found to contribute significantly to suspended particulate matter in urban areas (Barmpadimos et al. 2011). It is interesting to note that the second highest PM2.5, and PM10 concentrations were located at the University and Robie location (Appendix E), which does have higher traffic volumes than at the other locations. Overall, our results do not show any drastic difference between the morning and evening PM concentration levels.

The significantly higher particulate matter levels near the Dalplex may be attributed to the ongoing construction. The Dalplex is currently being expanded, and is undergoing large scale construction. Construction has been found to cause an increase in PM10 concentrations (Amato et al. 2009,), as well as PM2.5 (Wang & Fang 2016) relative to other areas in urban spaces. As well, the Dalplex did not significantly differ from all other locations except for the Coburg Bus Stop in the evening (Figure 3). Although no difference was seen between morning and evening particulate matter concentration. This slight discrepancy may be attributable to the particulate matter settling in the evening.

Another contributing factor to the higher particulate matter concentrations may be wind direction. Wind moves in a southwest direction in Nova Scotia. From Appendix E it is noticeable that the Dalplex is located at the south-west region of Studley campus. Therefore, particulate matter may accumulate more in that region. Previous studies have seen that wind direction does affect particulate matter concentration at different locations (Barmpadimos et al. 2011). In this study, the distances between the locations may not be expansive enough for wind direction to have a large impact. However, suspended particles from further high traffic areas may have travelled a south-west direction over time, and subsequently influenced the results.

The PM2.5 concentrations in the Dalplex location were higher than the CAAQ guidelines of 30 ug/m^3. However, since the values are very similar, more samples and further studies need to be conducted to determine whether the ongoing construction at Dalhousie is exceeding air quality standards. Furthermore, the set guidelines are for a 24hr average period. The data collected was not a 24-hour average. However, it is important to note that the Dalplex particulate matter concentrations were found to be higher than guidelines in both the morning and evening. This means that there is a realistic chance that the 24-hour average would have shown similar results. However, this was not tested for and more research needs to be conducted to provide evidence for this.

Air quality is an important issue to take note of on University campuses. They are centralized spaces, and high foot traffic areas. Many students are spending a considerable amount of time outside while travelling to classes, during breaks, or playing sports. Locations that have high particulate matter need to be more strictly monitored. Particulate matter has the potential to damage the health of students and faculty, who are on campus a considerable amount of time per week. Ideally more effort should be made to mitigate particulate matter suspension, and specifically target construction sites. One means of mitigation is the inclusion of increased urban green space. A high urban forest cover and green space have been linked to lowered suspended particle count (Irga et al. 2015).

Though our study had some limitations such as high precipitation and lack of time. It was found that there was poor air quality at a construction site on Studley campus. Therefore, there needs to be more green spaces, and increased monitoring as well as more mitigation techniques for air quality in construction areas at Dalhousie.

Conclusion

The conclusion of our project brought with it the opportunity to reflect on potential improvements to create a more complete analysis of the collected data and the project itself. Our data collection took place over the course of only five days, therefore it was restricted to only one season. As a means of gathering a more wholesome outlook on particulate matter trends on the campus, collecting air quality data throughout the year is key. Additionally, it would be proactive of Dalhousie's Environmental Health and Safety Office to remain vigilant of the seemingly heightened levels of particulate matter near to the Dalplex if they seek to abide by the air quality standards established by the CAAQS.

Regarding our findings, we have identified areas of additional research that would overall shed more light on our collected data. Further exploration of the climate trends and weather patterns that persist in Nova Scotia, specifically the Halifax peninsula, would allow for greater insight into the connection between atmospheric conditions and particulate matter concentrations. In relation to the latter area of research, deeper comprehension of prominent wind direction and patterns within the Halifax region would also play a major role in further interpretation of the collected data. As well, being aware of active construction sites within the city, as it is regularly developing and undergoing repair, would be of interest due to the link between construction projects and particulate matter in the atmosphere.

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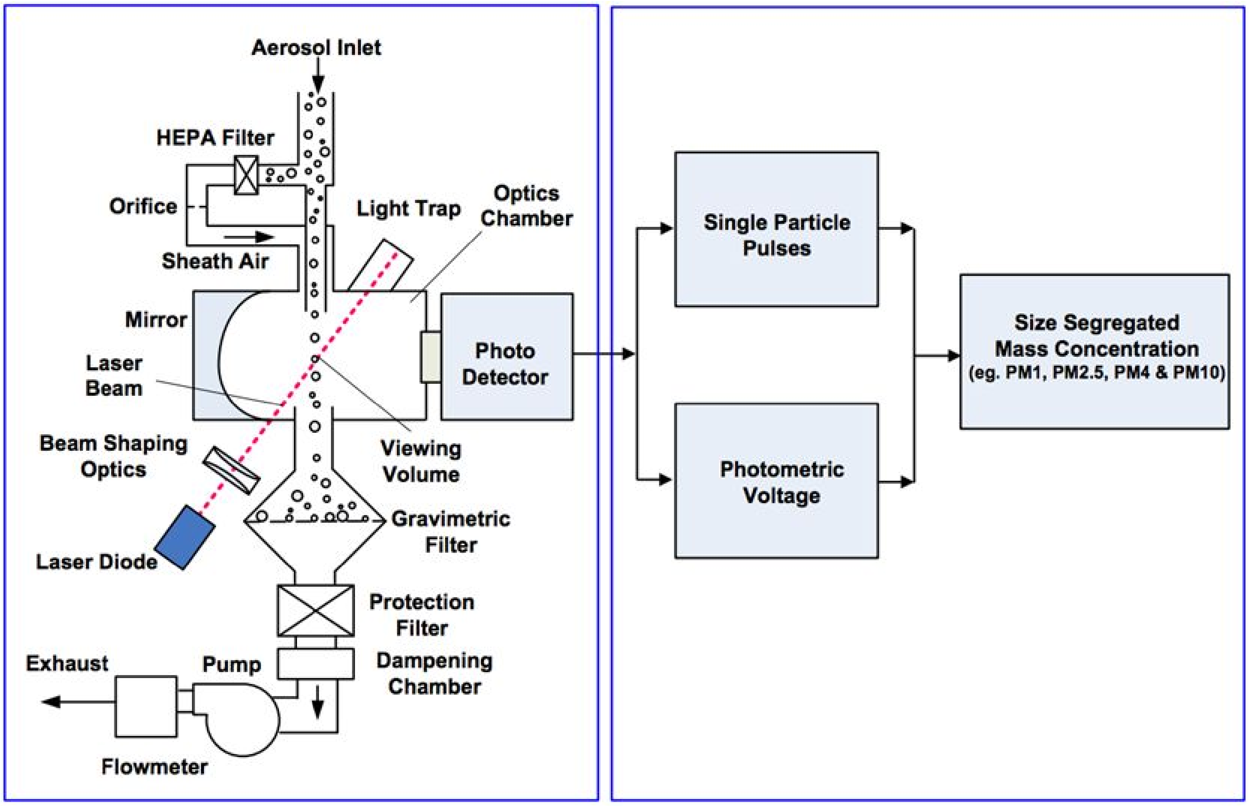
Appendices

Appendix A, DustTrak Monitor

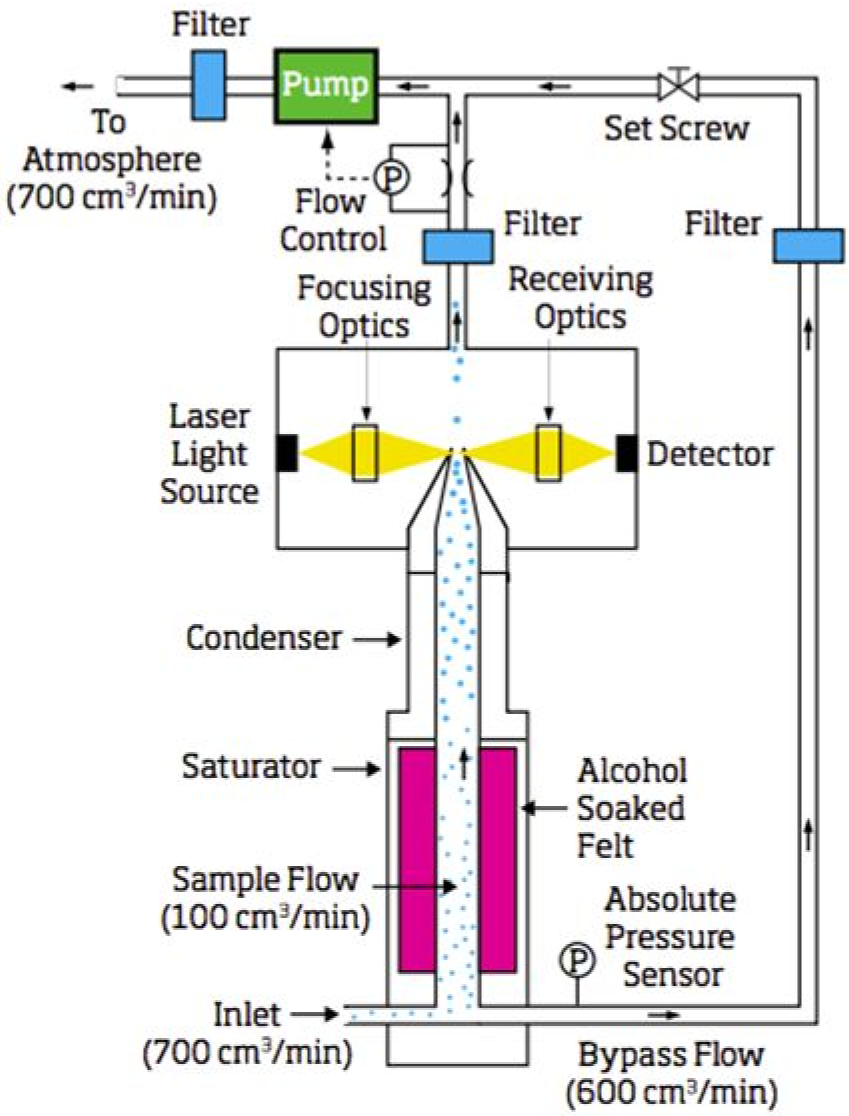
Appendix B, Condensation Particle Counter (CPC)


Model 3007
Condensation Particle Counter

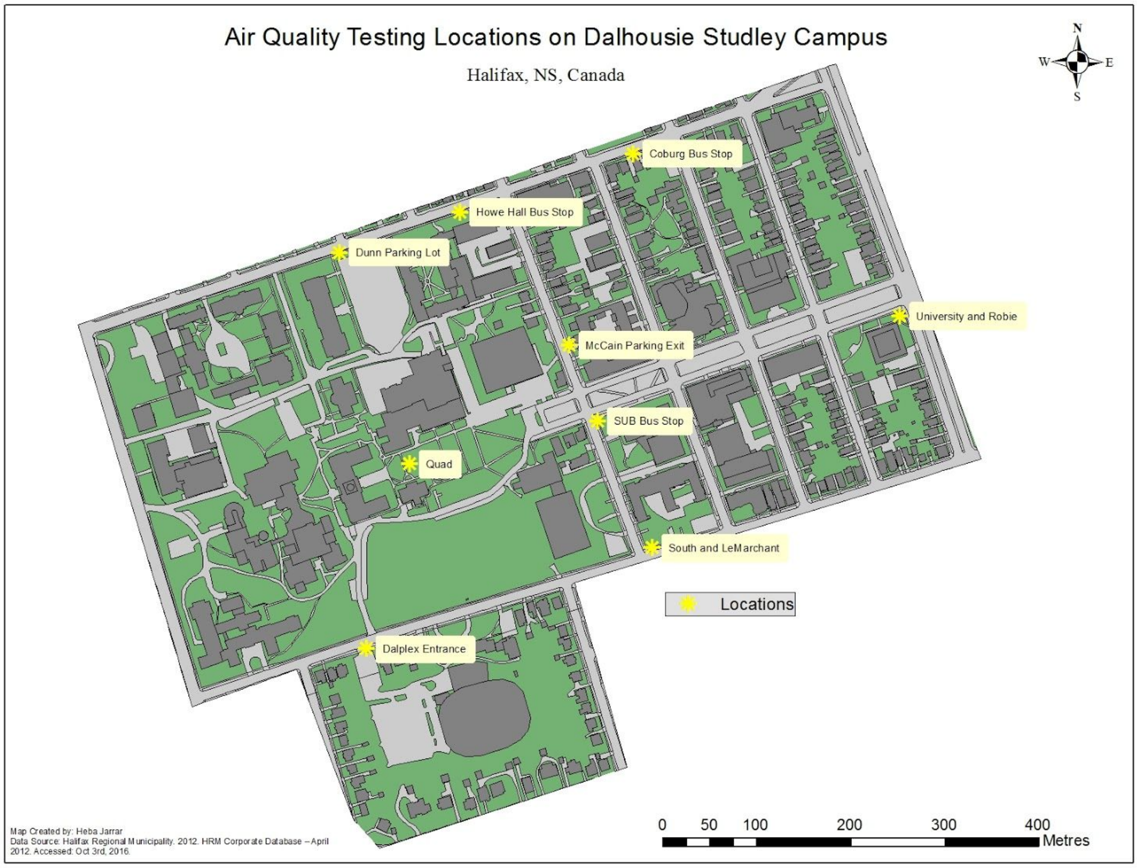
Appendix C, DustTrak DRK Theory of Operation
http://www.tsi.com/uploadedFiles/_Site_Root/Products/Literature/Application_Notes/EXPMN-002_DustTrak_DRX_Theory_of_Operation.pdf
Retrieved Apr 2, 2017



Appendix D, Condensation Particle Counter Theory of Operation (TSI, 2012) http://www.tsi.com/uploadedFiles/_Site_Root/Products/Literature/Spec_Sheets/3007_1930032.pdf Retrieved Apr 2 2017



Appendix E, GIS map of survey locations on the Studley Campus.



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