Traffic Flows and Black Carbon Monitoring in the Urban Seattle Environment

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FOR INTERNAL REVIEW ONLY

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Introduction

Seattle Metropolitan Area air toxics assessments propose that Diesel Particulate Matter (DPM) pose significant health risks to the community. DPM is a complex mixture of different materials, occurring from many sources, and currently there is not a specific monitor for it. A small network of Aethalometers™ measures black carbon (BC), which is a component of DPM.

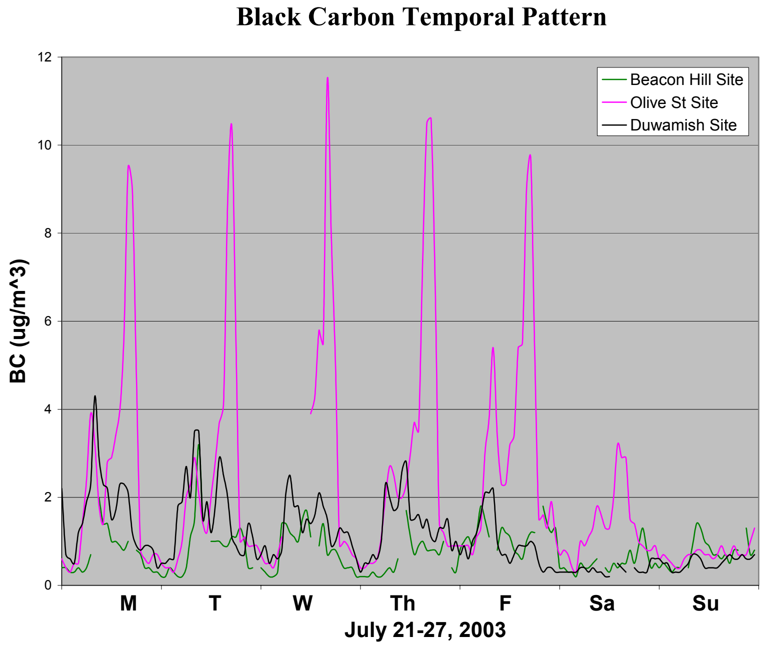

Figure 1. Black Carbon Temporal Patterns at Olive St, Duwamish, and Beacon Hill Site. BC data is from a PSCAA Aethalometer at 880nm.

A temporal BC pattern was found in prior analysis and its relation to traffic flows is being examined in this report. The Olive St. site represents the I-5 urban highway corridor, which has the highest traffic flows in the city of Seattle. The Duwamish site represents an industrial area that has a greater ratio of diesel vehicles than the highway corridor, and the Beacon Hill site is used as the urban background for Seattle. The distinctive pattern was thought to correspond to times of high traffic volumes.

Washington Sate Department of Transportation collects information on the state's transportation systems in order to provide data to be used for planning, maintenance and service enhancement.[1] The analysis of the information guides the decision-making process in the state, along with fulfilling federal requirements for transportation information. An integral portion of this data comes from Permanent Traffic Recorders (PTR) that collect data continuously. The network of highly resolved data provides for the correction factors needed to convert short count data to annualized values for sites that are similar to those with a PTR. The dominant factors to be accounted for are growth rate, seasonal and day of week variation, and axle correction factors to determine the types of vehicles using the highway. In trying to maximize resources and minimize error, WSDOT recommends taking short counts for 48-hour duration every three years at sites.[2]

The Seattle I-5 corridor is typical of an urban highway location with a peak Friday traffic volume and a Sunday low (See Figure 2). Meanwhile the Duwamish site is an urban work-related site that has mostly weekday traffic with vastly lower weekend flows. Therefore a weekly average traffic flow will hide the peaks and lows which can be a significant variation from an average value.

Typical Weekly Variation of Traffic Volumes

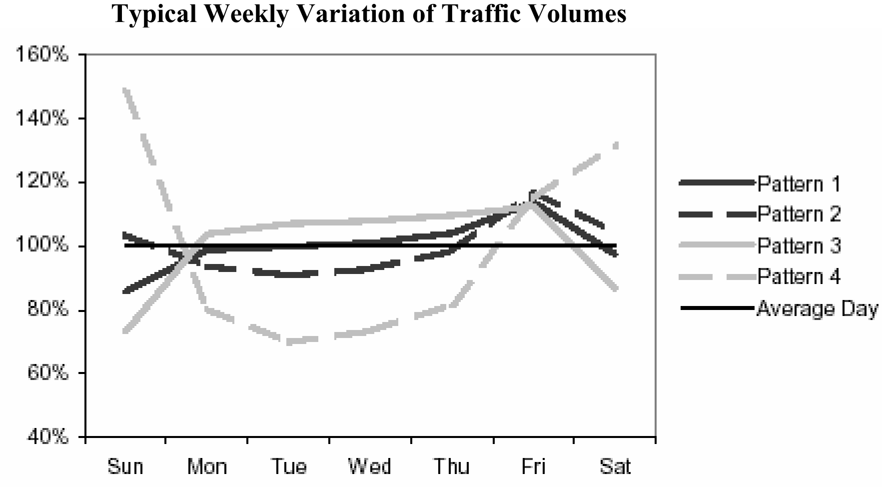

Figure 2. Daily Traffic as Percentage of Weekly Average Daily Traffic, Pattern 1: urban or rural highway, Pattern 2: rural with weekend recreation, Pattern 3: urban with work-related flows, Pattern 4: mountain passes and other recreation sites, Average Day: average taken from the entire week. Reproduced from WSDOT, Short Count Factoring Guide, June 2004, pg. 10.

Another influence on traffic flows is seasonal variation, which has a general pattern of below average during the winter and above average in the summer for Washington State. This correction is important since variation is found across the year depending on the type of roadway. Seattle would be represented by Pattern 1 on Figure 3.

Typical Seasonal Variation of Traffic Volumes

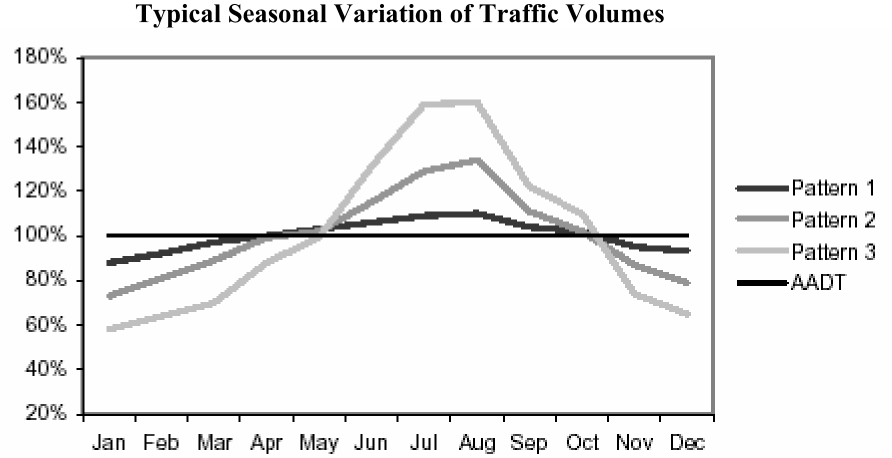

Figure 3. Monthly average daily traffic as a percentage of annual average daily traffic, Pattern1: urban/urbanized areas, Pattern 2: rural areas, Pattern 3: rural summer recreation areas AADT: annual average daily traffic. Reproduced from WSDOT, Short Count Factoring Guide, June 2004, pg. 15.

Method and Approach

Black Carbon

The Puget Sound Clean Air Agency monitors BC by using a Magee Scientific, Inc. Aethalometer™. The Aethalometer™ is a tape sampler that takes in air at a controlled flow rate, and then passes the air through a special glass fiber filter tape. As the pollutant accumulates, the Aethalometer™ measures the attenuation of light with the BC channel at 880 ηm. The light attenuation has been assigned a calibration factor that converts the attenuation information into micrograms per cubic meter (μg/m^3). A 5-minute average is determined and then recorded onto a data disk. The agency reviews, validates, and archives the BC data.

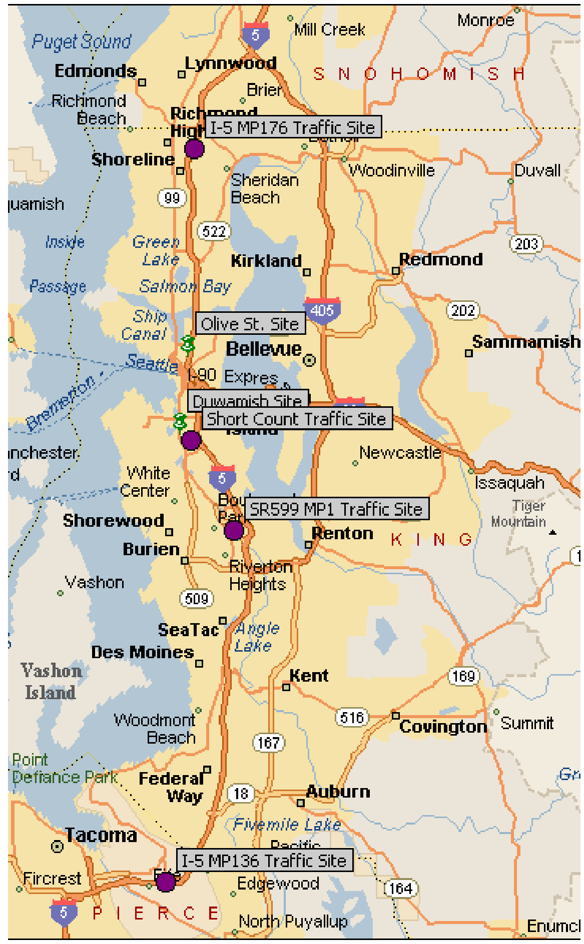

Figure 4. Map of Puget Sound Region.

Purple dots represent locations of WSDOT traffic sites and green pushpins represent PSCAA air monitoring sites.

Traffic

Data on traffic volumes and classification were obtained from Washington State Department of Transportation (WSDOT) Transportation Data Office's Automated Data Collection Network. Continuous data was available for two sites on I-5, at mile post (MP) 176 and 136, along with state route (SR) 599, MP 1. These locations are closest to the Puget Sound Clean Air Agency Aethalometer™ monitors at the Olive St. and Duwamish sites. Limited short count traffic data was available next (165 m north) to the Duwamish air monitoring site.

Volume is recorded by permanent inroad sensors that record volume and provide classification at the permanent locations. The classification scheme used is hourly or daily 4-bin, with vehicles sorted as passenger/light-duty, single-unit, double-unit, or triple-unit trucks.[3] This determination is based upon a vehicles length and axle number. Light-duty vehicles utilize gasoline as their fuel, while large trucks use diesel. Although there is some misclassification in the 4-bin scheme, it should be consistent and the Federal Highway Administration suggests that volume and classification equipment data is accurate to within 10%.[4] The short count traffic data was obtained by 4-hr manual counts over a three day period by WSDOT technicians.

Results

I-5 and Olive St.

Traffic data sets were compared with Aethalometer™ BC measurements to examine the relationship between peak measurements. A subset of hourly data was obtained for July 2003 for a refined analysis. Using WSDOT's data with 4-bin classification, traffic is defined as light-duty (bin 1) and diesel (bins 2-4) vehicles. Metropolitan traffic has a well-documented pattern based on weekday commuting and standard business hours, which creates changes between the weekdays and the weekend. These differences are also evident in light-duty versus diesel traffic patterns, yet traffic models tend to lump all traffic as the same.

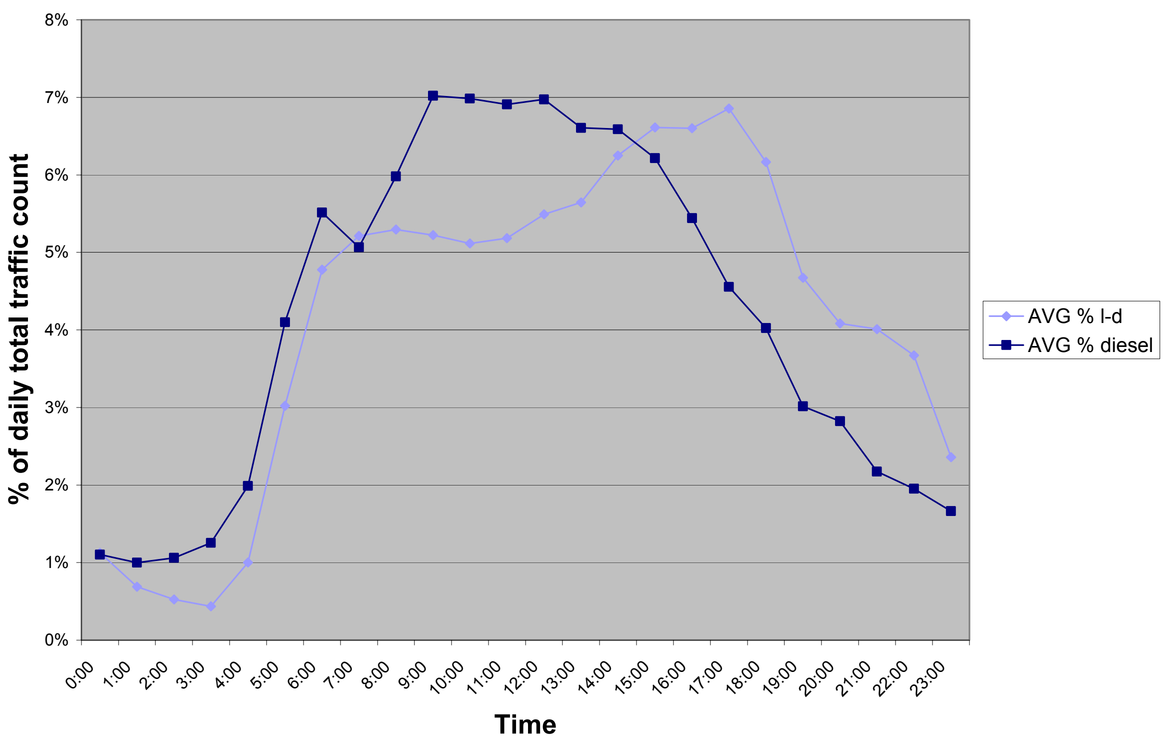

Figure 5. An average weekday hourly traffic pattern as a percentage of the total daily count. Based on hourly WSDOT traffic count data for I-5, MP176, traffic in both directions, from July 21-25, 2003. Traffic counts for each 1-hour interval were divided by the 24-hr total to give the percentage of the total daily count.

There is a difference in weekday traffic peaks depending on the vehicle class. Light-duty traffic tends to rise early in the morning, level off mid-day and then climbs to a peak at 5pm. Diesel traffic begins increasing earlier, peaks around noon and then smoothly drops off towards the late afternoon. Peak hourly traffic flows are about 7% of the daily total traffic count. These differing patterns represent vehicle use with light-duty being primarily used for commuting to work, while diesel is used for the actual work day.

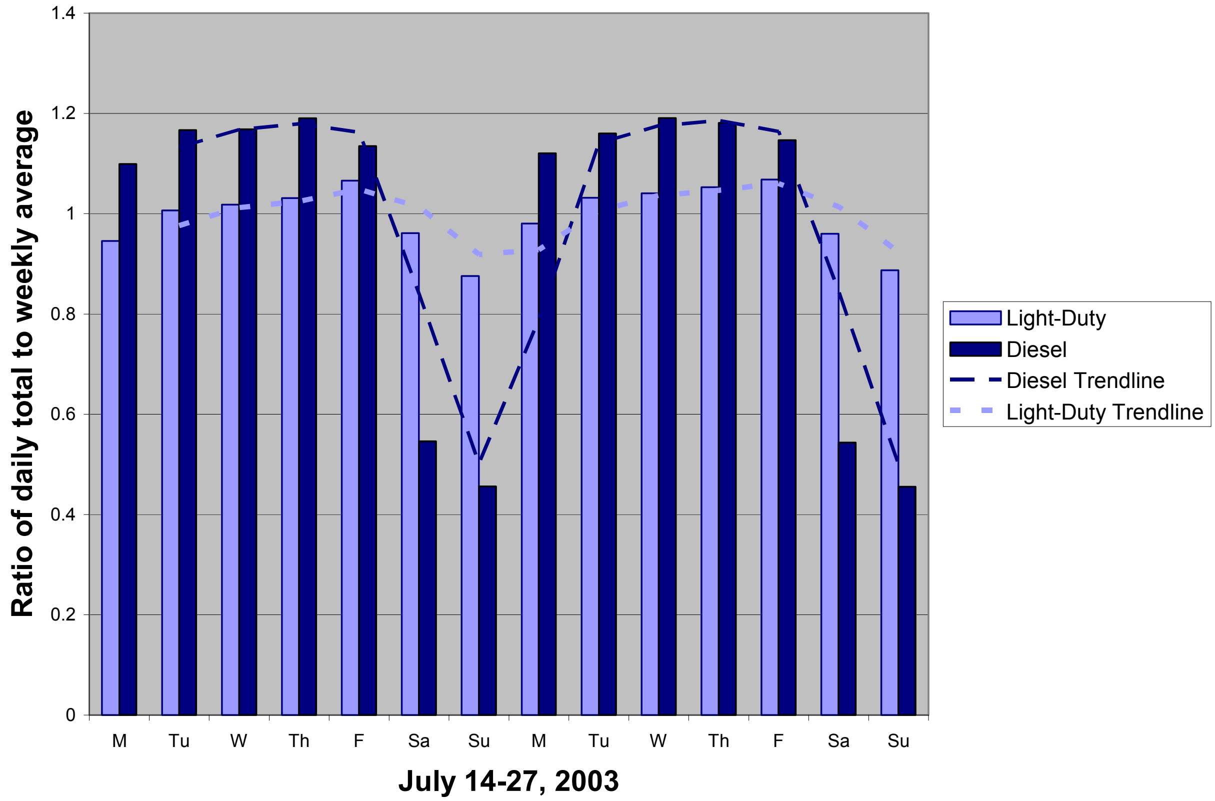

Figure 6. Ratio of daily total to weekly average traffic counts by vehicle class. The pink shaded areas denote Saturday and Sunday (weekend). Based on 24-hr WSDOT traffic count data for I-5, MP176, traffic in both directions, from July 14-27, 2003. Traffic counts for each day were divided by the July weekly average for each vehicle class. (Based on JAMA: 1998, 48, 352-358, Figure 1.)

The weekday/weekend patterns of light-duty and diesel vehicles are illustrated in Figure 2. Seattle I-5 light-duty traffic typically has a Friday peak and a Sunday low. The light-duty trendline demonstrates the small absolute change in light-duty traffic from Friday peak of 107% of the weekly average to a Sunday low of 88% in this typical two week period. Meanwhile, diesel vehicles experience a much greater absolute change with a mid-week peak of 119% of the weekly average to a Sunday low of 46%. During the weekend there is a significant drop in the amount of diesel traffic present on the I-5 Seattle corridor.

It is important to note that the overall traffic volume within the I-5 Seattle metropolitan area is dominated by light-duty traffic, as is consistent with other urban areas. In addition, the absolute number of vehicles is continuing to rise annually, since the region is still growing, with this expansion expected to continue for the foreseeable future.

Year	Annual Average Daily Traffic Volumes- bothways (Road/ MilePost/ Recorder #)		
	I-5/ MP176/ P3	I-5/ MP136/ S837	SR599/ MP1/S839
1994	165861	154182	32679
1995	165608	155467	30018
1996	168767	155974	31063
1997	176631	*	32738
1998	180522	*	34291
1999	182567	*	36255
2000	181031	178430	*
2001	186811	177412	*
2002	186310	179904	36794
2003	186852	179798	37748

* denotes no data available

Table 1. Annual Average Daily Traffic Volumes for 1994-2003. Traffic counts are from WSDOT TRIPS system automated data collection recorders urban stations report, traffic in both directions.[5]

The totals given in Table 1. are annual average daily volumes, therefore the actual weekday volumes are higher, while the weekend/holiday volumes are lower.

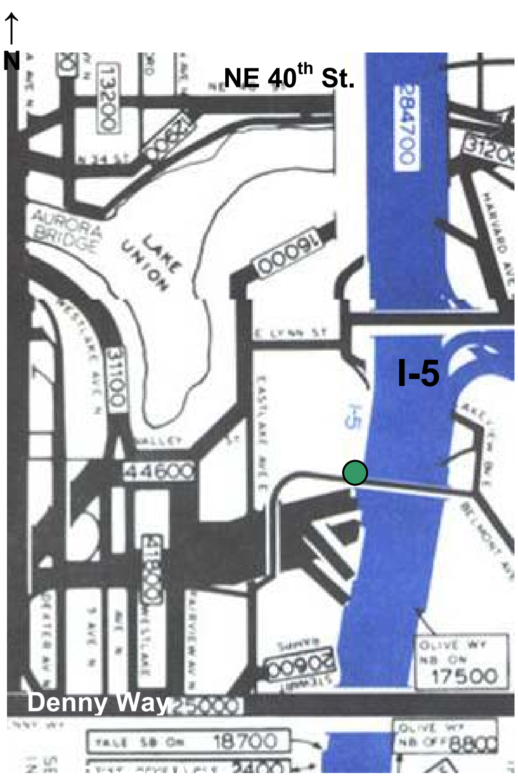

Figure 7 is a diagram of Seattle average annual daily traffic, with I-5 depicted as the wide blue line, with an average annual daily traffic (AADT) for 2003 estimated to be 284,700 vehicles/day. This area of I-5 contains the express lanes along several high use overpasses, which all contribute to the area traffic. The bottom border is defined by Denny Way with AADT of 25,000 vehicles/day. The top of the diagram is bounded by NE 40th St, just north of Lake Union and the I-5 bridge over the Montlake cut. The green dot gives an approximation of the location of the Olive St. air monitoring site, which is about 20 m from the southbound lane of I-5.

Figure 7. Map of Olive St. site at I-5 and Belmont Ave. The average annual daily traffic (weekday, 24-hr) for a section of roadway are given. Distance is not accurate. Adapted from 2003 Annual Average Traffic Flows by SDOT, http://www.ci.seattle.wa.us/transportation/images/03tfdgrid5.jpg

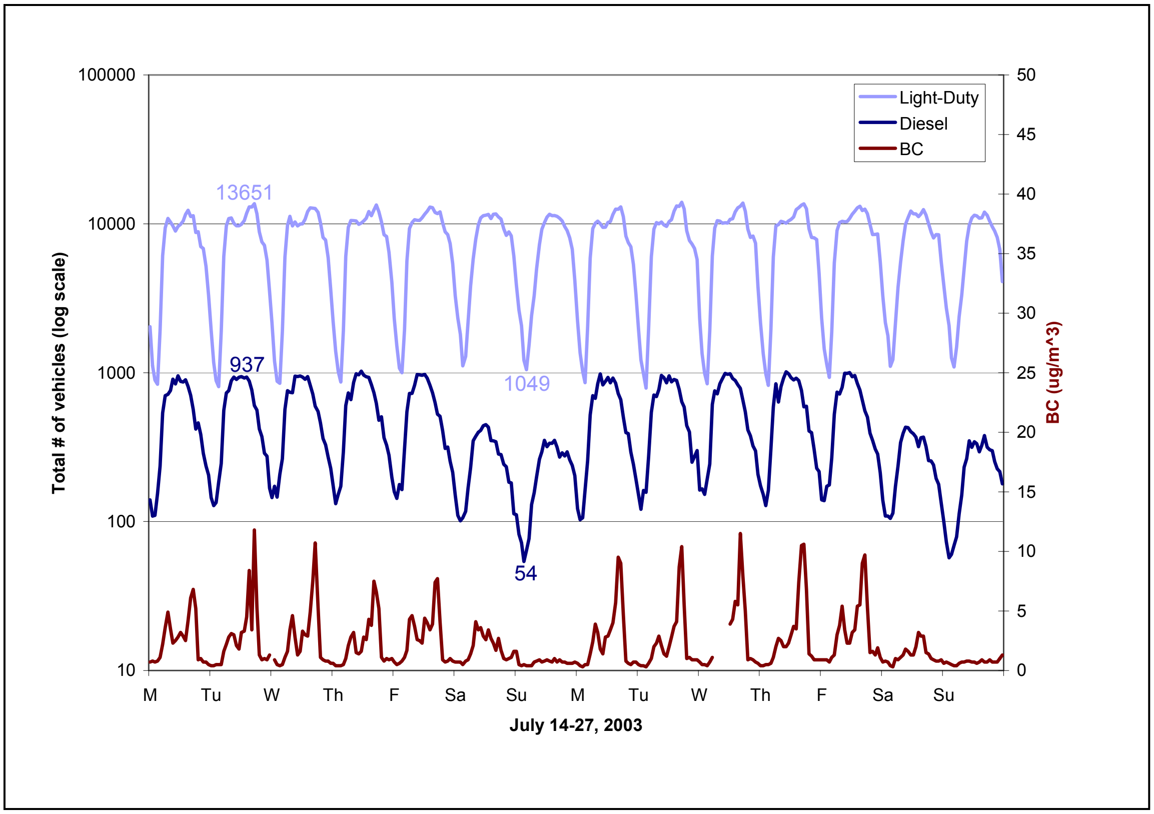

Figure 8. Log scale hourly diesel and light-duty traffic counts with black carbon (BC). The dark grey shaded areas denote Saturday and Sunday (weekend). Traffic counts based on hourly WSDOT traffic count data for I-5, MP176, traffic in both directions, from July 10-31, 2003. The BC data is from the PSCAA Aethalometer located at the Olive St. site located at MP166, approximately 20m from I-5.

The typical weekly pattern of traffic in absolute number by vehicle class with black carbon aerosol particles (BC) measurement from the Aethalometer is illustrated by Figure 3. The sine wave pattern shows how traffic decreases sharply during the late night hours, which is also demonstrated by the BC readings.

Note that the absolute number of vehicles is measured on the log scale with light-duty vehicles being an order of magnitude greater than diesel traffic. Light-duty traffic has peak weekday flows above 10,000 vehicles per hour, while diesel traffic has around 1000 vehicles per hour. BC tends to peak during weekdays with traffic peaks and then has a sharp reduction during the weekend. This reduction corresponds to the significant decrease in diesel traffic that occurs during the weekend.

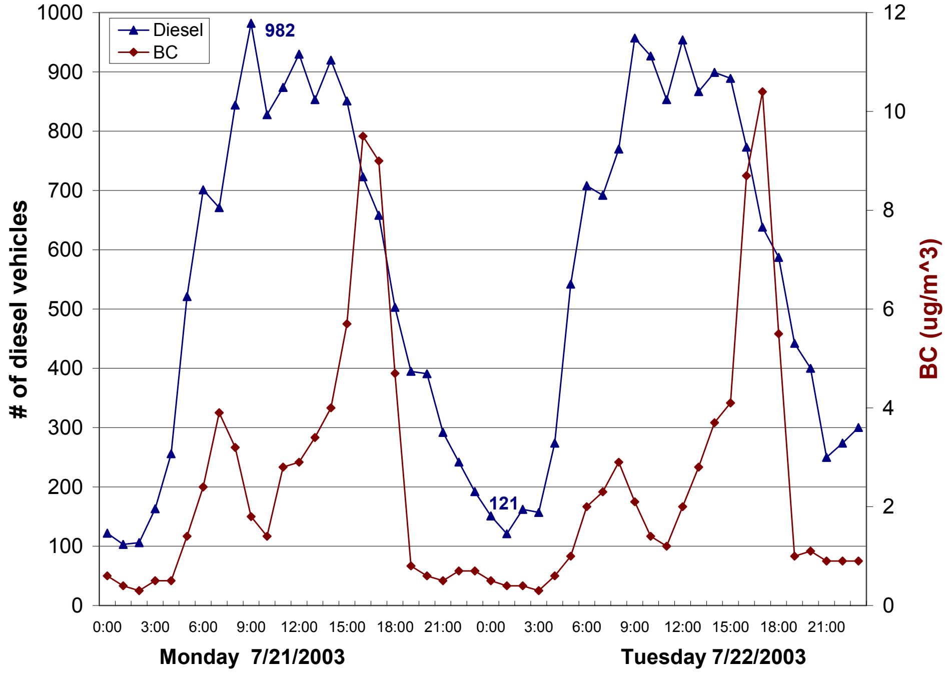

Figure 9. Overlay of weekday hourly diesel counts with black carbon (BC). Pink shaded areas are BC > $5\mu g/m^3$. Traffic counts based on hourly WSDOT traffic count data for I-5, MP176, traffic in both directions, from July 21-22, 2003. BC data is from the PSCAA Aethalometer, Olive St. site.

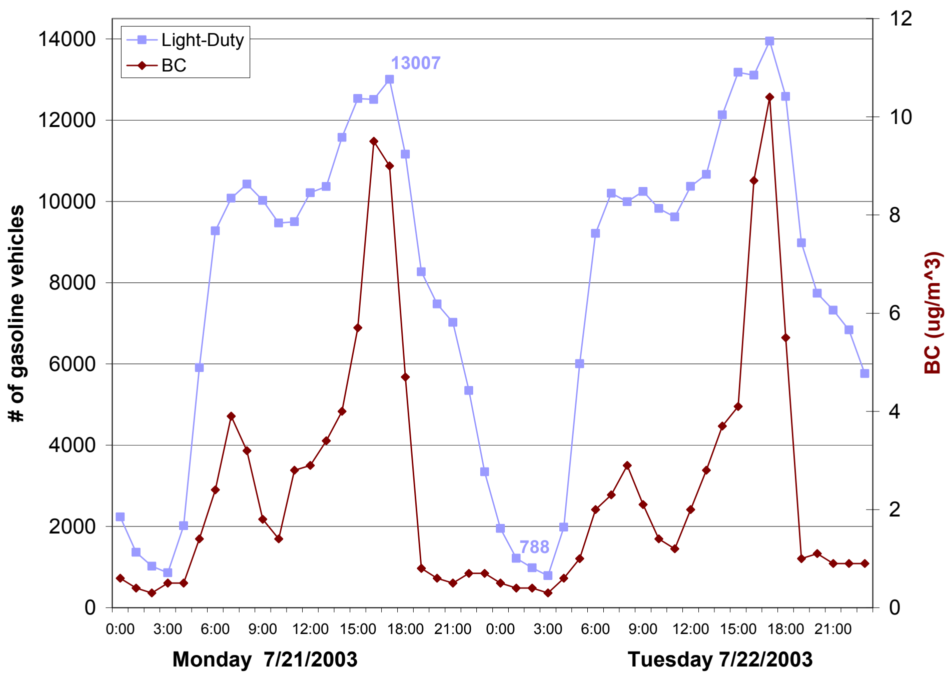

Figure 10. Overlay of weekday hourly light-duty counts with black carbon (BC). Pink shaded areas are BC > $5\mu g/m^3$. Traffic counts based on hourly WSDOT traffic count data for I-5, MP176, traffic in both directions, from July 21-22, 2003. BC data is from the PSCAA Aethalometer, Olive St. site.

Figure 4 and 5 illustrate peak BC readings with weekday traffic counts divided by vehicle class. Peak BC measurements occur during afternoon rush hour, 4-6:00pm, with a distinctive lower peak during morning rush hour, 6-9:00am. There is a better correlation with the light-duty traffic peaks and BC peaks (>5μg/m^3) than with the diesel traffic. Note that the left-hand axes, number of vehicles, are depicting different scales. Figure 9 has a peak diesel vehicle of 982, while Figure 10 has a peak of 13,007 gasoline vehicles.

This may be a function of the difference of vehicle number, with overall July weekday traffic consisting of approximately 93% light-duty vehicles. The light-duty traffic flows during peak vehicle times might overwhelm the contribution of diesel vehicles to black carbon readings. During the weekend BC readings are below 4μg/m^3 and the traffic pattern for both light-duty and diesel is more variable, with the absolute number of diesel vehicles much reduced from weekday totals.

SR99 and Duwamish

The Duwamish air monitoring site is located in an industrial area of town that was thought to have a greater percentage of its traffic from diesel vehicles. The nearest permanent traffic recording site is located several miles south on SR599, it does demonstrate a different traffic profile than I-5. The average daily volume is significantly less (see Table 1.) and the percentage of traffic that is diesel is slightly higher.

Figure 11 is a diagram of Seattle average annual daily traffic in the Duwamish industrial area. The region shown includes Spokane St. running east/west where it becomes the West Seattle Bridge, with AADT between 107,600 and 79,600 vehicles depending on input into the viaduct. The major north/south roadway is the Alaskan Way Viaduct, which splits just south of Spokane St. to form E. Marginal Way with 59,300 vehicles/day and 1st Ave S with 14,600 vehicles/day. The green dot gives an approximation of the location of the Duwamish air monitoring site, which is about 10 m from East Marginal Way.

Figure 11. Map of Duwamish Site at E. Marginal Way. The average annual daily traffic (weekday, 24-hr) for a section of roadway are given. Distance is not accurate. Adapted from 2003 Annual Average Traffic Flows by SDOT, http://www.ci.seattle.wa.us/transportation/images/03tfdgrid8.jpg

WSDOT uses a method called short counts in order to get an understanding of traffic flows without using permanent in road sensors. Short counts can consist of temporary sensors, often induction tubes, or physical counts by trained technicians. The data-gathering period generally consists of a few days and then this information is used to extrapolate annual averages. A short count was performed in April of 2004, about 50 m from the Duwamish site. On three consecutive weekdays, two technicians counted three separate four-hour intervals.

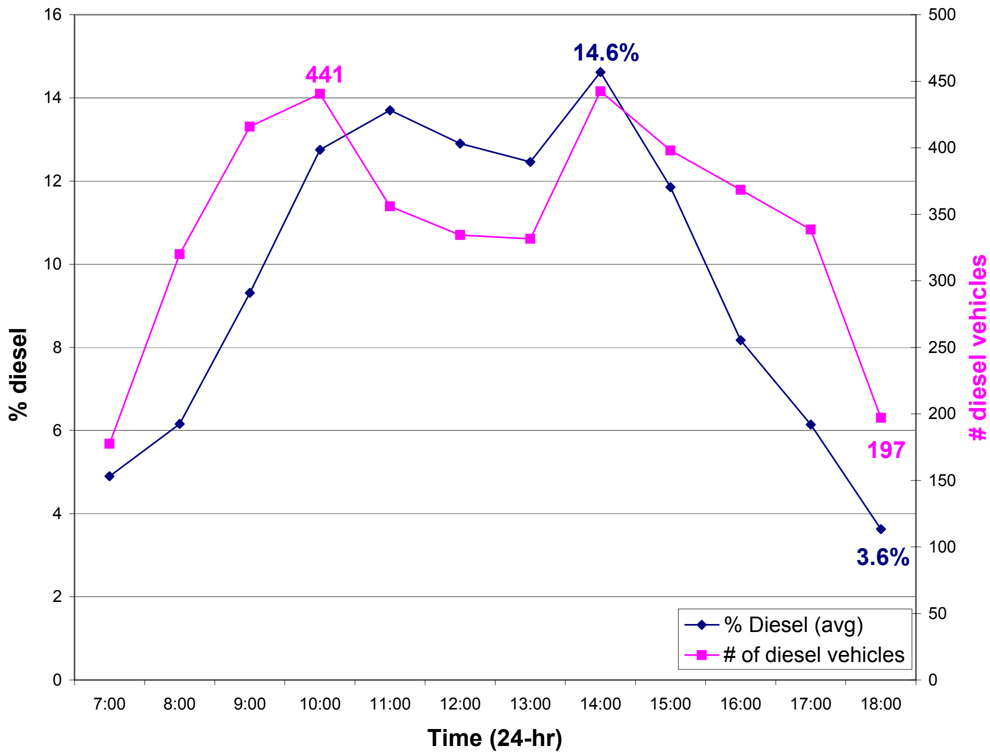

Figure 12. Short count Diesel weekday hourly traffic as a percentage of the total hourly count. Based on hourly WSDOT traffic count data for SR99, MP28, interval counts from April 27-29, 2004. Traffic counts for each 1-hour interval were averaged from counts from two technicians.

The data is limited but it does show a much higher percentage of the traffic flow to be diesel, along with the volumes being time sensitive. The diesel traffic pattern is consistent with Figure 1. The Duwamish industrial area had 12-14% peak diesel traffic, while the I-5 corridor had peaks between 5-7%. The overall volume is decreased, with peak flows above 400 diesel vehicles per hour at the Duwamish, as opposed to 1000 diesel vehicles per hour at the Olive St. site.

Discussion

WSDOT maintains traffic volume data in order to understand the state's traffic flows for maintenance and planning needs. It has little need for many permanent recorders that are necessary for fine enough resolution needed for comparisons with air monitoring data. The current locations of PSCAA monitors do not correspond with many of the WSDOT recorders.

The I-5 traffic corridor is a microscale monitoring site represented by the Olive St. BC data. The traffic volumes and BC readings correlate well, supporting the hypothesis that traffic is a major contributor to $PM_{2.5}$ at the site. Mobile source air pollution modeling would benefit from refining the contribution from diesel vehicles to differ from that of light-duty vehicles, as shown in Table 1.

The Duwamish traffic data lacks the resolution of the I-5 permanent recorder. It does illustrate that there is a measurable amount of black carbon that correlates with the temporal traffic pattern. The distribution of traffic, as described by the percentage of diesel versus gasoline vehicles of the total traffic, is made up more heavily of diesel vehicles at the more industrial site.

More information on the relationship between diesel $PM_{2.5}$ and diesel BC data would be useful in being able to separate the diesel contribution from other ambient sources. Further research using the Aethalometer™ could help to illuminate the diesel contribution to black carbon air monitoring data.

Endnotes:

[1] WSDOT, Short Count Factoring Guide, June 2004, pg. 1.
http://www.wsdot.wa.gov/mapsdata/tdo/PDF_and_ZIP_Files/ShortCountFactoringGuide2004_external.pdf

[2] WSDOT, Short Count Factoring Guide, June 2004, pg. 13,
http://www.wsdot.wa.gov/mapsdata/tdo/PDF_and_ZIP_Files/ShortCountFactoringGuide2004_external.pdf

[3] WSDOT, Short Count Factoring Guide, June 2004, pg. 21.
http://www.wsdot.wa.gov/mapsdata/tdo/PDF_and_ZIP_Files/ShortCountFactoringGuide2004_external.pdf

[4] WSDOT, Short Count Factoring Guide, June 2004, pg. 28.
http://www.wsdot.wa.gov/mapsdata/tdo/PDF_and_ZIP_Files/ShortCountFactoringGuide2004_external.pdf

[5] WSDOT. 2003 Annual Traffic Report, 2003.
http://www.wsdot.wa.gov/mapsdata/tdo/PDF_and_ZIP_Files/Annual_Traffic_Report_2003.pdf