



## **APPENDIX AVAILABLE ON WEB**

### **Research Report 138**

#### **Health Effects of Real-World Exposure to Diesel Exhaust in Persons with Asthma**

#### **Appendix E. Pilot Study to Support the Selection of Diesel Exhaust Exposure Site and Control Site**

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Note: Appendices Available on the Web appear in a different order than in the original Investigators' Report. HEI has not changed these documents. Appendices were relettered as follows:

Appendix E was originally Appendix B  
Appendix F was originally Appendix C  
Appendix G was originally Appendix D  
Appendix H was originally Appendix E

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## APPENDIX B: PILOT STUDY TO SUPPORT THE SELECTION OF DIESEL EXHAUST EXPOSURE SITE AND CONTROL SITE

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### OBJECTIVES

We have proposed to study the health effects of diesel exhaust in asthmatic patients under real-world conditions in London, UK. The proposed study consists of one exposure session and one control session, each of 2-hr duration, for each study subject. The exposure sessions were to be conducted on Oxford Street where only pedestrians, diesel-powered buses and diesel-powered taxicabs are permitted. The control sessions were to be conducted in Hyde Park where motor vehicles are prohibited. The locations of Oxford Street and Hyde Park are shown in Map 1. To conveniently implement the study, we planned to conduct all sessions during 10:00 – 14:00 on non-rainy weekdays in winter months when pollen levels are low.

To verify the feasibility of the study, we measured ambient concentrations of  $PM_{2.5}$  and elemental carbon (EC) on Oxford Street and in Hyde Park for two weeks in November 2001. EC concentrations were measured because EC can serve as a proxy for diesel exhaust particles (DEP). Specifically, we collected the data to: (1) define areas and walking paths of the exposure and control sites, (2) verify that EC levels were sufficiently higher at the exposure site than at the control site, (3) verify that the planned session hours are appropriate in terms of DE levels, (4) examine day-to-day variations in  $PM_{2.5}$  and EC at both sites, and (5) evaluate the usefulness of a high-flow personal  $PM_{2.5}$  sampler to measure integrated  $PM_{2.5}$  and EC concentrations during the 2-hr exposure and control sessions.

## **METHODS**

The measurements were carried out from November 12 (Monday) through November 23 (Friday), 2001, excluding November 18 (Sunday), on a daily basis. Two types of measurements were made including (1) PM<sub>2.5</sub> and EC measurements using 37 mm quartz fiber filters and (2) real-time EC measurements using an Aethalometer.

### **Sampling Locations**

Measurements on Oxford Street were taken primarily from a single location. The location was from within a locked, steel cage (see Map 2, Point 4) located about 1 foot from the curbside of Oxford Street. The cage was protected by a barricade surrounding it, which encompasses an area approximately 36 square feet (6 ft. x 6 ft.). This steel cage, used by the City of Westminster to protect its own PM<sub>10</sub> sampler, was located within the planned walking area (between Orchard Street and Regent Street) for the exposure sessions. To define the walking paths for the study, we monitored EC concentrations using the Aethalometer on Oxford Street from near the Marble Arch area (Map 2, Point 3) all the way to New Oxford Street, about 5 blocks east of Regent Street (Map 2, Point 2).

The control sessions were to be conducted in the central part of Hyde Park, in the west side. The park is suited approximately 1 mile from the base hospital of the study (Royal Brompton Hospital) and 1 to 1.5 miles from Oxford Street. The park is huge in size with 635 acres. Motor vehicles are not permitted to travel within the boundary of the park except on a road (West Carriage Drive) crossing the middle of the park (see Map 3). We collected samples from both sides of this road, along the dotted lines connected to Point B in the west side and near Point C in the east side. At Point C,

there was a cage very similar to the one used on Oxford Street. This was the location used by the City of Westminster as the (urban) background  $PM_{10}$  site. Point C is between the Physical Energy Statue and the Round Pond.

### **Real-time EC Measurement**

Elemental carbon was measured using an aethalometer (Model AE-41, Magee Scientific, Berkeley, California, USA). Using an internal pump, the aethalometer continuously drew particulate laden air through a tape made up of quartz fiber filter. The particulate matter was then trapped on the filter tape, where an infrared beam of light, with a wavelength of 880 nm, determines the concentration of the black carbon by measuring the 'blackness' of particulate matter deposited. The infrared light was transmitted through the quartz fiber filter tape, where the PM sample had been deposited, and the attenuation was measured. The measured attenuation was directly proportional to the loading of the black carbon on the filter tape. The real-time measurements taken were the average of every 5 minutes. The monitor automatically calculated the concentrations detected using algorithms pre-programmed at Magee Scientific. For this purpose, an assumed constant flow rate of 5 L/min was programmed into the equations. However, we corrected the concentration data using the actual sampling flow rates that were measured using a primary flow meter (Drycal DC-Lite, SKC Inc., Eighty Four, PA, USA). The data were stored on a 3.5" floppy diskette and were readily imported into Microsoft Excel.

### **$PM_{2.5}$ Mass Concentration Measurement and EC Analysis**

We used a high-flow personal  $PM_{2.5}$  sampler (HFPS) to collect  $PM_{2.5}$  (Adams, et al, 2001). The sampler used a porous polyurethane foam for size selectivity, 37 mm quartz

fiber filter, and a Vortex Ultra Flows (Casella, UK) pump capable of sampling at 16 L/min with flow rate change typically less than 5%. The flow rate was measured using a Gilibrator Flow Calibrator (Gilian Instruments, FL). This allowed us to make short-term (e.g., 1 to 2 hours) PM<sub>2.5</sub> measurements. The limiting factor to this sampling technique lied mainly in the pump. The Vortex is equipped with a very heavy battery providing a great burden to the operator. The lifetime of the battery when the pump was operated at such a high flow rate was no longer than 3 hours. During our sampling period in Hyde Park, the pumps lasted 2.2 hours on average, therefore, we carried two pumps with us, and when the first pump's battery was exhausted, we changed pumps. Our sampling period was over when the second pump was finished. While sampling at Oxford Street, the pump was plugged in and placed in the sampling cage; therefore, these limiting factors were not a problem. In addition to the collection of PM<sub>2.5</sub>, these filters were used for the analysis of EC. The quartz filters used were all pre-heated in an oven at 680 °C for 1.5 hours to remove any organic contaminants present on the filters. The filters were pre-weighed on a Metlar-Toledo microbalance (sensitivity: 1 µg) (Metlar-Toledo, Greifensee, Switzerland), equipped with an ionizing blower to eliminate electrostatic effects, after 24-hour equilibration in a constant temperature/humidity weighing room. The filters were stored in small Petri dishes and then brought to the field. After sampling, the filters were removed from the sampling heads and replaced in the original Petri dishes. Two field blank filters were taken. Post-sampling weighing was conducted in the same weighing room as the pre-sampling weighing. Prior to post-weighing, the filters were placed in the weighing room for 24 hours.

Carbon contents of PM<sub>2.5</sub> collected on the quartz fiber filters were analyzed at a Rutgers University lab using a thermal/optical carbon analysis technique (US NIOSH Method 5040). This analyzer had a two-tiered burn program. The high-temperature burn, in the presence of helium, burned all the organic materials. The second burn, in the presence of oxygen, burned the elemental carbon. Prior to analysis, a system cleaning method was performed to ensure there would be no contamination of the samples. After the cleaning method, two system blanks were run. Also, the final step at the end of every sample analysis was the automatic injection of a known concentration of methane gas, used as an internal standard reference. In order to ensure consistency in the size of samples, we used a 1cm<sup>2</sup> punch. This punch cut a square, exactly the same size every time.

## **RESULTS AND DISCUSSIONS**

### **Comparison of Aethalometer EC and Quartz Filter EC**

Thirteen 2- to 4-hr integrated quartz filter samples were taken on Oxford Street and two were taken in Hyde Park with collocated aethalometer measurements. To compare the collocated quartz filter EC concentrations and aethalometer EC concentrations, we calculated time-averaged aethalometer concentrations for the same durations of quartz filter samples. We found that the two methods were highly correlated ( $R^2 = 0.93$ ) (see Figure B1). The regression equation is as follows:

$$\text{Aethalometer EC} = 0.774 (\text{quartz filter EC}) + 1.233$$

Some early studies conducted in various urban and non-urban locations also found that aethalometer EC (or BC- black carbon) data and quartz fiber EC (thermal EC) data were highly correlated but the slope was not 1 (Babich et al, 2000). Our results indicate that the aethalometer appeared to underestimate EC at higher concentrations (above  $5.5 \mu\text{g}/\text{m}^3$ ) and overestimate EC at lower concentrations (less than  $5.5 \mu\text{g}/\text{m}^3$ ) in central London. This finding confirmed one of the major limitations of aethalometer in measuring aerosol EC concentrations: the instrument needs to be calibrated with site-specific aerosols to get accurate measurements. Since the aethalometer was manufacturer calibrated with reference materials, we have corrected all the aethalometer EC data using the above regression equation.

### **Spatial EC Variation and Walking Paths Selection**

On Oxford Street, we observed that the aethalometer real-time EC concentrations decreased rapidly when walking west of Orchard Street and east of Regent Street (see Map 2). For example, in the morning of November 21, the EC concentration (uncorrected aethalometer reading) was about  $2.5 \mu\text{g}/\text{m}^3$  a few blocks east of Regent Street, whereas, at a spot between Regent and Orchard, it was about  $10 \mu\text{g}/\text{m}^3$ . This finding was consistent with our visual observations that the diesel fuel traffic density was substantially higher between Orchard and Regent. Therefore, the study subjects were to be restricted to walk up and down Oxford Street between Orchard Street and Regent Street during their exposure sessions.

With only one aethalometer available and due to the overwhelming burden of carrying multiple high flow pumps, we were unable to measure EC or PM at both points B and C on the same days in Hyde Park (Map 3). Therefore the interpretation of the

following results was somewhat speculative. The EC concentration measured near Point C was  $5.67 \mu\text{g}/\text{m}^3$  (average of collocated quartz fiber filter and time weighted average aethalometer corrected data) in the morning of November 16 (Friday), whereas, the EC concentration near Point B was  $3.47 \mu\text{g}/\text{m}^3$  (time weighted average of 6 day quartz fiber filter sampling analysis results). It is expected that EC levels would be higher at Point C than at Point B, because Point C was closer to vehicular traffic. In addition, a small police building nearby Point C draws some traffic, which may affect the EC concentration. Therefore, we decided to use the area indicated by the dotted lines on Map 3 as the defined walking paths for the study subjects during their control sessions.

### **Diurnal EC Variation**

Thanks to the access to the monitoring site (cage) of the City of Westminster on Oxford Street, we were able to measure EC using the aethalometer continuously throughout the 24-hr period for three days (November 21, 22, and 23). The diurnal EC patterns on these days are overlaid in Figure B2. The daily patterns were similar with lowest EC concentrations occurring during late night hours and highest EC concentrations occurring between 7:00 – 16:00 (4:00 pm). In Hyde Park, due to the short battery life (about 3 hours) of the aethalometer and lack of access to an electric power outlet near the Round Pond, we were only able to cover time periods ranging from 10:30 – 16:00 by overlaying three days of data (November 13, 17, and 20). Nevertheless, the EC levels in this part of the Hyde Park were in general low even during these day-time hours, even lower than the EC levels observed in the late night hours at the Oxford Street site (see Figure B2). On November 20, high EC concentrations, relative to “normal” Hyde Park levels, were observed during about 10:30

– 12:30 when we noticed two large tractors clearing leaves in the Park near the monitoring area.

Given that the pre-session health measurements take about 2 hours and the post-session health measurements take about 6 hours at the base hospital on each day of the exposure or control session, it would be most convenient to implement experiments if the subjects were to perform walking exercises during the period of 10:00 – 14:00. As shown in Figure B2, EC levels remained relatively stable and high during this time period on Oxford Street. Therefore, the time period (10:00 – 14:00) during which we were to conduct the exposure sessions was ideal from the standpoint of exposure. (The actual time period was from ~ 10:00 to 12:30).

### **Day-to-Day Variation in PM<sub>2.5</sub> and EC**

Figure B3 shows time-averaged concentrations of PM<sub>2.5</sub> and EC, both measured using quartz fiber filter analysis, at the Oxford Street site (Monday through Friday) and the Hyde Park site (Monday through Thursday) between November 19 and November 23. The Oxford Street samples were taken within the range of 7:02 – 19:14 on each day and the concentrations were averaged over approximately 8 hours. The Hyde Park samples were taken within the range of 9:00 – 16:17 on each day and the concentrations were averaged over a shorter period of time (2.5 hours to 5.5 hours).

PM<sub>2.5</sub> concentrations measured on the quartz fiber filters had a relatively small range (53.5 to 76.4 µg/m<sup>3</sup>) at the Oxford Street site. The mean concentration was 71.3 µg/m<sup>3</sup> and standard deviation (SD) was 10.0 µg/m<sup>3</sup> (CV = 14%). PM<sub>2.5</sub> concentrations at the Hyde Park site had a larger variation: range from 19.2 to 50.0 µg/m<sup>3</sup>, mean = 33.0 µg/m<sup>3</sup>, and SD = 12.6 µg/m<sup>3</sup>, and CV = 38%.

At the Oxford Street site, EC concentrations had a range of 6.6 to 15.7  $\mu\text{g}/\text{m}^3$ , mean of 11.7  $\mu\text{g}/\text{m}^3$ , SD of 3.8  $\mu\text{g}/\text{m}^3$ , and CV of 33%. At the Hyde Park site, EC concentrations had a range of 1.1 to 3.7  $\mu\text{g}/\text{m}^3$ , mean of 2.7  $\mu\text{g}/\text{m}^3$ , SD of 1.1  $\mu\text{g}/\text{m}^3$ , and CV of 43%. All of these values were determined using the results of the quartz fiber filter analysis.

In general, day-to-day variations in  $\text{PM}_{2.5}$  and EC were larger in Hyde Park than on Oxford Street. This can be reasonably explained by the differences in major influencing factors. For instance, local vehicular traffic had larger impacts on Oxford Street concentrations, and the day-to-day variation in traffic density is expected to be low on weekdays. On the other hand, the concentrations measured in Hyde Park were urban background levels and could be influenced more heavily by weather conditions.

### **EC Levels**

The data from Figure B3 generated a mean EC concentration of 11.7  $\mu\text{g}/\text{m}^3$  for Oxford Street and 2.7  $\mu\text{g}/\text{m}^3$  for Hyde Park. Thus, on average, the EC level on Oxford Street was 4.4 times that in Hyde Park. This roughly reflects the situation for the daytime hours.

The proposed exposure and control sessions were to be conducted during a narrower time window (i.e., between 10:00 – 14:00) on weekdays. Therefore, it would be more meaningful to compare EC levels between the two sites during this time period. We had EC data that were collected simultaneously at both sites on four days, as shown in Figure B4. The results from these four days of measurements indicate that the Oxford Street site had EC levels of  $11.5 \pm 4.1 \mu\text{g}/\text{m}^3$ , or 2.5 to 8.1 times (5.7 times on average) higher than the Hyde Park site had of  $2.2 \pm 0.9 \mu\text{g}/\text{m}^3$ .

Previous measurements showed ambient EC concentrations of  $0.1 \mu\text{g}/\text{m}^3$  at a remote site,  $2.6 \mu\text{g}/\text{m}^3$  in a densely populated community in southern California, and  $5.4 \mu\text{g}/\text{m}^3$  (maximum daily concentration) in Los Angeles (Chow et al, 1994). Kinney et al (2000) reported that EC concentrations averaged  $3.4 \mu\text{g}/\text{m}^3$  (ranging from  $1.5$  to  $6 \mu\text{g}/\text{m}^3$ ) on street sidewalks in Harlem, New York City, an urban district impacted by local diesel traffic. In Mexico City, a daily EC average of  $4.0 \mu\text{g}/\text{m}^3$  was reported for a downtown monitoring site and that of  $2.9 \mu\text{g}/\text{m}^3$  was reported for a suburban site. At the high end, black smoke (similar to EC) concentration of  $14.9 \mu\text{g}/\text{m}^3$  was measured near a freeway in Delft, the Netherlands (van Vliet et al, 1997). Therefore, the EC concentrations measured at the Hyde Park site were comparable to typical urban/suburban background levels, whereas the EC concentrations on Oxford Street were closer to those observed near a heavily traveled freeway.

## **CONCLUSIONS**

Our results have proven that the previously validated high-flow personal  $\text{PM}_{2.5}$  sampler (HFPS) can be reliably used to measure 2-hr integrated  $\text{PM}_{2.5}$  mass and EC concentrations at Oxford Street and Hyde Park. Using the spatial data, we have defined walking paths for the conducting exposure and control sessions. The EC level was highest between Orchard Street and Regent Street on Oxford Street, and thus, this section of Oxford Street was chosen as the exposure site. The EC level was lowest in the area near Round Pond in Hyde Park, and thus, this part of the Park was selected as the control site.

The diurnal pattern of EC concentrations confirmed that the time period (between 10:00 and 14:00) was optimal for conducting exposure sessions. During this time period the EC levels remained relatively stable at the exposure site. Based on five consecutive weekdays of measurements, we found relatively small day-to-day variations in PM<sub>2.5</sub> and EC at both sites (ranging from 14% to 41%), with larger variations at the Hyde Park site than the Oxford Street Site. On average, the Oxford Street site had an EC level 5.7 times higher than the Hyde Park site at which typical urban/suburban background EC concentrations were measured. Interestingly, the two sites had a much smaller difference in PM<sub>2.5</sub> concentration (On average, Oxford Street PM<sub>2.5</sub> = 2.2 x Hyde Park PM<sub>2.5</sub>), confirming the relative larger contribution of diesel exhaust (EC as a proxy) to PM<sub>2.5</sub> in Oxford Street.

## REFERENCES

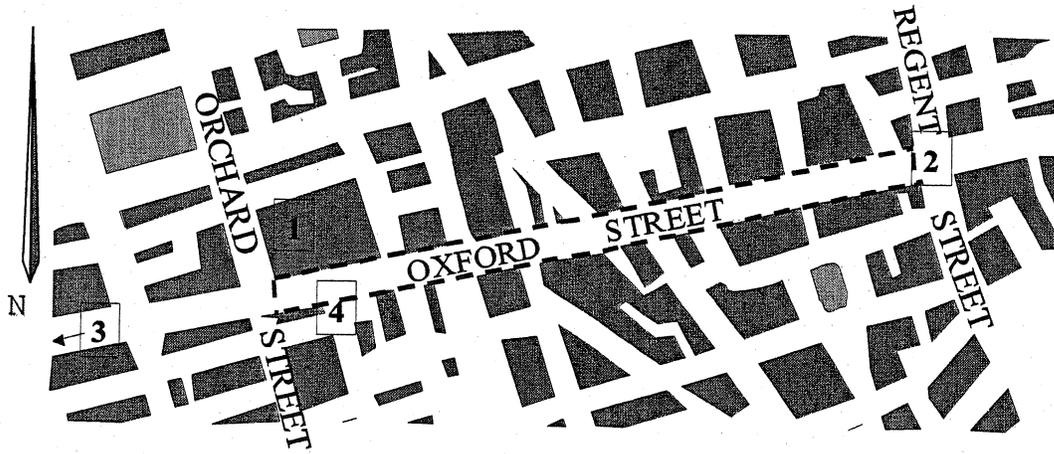
- Adams HS, Kenny LC, Nieuwenhuijsen MJ, Colville RN, Gussman RA. Design and validation of a high-flow personal sampler for PM<sub>2.5</sub>. *J Expos Anal & Environ Epidemiol* 2001; 11:5-11.
- Babich P, Davey M, Allen G, Koutrakis P. Method comparisons for particulate nitrate, elemental carbon, and PM<sub>2.5</sub> mass in seven US cities. *J Air & Waste Manag* 2000; 50:1095-1105.
- Chow JC, Watson JG, Fujita EM. Temporal and spatial variations of PM<sub>2.5</sub> and PM<sub>10</sub> aerosol in the southern California air quality study. *Atmos Environ* 1994; 28:2061-2080.
- Kinney PL, Aggarwal M, Northridge ME, Janssen NAH, Shepard P. Airborne concentrations of PM<sub>2.5</sub> and diesel exhaust particles in Harlem sidewalks: a community-based pilot study. *Environ Health Perspect* 2000; 8:213-218.
- van Vliet P, Knape M, de Hartog J, Janssen N, Harssema H, Brunekreef B. Motor vehicle exhaust and respiratory symptoms in children living near freeways. *Environ Res* 1997; 74:122-132.



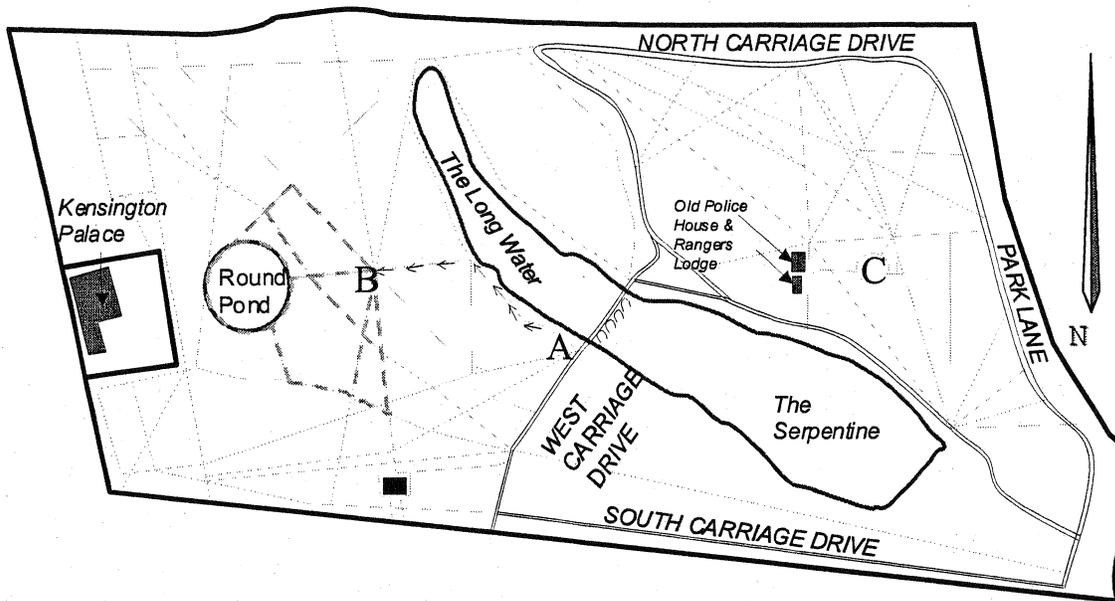
Hyde Park

Oxford Street

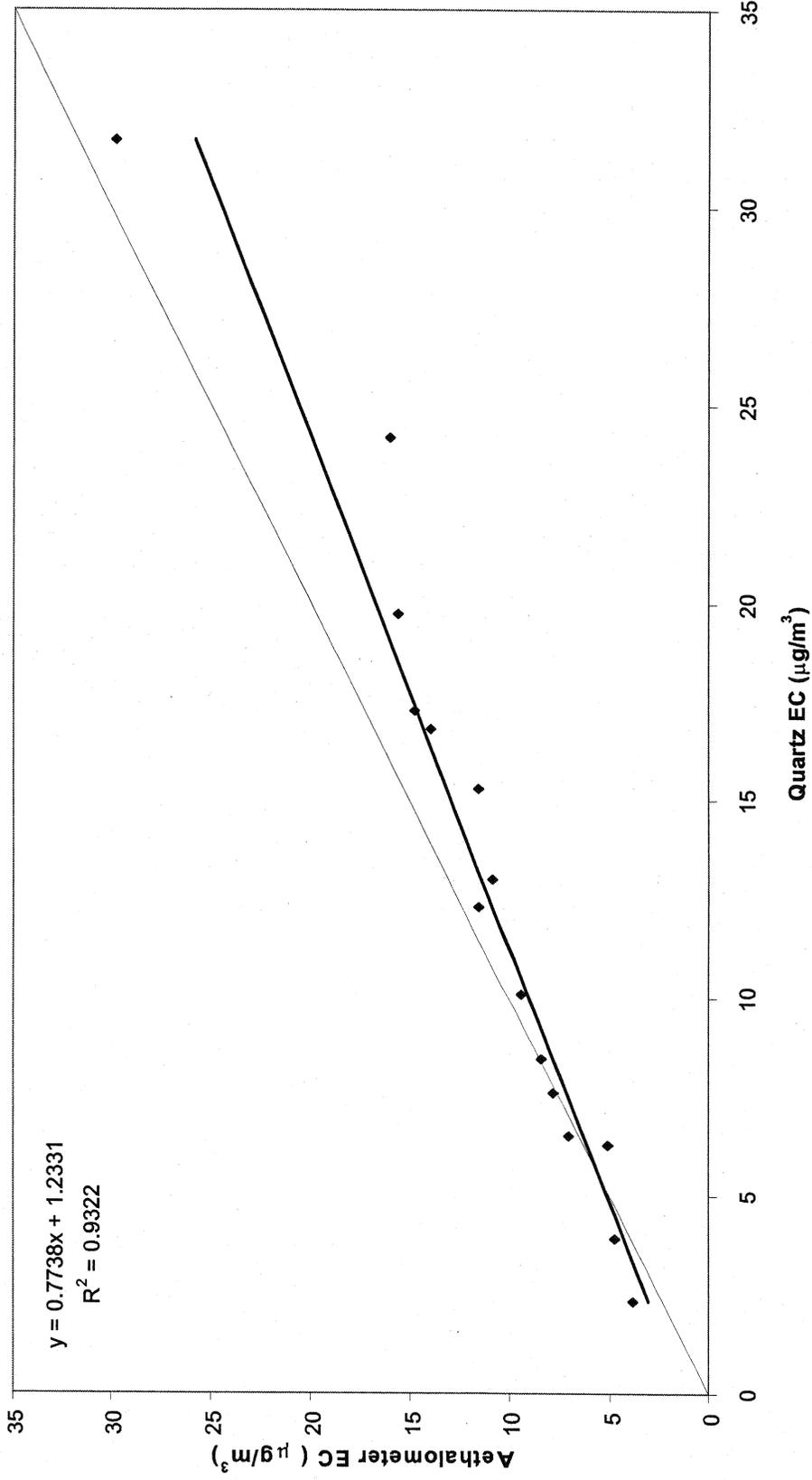
Map 1. Central London Map showing the Oxford Street and Hyde Park, the exposure site and the control site of the study, respectively



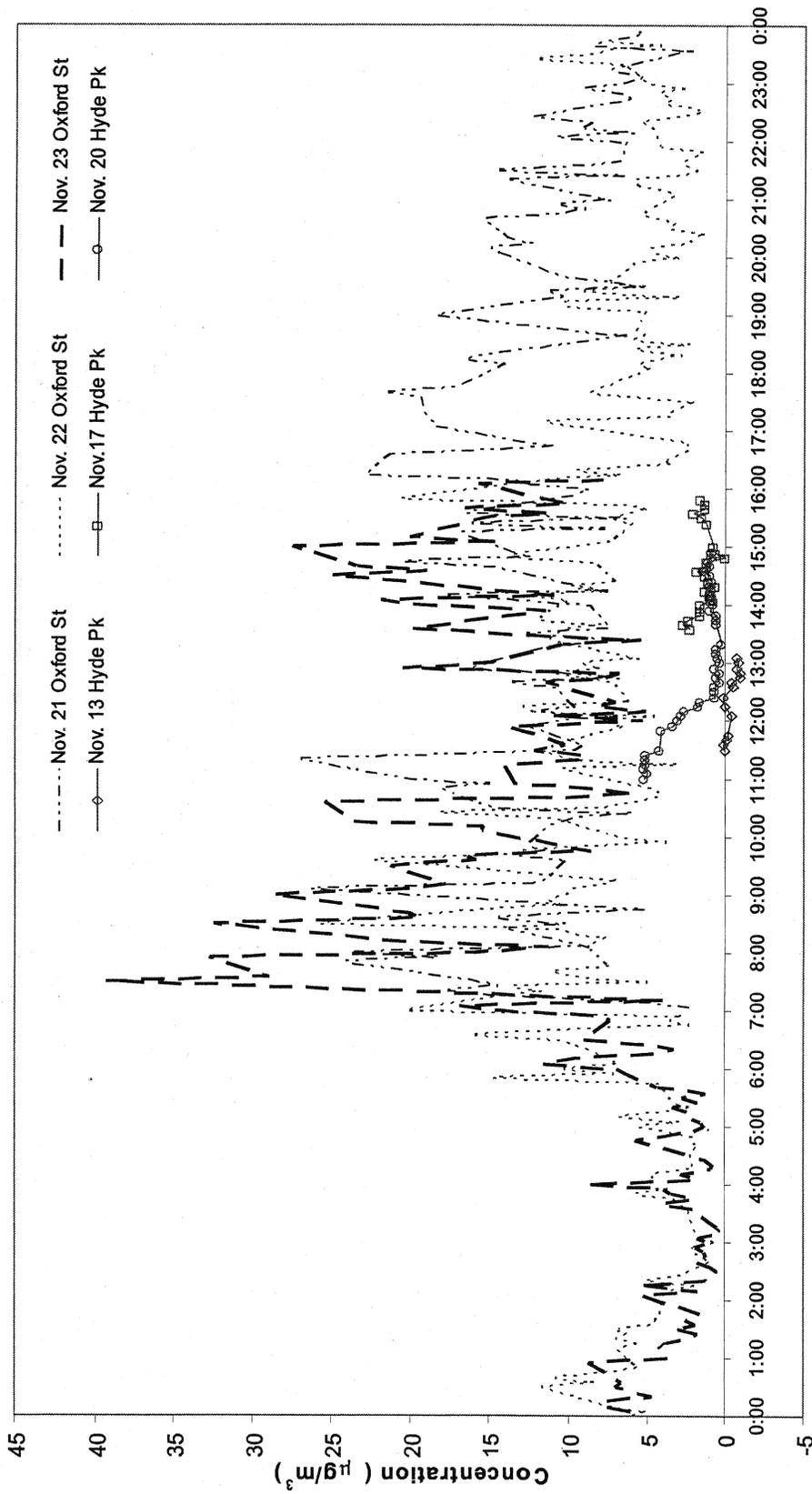
**Map 2.** Map of Oxford Street, showing, 1 = Selfridges department store, 2 = Oxford Circus, 3 = Marble Arch, and 4 = Sampling cage



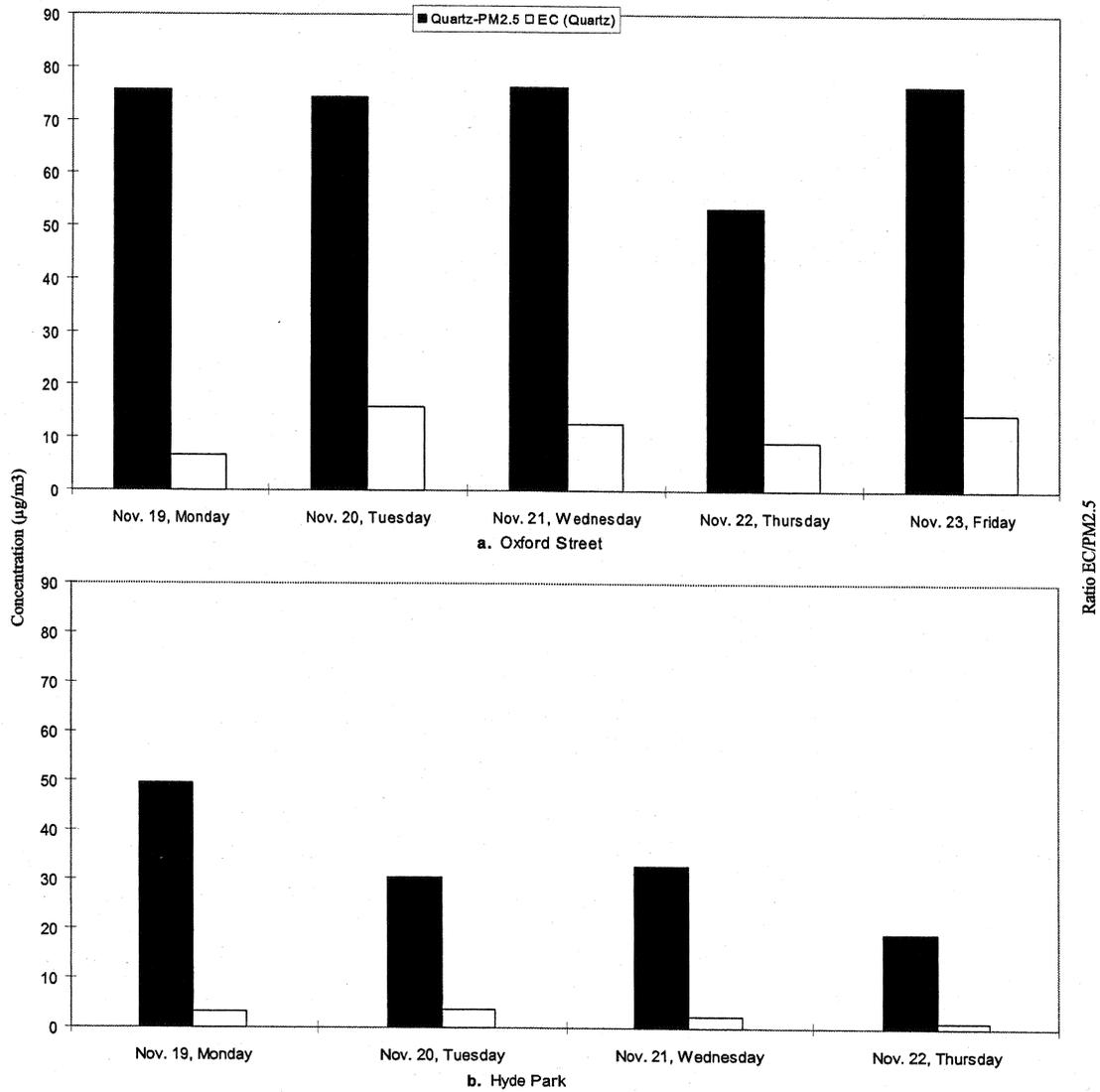
**Map 3.** Map of Hyde Park, showing A = Drop-off point, B = Physical Energy Statue, and C = Hyde Park, East side sampling site



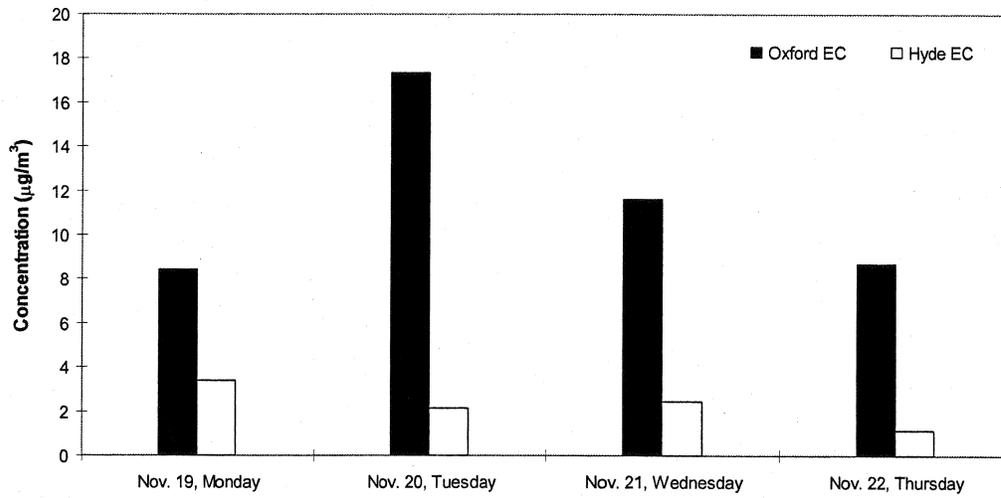
**Figure B1.** Comparison of EC measured using co-located quartz fiber filters and the Aethalometer real-time monitor on Oxford Street (N=13) and in Hyde Park (N=2)



**Figure B2.** Diurnal EC variations measured using the Aethalometer at the proposed exposure site on Oxford Street and at the proposed control site in Hyde Park



**Figure B3.** Day-to-day variations in PM2.5 and EC, both measured using quartz fiber filters, at the proposed exposure site on Oxford Street and at the proposed control site in Hyde Park.



**Figure B4.** Comparison of EC measured at the proposed exposure and control sites, between 10:00 and 14:00 using quartz fiber filter results and Aethalometer data that were corrected using equation (1)