American Petroleum Institute

STEP Strategies for Today's Environmental Partnership

A STUDY TO QUANTIFY ON-ROAD EMISSIONS OF DIOXINS AND FURANS FROM MOBILE SOURCES: PHASE 2

Health and Environmental Sciences Department
Publication Number 4642
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A Study to Quantify On-Road Emissions of Dioxins and Furans from Mobile Sources: Phase 2

Health and Environmental Sciences Department

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ABSTRACT

This report describes the results of a study of the on-road emissions of dioxins and furans from mobile sources. This work was done in response to the US EPA's draft Dioxin Reassessment document which used data from sources outside the US to estimate an emission factor for the US fleet. The EPA estimate for dioxin emissions from the heavy-duty fleet was 0.8 ng/mile expressed in terms of TEQ or Toxicity EQuivalents (a set of factors intended to adjust concentrations based on relative toxicity). The primary objective of this work was to develop on-road chlorinated dioxin and furan emission factors for in-use vehicles operating in the US with particular emphasis on heavy-duty vehicles. The experimental approach was to measure emissions in the Fort McHenry Tunnel, Baltimore, Maryland. All air entering and leaving the tunnel was sampled for concentrations of dioxins and furans (during ten sampling periods of 24 hours each). The difference between the mass of material entering and the mass of material leaving the tunnel was taken to be the amount produced by the vehicles in transit. These measurements were combined with information on vehicle counts (obtained through videotapes) and tunnel length to determine an average emission factor. The study was conducted from October 25 to November 6, 1995. The average heavy-duty diesel emission factor determined in this study was 0.28 ng TEQ/mile.

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EXECUTIVE SUMMARY

This report describes the results of Phase 2 of "A Study To Quantify On-Road Emissions Of Dioxins From Mobile Sources." This builds upon the results of the Phase 1 study in which preliminary measurements were made in the Van Nuys Tunnel to verify application of the dioxin and furan collection and analytical methods to tunnel conditions and to develop recommendations for a more complete experiment. Phase 2 continued this work while focusing on emissions from heavy-duty diesel vehicles and consisted of measurements of dioxin and furan emissions in the Fort McHenry Tunnel.

Background

In a recent draft Dioxin Reassessment document, the US EPA reports estimated dioxin and furan emission factors from mobile sources. The EPA estimated dioxin emission factor for the heavy-duty fleet was 0.8 ng/mile expressed in terms of TEQ or Toxicity EQuivalents (a set of factors intended to adjust concentrations of various chlorinated dioxins and furans based on relative toxicity). This estimate was primarily based on studies conducted outside the US, including one on-road study done in a tunnel in Norway. The EPA report also presents evidence that light-duty and heavy-duty diesel vehicles are sources of dioxins and furans based on dynamometer tests and muffler scrapings. While there is little doubt that motor vehicles are sources of dioxins and furans, the magnitude of these emissions is uncertain. The application of the Norwegian results, which were confounded by a light-duty fleet operating on leaded gasoline, to the US fleet has also been criticized and the US EPA has indicated additional research is needed.

The approach supported by EPA to address this question is to perform engine dynamometer tests of heavy-duty diesel emissions. An alternative approach to determine mobile source emissions of dioxins and furans, applied in this study, is to perform an on-road experiment in a roadway tunnel to determine emission factors. While this method does not permit the same degree of control over operating conditions as could be obtained in a dynamometer study (fuel, load, etc.) it does enable one to quantify emissions from the in-use fleet.

Results of Phase 1

Prior to performing this experiment, an initial study (Phase 1) was undertaken in June 1995 in the Van Nuys Tunnel (Sherman Way under the Van Nuys Airport, Van Nuys, California). The objectives of Phase 1 were to lay the groundwork for a more complete experiment, to verify application of the dioxin and furan collection and analytical methods to tunnel conditions, and to assess the ability of the current tunnel methodology to determine mass emission rates for dioxins and furans.

The Phase 1 study showed that the methodology employed for determining mass emissions of various pollutants in roadway tunnels was applicable to the

study of dioxins and furans from mobile sources. It also provided the basis for several changes in the experimental procedure for Phase 2 to improve the capability of detecting and measuring dioxin and furan emissions at the lowest levels feasible. These were:

- Increasing the sampler flow rate by a factor of 2.
- Increasing the sample duration from 12 to 24 hours.
- Changing to a day/day and a night/night sampling schedule to examine cases which maximize traffic count and thus concentration (day/day) and maximize the fraction of heavy-duty vehicles (night/night).

These steps were designed to increase measurement sensitivity and enable calculation of emission factors of <0.075 ng-TEQ/mile.

Objectives of Phase 2

The primary objective of this work was to develop on-road emission factors for chlorinated dioxins and furans from in-use vehicles operating in the US. The approach taken was to measure mobile source emissions in a tunnel — the same methodology as was previously applied in tunnel studies to measure regulated gaseous emissions from mobile sources.

As part of this work answers were sought for the following questions:

- Are heavy-duty dioxin emission factors from the US fleet as high as those observed in the Norwegian study?
- How do emission factors for heavy-duty and light-duty vehicles that are calculated from US roadway tunnel measurements compare with current EPA estimates?
- Is resuspended road dust a significant source of the observed dioxin emissions?

Experimental Description

The Fort McHenry Tunnel is a four-bore tunnel, two lanes per bore, carrying Interstate 95 east-west traffic under the Baltimore Harbor. The downgrade reaches –3.76% and the upgrade reaches +3.76%, with no significant level portion. Average grade from west portal to bottom is –1.8% and, from bottom to east portal, +3.3%. The tunnel's four bores are designated 1 and 2 westbound (towards Washington, DC), and 3 and 4 eastbound (towards Philadelphia, PA). This study was performed in Bores 3 and 4, the eastbound bores (length 2174 meters). Light-duty vehicles are allowed in both bores, while trucks are directed into Bore 4, the right-hand bore. The fleet in Bore 3 generally contained less than 2% heavy-duty diesel vehicles, while Bore 4 contained on average 24 to 25% heavy-duty diesel vehicles during the course of this experiment. Posted speed was 50 mi/hr in the tunnel, 55 outside. Traffic flowed freely except for sporadic light braking/slowdown at the exit at rush hour.

The ventilation system of the Fort McHenry Tunnel comprises two sections. Ventilation air, drawn in through the ventilation buildings, is supplied through

ducts beneath the roadway, and tunnel air can be removed through overhead exhaust ducts. During this experiment, the exhaust fans were shut off. In this situation, typically 10% of the air comes in through the east supply duct, 10% through the west supply duct, and 80% through the west portal. Actual tunnel flow volumes were determined in each run from anemometer measurements and known cross sections in the tunnel. Air flows through the supply ducts were determined from the stated fan ratings reported by the Tunnel Operations. All of the air leaves through the tunnel exit portal. Flow balances (in *vs.* out) were within ±9%, on average.

The Fort McHenry Tunnel is generally very well maintained and very clean relative to other tunnels. The Tunnel maintenance personnel cleaned the tunnels (a process which includes cleaning the walls in addition to street-sweeping) the weekend of the 22nd and 23rd of October, 1995, which is the weekend before this study began.

Sampling Stations

Sampling stations were set up at six locations: one each at the supply (air intake) for the ventilation air at the west and east ventilation buildings, one each on the catwalk in bores 3 and 4 at the west (entrance) end of the tunnel, and one each on the catwalk in bores 3 and 4 at the east (exit) end of the tunnel.

At each of the air intakes there was a high volume dioxin sampler and a sampler for particles less than 10 μm in aerodynamic diameter (PM_{10}).

At each entrance roadway station there was a propeller anemometer for air flow, a high volume dioxin sampler, and, in Bore 4 only, a PM_{10} sampler.

At each exit roadway station there was a propeller anemometer for air flow, a high volume dioxin sampler and, in Bore 4 only, a PM_{10} sampler. Starting with the 3rd sampling period a second high volume dioxin sampler was added at the Bore 4 site to increase the amount of sample collected at this important site. The samples from the two dioxin samplers were combined and analyzed as one.

A video camera was placed at each exit station and video tapes from the cameras were used to determine vehicle counts and traffic composition.

Run Descriptions

A total of 15 runs during the 10 sampling periods were performed in the two bores. There were 5 daytime experiments performed in Bores 3 and 4 (10 runs total) and 5 nighttime runs performed only in Bore 4 (5 total runs). Day runs commenced at 0600 and ended at approximately 1800. Night runs began at 1800 and ended at approximately 0600 the next day. End times are approximate since time was required to change out the sample media for the dioxin samplers.

No speed data were recorded as part of this study. Based on previous Fort McHenry work speeds were on the order of 50 mi/hr with the entering traffic slightly higher and the exiting (uphill) traffic slightly slower.

Bore 3 contained, on average 1.9% heavy-duty vehicles, while Bore 4 contained 24.2% heavy-duty vehicles. The fraction of heavy-duty vehicles in Bore 4 was similar for the day and night periods — 24.0% and 24.8%, respectively. Daytime vehicle counts in Bore 4 were 2.25 times greater than the nighttime counts. Bore 4 and Bore 3 daytime vehicle counts were, on average, within 10% of each other.

Results and Conclusions

The results of the chemical analyses were tabulated and validated, and emission factors were calculated for each run period. For Bore 3, the difference between the outlet and inlet concentrations was too small to accurately estimate emission factors. This precluded directly separating the light-duty component form the Bore 4 results to obtain heavy-duty diesel emission factors. Given the large fraction of heavy-duty diesel vehicles in Bore 4 and the assumption that heavy-duty diesel dioxin and furan emissions are significantly greater than light-duty dioxin and furan emissions, all observed emissions in Bore 4 were attributed to the heavy-duty diesel fleet. This means the resulting estimate will be an upper bound for the actual emission factor. The average for the 7 valid runs in Bore 4 was 0.28 ± 0.13 ng-TEQ/mile.

These results are lower than the EPA estimate of 0.8 ng-TEQ/mile. Possible explanations for the difference may be because the EPA estimate is based in part on a Norwegian study, where:

- The heavy-duty diesel fraction in the Norwegian study was between 3 and 15% of the total fleet and the results were extrapolated to 100% heavy-duty diesel.
- The light-duty fleet in the Norwegian study was operating using leaded fuel, a source of dioxins and furans.
- There are likely to be technology and fuel differences between Norwegian and US heavy-duty diesel vehicles.
- It is possible there were differences in load on the vehicles in the two studies.

Emission profiles were also compared with the results of German dynamometer tests. Given the differences in the tests, the results were in good agreement.

PM_{10} emission factors were also estimated as part of this work. The observed heavy-duty diesel emission factor of 0.32 ± 0.11 g/mile was lower than the 0.54 ± 0.12 g/mile observed in a study in the Fort McHenry Tunnel in 1993. Although the results agree to within the experimental uncertainty, possible reasons for the apparent difference may be due to the shorter run periods (1-hr.) and the dominance of 5 high emission factor runs in the 1993 study.

Chemical Mass Balance (CMB) modeling was conducted on the Bore 4 outlet PM_{10} filters. Resuspended road dust was found to account for 15.5 ± 3.3 % of the measured mass. The contribution from resuspended road dust to the observed dioxin and furan emission factors was estimated to be approximately 4%, calculated by incorporating the measured concentrations of dioxins and

furans in collected road dust. Results of the inorganic analyses were also used to determine the impact of ambient PM_{10} chlorine levels on dioxin and furan mass emission factors. An analysis of these data indicated there was no correlation between ambient PM_{10} chlorine and dioxin and furan emissions.

1.0 INTRODUCTION

This report describes the results of Phase 2 of "A Study To Quantify On-Road Emissions Of Dioxins From Mobile Sources." This builds upon the results of the Phase 1 study (Gertler *et al.*, 1995a) in which preliminary measurements were made in the Van Nuys Tunnel to verify application of the dioxin and furan collection and analytical methods to tunnel conditions and to develop recommendations for a more complete experiment. Phase 2 emphasized studying emissions from heavy-duty diesel (HDD) vehicles and consisted of measurements of dioxin and furan emissions in the Fort McHenry Tunnel (Baltimore, Maryland).

1.1 Background

In a draft report entitled "Estimating Exposure to Dioxin-Like Compounds" (EPA, 1994a) the EPA reports estimated dioxin and furan emission factors from mobile sources. The EPA estimated dioxin emission factor for HDD vehicles was 0.8 ng-TEQ[1]/veh-mi. To arrive at this value the EPA used several values, including a study of the Norwegian fleet by Oehme *et al.* (1991), which reported HDD dioxin and furan emission factors of 5.1 ng-TEQ/km (or 8.2 ng-TEQ/veh-mi). The Norwegian value was derived from the average of emissions measurements made in both the uphill and the downhill directions of a highway tunnel.

The report also presents evidence that light-duty (LD) and HDD vehicles are sources of dioxins and furans based on dynamometer tests and muffler scrapings. The magnitude of dioxin and furan emissions from motor vehicles is uncertain. The application of the results from Oheme *et al.* to the US fleet has also been criticized (Unsworth, 1994) and the US EPA has indicated additional research is needed.

The approach supported by EPA to address this question is to perform engine dynamometer tests of HDD emissions. An alternative approach to determine mobile source emissions of dioxins and furans, applied in this study, is to perform an on-road experiment in a roadway tunnel to determine emission factors. While this method does not permit the same degree of control over operating conditions as could be obtained in a dynamometer study (fuel, load, etc.) it does enable one to quantify emissions from the in-use fleet.

1.2 Results of Phase 1

Prior to performing this experiment, an initial study (Phase 1) was undertaken in June 1995 in the Van Nuys Tunnel (Sherman Way under the Van Nuys Airport, Van Nuys, California). The objectives of Phase 1 were to lay the groundwork for a more complete experiment, to verify application of the dioxin and furan collection and analytical

[1] 2,3,7,8-TCDD toxicity equivalents. A series of factors intended to adjust concentrations of other dioxin isomers to equivalent concentrations of 2,3,7,8-TCDD, based on relative toxicity.

methods to tunnel conditions, and to assess the ability of the current tunnel methodology to determine mass emission rates for dioxins and furans.

The Phase 1 study showed that the tunnel methodology employed for determining mass emissions of various pollutants was applicable to the study of dioxins and furans from mobile sources. It also provided the basis for several changes to experimental procedures for Phase 2 to improve the capability of detecting and measuring dioxin and furan emissions at the lowest levels feasible. However, it also demonstrated the limitations in detecting the low level of emissions from these sources (Gertler *et al.*, 1995a). The Van Nuys experiment was not an ideal case: the tunnel was relatively short (222 m), the traffic volumes were fairly low and the traffic composition was nearly completely light-duty. This did not allow for estimation of HDD emissions. In addition, most species were below the analytical detection limit for the 12-hr. sampling periods. Given these limitations, absolute emission factors could not be calculated. Upper limits for mass and TEQ emission factors were made assuming the non-detected species at the tunnel outlet were present at their detection limits and the inlet concentrations were zero. For the mixed fleet observed in Van Nuys (approximately 99% light-duty), the upper limit mass emission factor for all isomers was <0.3 ng/veh-mi and the TEQ emission factor was <0.03 ng-TEQ/veh-mi.

Based on the Phase 1 study, our previous work in Fort McHenry (Pierson *et al.*, 1996), and the assumption that all species may be below the detection limit, estimated HDD detection limits in Fort McHenry were <7.5 ng/veh-mi and <0.3 ng-TEQ/veh-mi. In order to lower these limits in the Phase 2 study, we proposed several experimental changes to improve our ability to determine emission factors. These were:

- Increasing the sampler flow rate by a factor of 2.
- Increasing the sample duration from 12 to 24 hours.
- Change to a day/day sampling schedule in Bores 3 and 4 and a night/night sampling schedule in Bore 4 to look at cases where we have the maximum traffic count and thus concentration (day/day) and maximum fraction of HDD vehicles (night/night).

We estimated these steps should increase our measurement sensitivity and enable us to develop upper limit emission factors of <1.9 ng/veh-mi and <0.075 ng TEQ/veh-mi.

1.3 Objectives

The primary objective of this work was to develop on-road dioxin and furan emission factors from in-use vehicles operating in the US. The approach taken was to measure mobile source emissions in a tunnel employing the same methodology applied in previous tunnel studies to quantify CO, NMHC, NO_x, and CO_2 emissions from mobile sources (e.g., Pierson *et al.*, 1990, 1996).

As part of this work we attempted to answer the following questions:

- Are HDD dioxin emission factors from the US fleet as high as those observed in the earlier Norwegian study?
- How do measured emission factors for HDD and LD vehicles compare with current EPA estimates?

- Is resuspended road dust a significant source of the observed dioxin emissions?

Initially we had planned to assess downhill vs. uphill emission factors by placing a sampler at the low point of the tunnel, near the air handling bulkhead (see Section 2.1). However, due to safety concerns, the Tunnel Authority did not allow sampling at this location so this objective had to be dropped. This change did, however, make an additional sampler available that was collocated with the other sampler at the Bore 4 exit to increase the sample collected there.

We had also planned on measuring the light-duty emissions in Bore 3 and subtracting this value from that determined in Bore 4 to calculate a heavy-duty only emission factor. However, the Bore 3 emissions were too low to estimate with this methodology (see Section 4.2), so we calculated heavy-duty emission factors by assuming that all emissions of dioxins and furans came from heavy-duty vehicles. This approximation will result in an over-estimate of the heavy-duty emission factor.

1.4 Guide to Report

This first section has provided the background on the project, summarized the Phase 1 results and recommendations, and outlined the objectives of the current study. Section 2 contains a description of the Fort McHenry Tunnel and outlines the sampling runs and vehicle counts. Section 3 details the experimental methods used to perform the study. The results for the dioxin and furan emissions and a comparison with previous studies are presented in Section 4. PM_{10} emission factors and an estimate of resuspended road dust to the observed emission factors are reported in Section 5. Section 6 contains the summary, and all references for the report are listed in the References section. The Appendices contain all analytical results and calculated concentrations for cases where only summary tables are provided in the main body of the text as well as all tunnel volumetric flows by run.

2.0 EXPERIMENTAL DESCRIPTION

In this section, we briefly describe the physical layout of the Fort McHenry Tunnel and present run descriptions of the sampling periods.

2.1 Tunnel Description

The Fort McHenry Tunnel (Figure 2-1) is a four-bore tunnel, two lanes per bore, carrying Interstate 95 east-west under the Baltimore Harbor. The downgrade reaches –3.76% and the upgrade reaches +3.76%, with no significant level portion. Average grade from west portal to bottom is –1.8% and, from bottom to east portal, +3.3%. The tunnel has four bores (Figure 2-2), designated 1 and 2 westbound (towards Washington, DC), and 3 and 4 eastbound (towards Philadelphia). This study was performed in Bores 3 and 4, the eastbound bores (length 2174 meters). LD vehicles are allowed in both bores. Trucks are directed into Bore 4, the right-hand bore. The fleet in Bore 3 generally contained less than 2% HDD vehicles, while Bore 4 contained on average 24-25% HDD vehicles. Posted speed was 50 mi/hr in the tunnel, 55 outside. Traffic flowed freely except for sporadic light braking/slowdown at the exit at rush hour.

The ventilation system of the Fort McHenry Tunnel comprises two sections. Ventilation air, drawn in through the ventilation buildings (Figure 2-1), is supplied through ducts beneath the roadway, and tunnel air can be removed through overhead exhaust ducts. During this experiment, the exhaust fans were shut off. In this situation, typically 10% of the air comes in through the east supply duct, 10% through the west supply duct, and 80% through the west portal. Actual tunnel flow volumes were determined in each run from anemometer measurements and known cross sections in the tunnel. Air flows through the supply ducts were determined from the stated fan ratings reported by the Tunnel Operations. All of the air leaves through the tunnel exit portal. Flow balances (in vs. out) were within ±9%, on average. All reported and measured air flows are in Appendix 4.

There is a bulkhead in the ventilation ducts 95 meters before (i.e., west of) the low point of the tunnel. This bulkhead effectively separates the tunnel into west and east sections. The west ventilation section contains 93% of the downhill travel while the east section contains the rest of the downhill and all of the uphill. We had hoped to sample at the dividing bulkhead to allow determination of downhill vs. uphill emission factors; however, this was dropped because the Fort McHenry Tunnel Authority would not allow samplers to be placed near the bulkhead due to safety concerns.

The Fort McHenry Tunnel is generally very well maintained and very clean relative to other tunnels. The Tunnel maintenance personnel cleaned the tunnels (a process which includes cleaning the walls in addition to street-sweeping) the weekend of the 22nd and 23rd of October, 1995, which is the weekend before we began sampling.

2.2 Sampling Stations

Sampling stations were set up at six locations: one each at the supply (air intake) for the ventilation air at the west and east ventilation buildings, one each on the catwalk in bores 3 and 4 at the west (entrance) end of the tunnel, and one each on the catwalk in bores 3 and 4 at the east (exit) end of the tunnel.

At each of the supply (air intake) stations for the ventilation air there was a high volume dioxin sampler and a sampler for particles less than 10 μm aerodynamic diameter (PM_{10}).

At each west (entrance) roadway station there was a propeller anemometer for air flow, a high volume dioxin sampler, and, in Bore 4 only, a PM_{10} sampler.

At each east (exit) roadway station there was a propeller anemometer for air flow, a high volume dioxin sampler and, in Bore 4 only, a PM_{10} sampler. Starting with the 3rd sampling period (0600 on 27 October 1995), a second high volume dioxin sampler was added at the Bore 4 site. The samples from the two dioxin samplers were combined and analyzed as one.

Also at each east station there was a small black-and-white video camera aimed to be able to see the tunnel traffic. The signals from both video cameras were merged by a screen splitter and recorded, along with the date and time, on a long-play video recorder that can record 24 hours on a single tape. These video tapes were used to determine vehicle counts and traffic composition.

2.3 Run Descriptions

Descriptions of the 10 sampling periods are contained in Table 2-1. A total of 15 runs was performed in the two bores. There were 5 daytime experiments performed in Bores 3 and 4 (10 runs total) and 5 nighttime runs performed only in Bore 4 (5 total runs). Day runs commenced at 0600 and ended at approximately 1800. Night runs began at 1800 and ended at approximately 0600 the next day. End times are approximate since time was required to change out the polyurethane foam (PUF) and filter media for the dioxin samplers.

Weather observations during sampling runs are also recorded on Table 2-1. Since each run consisted of two 12-hour periods separated by at least another 12 hours, the weather observations for the two separate periods are presented. The temperature data are the highest and lowest recorded values for that period, based on hourly observations, and the sky conditions are those observed by the National Weather Service office at the Baltimore-Washington Airport.

No speed data were recorded as part of this study. Based on our previous Fort McHenry work (Pierson *et al.*, 1996) speeds were on the order of 50 mi/hr with the entering traffic slightly higher and the exiting (uphill) traffic slightly slower.

Bore 3 contained, on average 1.9% HD vehicles, while Bore 4 contained 24.2% HD vehicles. The fraction of HD vehicles in Bore 4 was similar for the day and night periods — 24.0% and 24.8%, respectively. Daytime vehicle counts in Bore 4 were 2.25 times greater than the nighttime counts. Bore 4 and Bore 3 daytime vehicle counts were, on average, within 10% of each other.

Figure 2-1. Cross Sectional View, Fort McHenry Tunnel

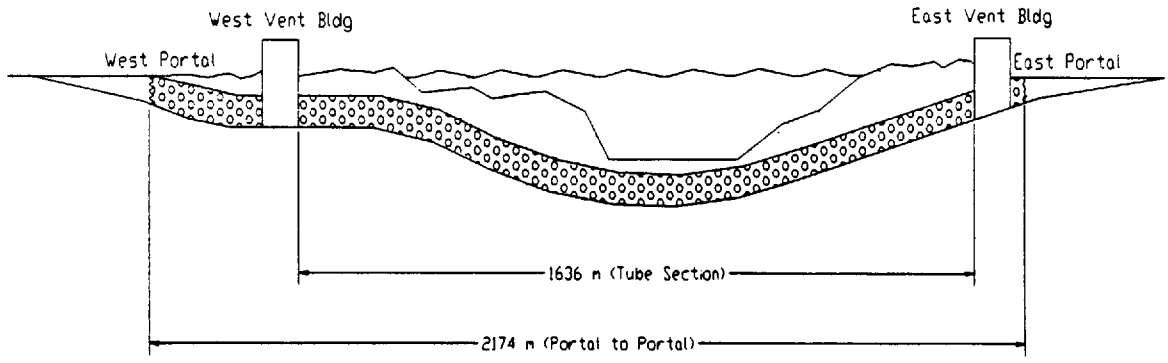


Figure 2-2. Cross Sectional View of Bores, Fort McHenry Tunnel

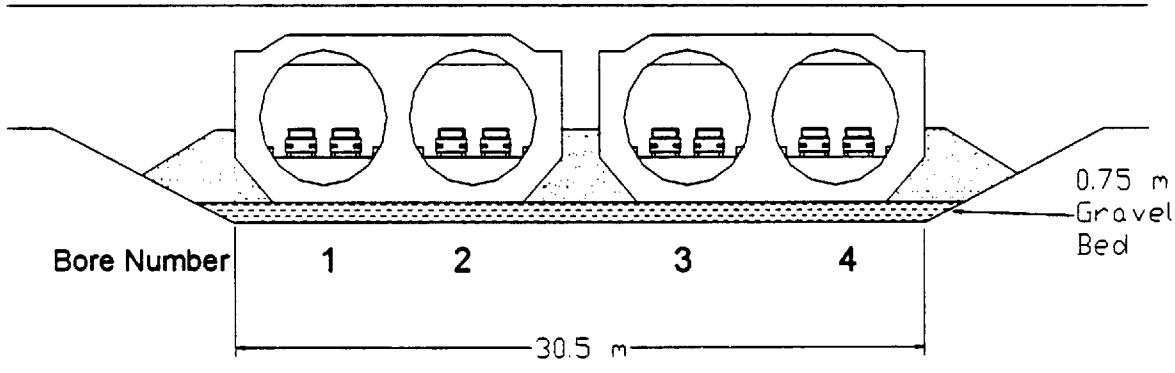


Table 2-1. Run Descriptions, Fort McHenry Tunnel. Weather observations show range of temperatures and sky conditions.

Run	1	2	3	4	5	6	7	8	9	10	AVG.
Start Date	25-Oct	25-Oct	27-Oct	27-Oct	31-Oct	31-Oct	2-Nov	2-Nov	6-Nov	6-Nov	
Day	Wed/Thur	Wed/Thur	Fri/Mon	Fri/Mon	Tues/Wed	Tues/Wed	Thur/Fri	Thur/Fri	Mon/Tues	Mon/Tues	
Start Time: Day 1	600	1800	600	1800	600	1800	600	1800	600	1800	
Start Time: Day 2	600	1800	600	1800	600	1800	600	1800	600	1800	
Total Vehicles: Bore 3	34,468		36,554		28,015		35,214		15,910		30,032
LD: Bore 3	33,858		35,897		27,474		34,432		15,625		29,457
HD: Bore 3	610		657		541		782		285		575
Total Vehicles: Bore 4	33,668	13,128	36,173	18,404	38,578	10,548	16,719	14,164	16,876	6,824	20,508
LD: Bore 4	24,774	10,346	28,228	15,076	29,842	6,959	12,285	10,088	12,789	4,957	15,534
HD: Bore 4	8,894	2,782	7,945	3,328	8,736	3,589	4,434	4,076	4,087	1,867	4,974
% HD: Bore 3	1.8%	--	1.8%	--	1.9%	--	2.2%	--	1.8%	--	1.9%
% HD: Bore 4	26.4%	21.2%	22.0%	18.1%	22.6%	34.0%	26.5%	28.8%	24.2%	27.4%	24.3%
Weather Observations											
Temps: Day 1 (°F)	53-60	40-57	52-68	61-67	48-60	53-56	65-68	65-64	32-51	34-40	
Temps: Day 2 (°F)	40-60	44-59	42-62	47-52	58-61	61-63	58-73	37-58	38-49	40-49	
Weather: Day 1	Clear	Pt. Cloud	Overcast	Rain	Overcast	Overcast	Fog/Rain	Rain/Cloud	Clear/Scat.	Scat.Cld	
Weather: Day 2	Fog	Cloud/Fog	Scat. Cld	Scat. Cld	Rain/Fog	Fog/drizzle	Overcast	Clear/Scat.	Cloud/Rain	Overcast	

3.0 EXPERIMENTAL METHODS

In this section we describe the measurement and dioxin and furan analytical methods along with the methodology for calculating emission factors in tunnels. PM_{10} analytical methods are detailed in Section 5.

3.1 Measurement Methods

As described in the previous section, sampling stations were required at six locations: Two at the west portal (tunnel entrance), one at east supply, one at west supply, and two at the east portal (tunnel exit). At each sampling location there was a propeller anemometer for air flow measurements and high volume sampler for collection of dioxins and furans. PM_{10} samplers were also located in the two supplies and Bore 4 inlet and outlet to collect size fractionated particulate matter.

The anemometers used were RM Young Model 05103, interfaced to a Campbell 21x datalogger. The flow measurements were recorded in Campbell battery-backed memory modules and downloaded to a computer once each week and at the end of the study.

The PM_{10} samples were collected using DRI medium-volume PM_{10} samplers designed to collect samples for chemical analysis (Gertler *et al.*, 1993). This type of sampler employs a Sierra-Andersen 254 PM_{10} inlet to collect only those particles with aerodynamic diameters less than 10 μm. The ambient air is transmitted through the size-selective inlet and into a plenum. The flow rate is controlled by maintaining a constant pressure across a valve with a differential pressure regulator. For the size selective inlet to work properly, a flow rate of 113 liters per minute (lpm) must be maintained through the sampler. Flow rates of 20 lpm through each filter are standard for these studies because they generally provide adequate sample loadings for analysis without overloading the filters. This flow rate is drawn simultaneously through two parallel filter packs, one with a Teflon® substrate (for mass and metals) and one with a quartz substrate (for carbon and ions). The remaining 73 lpm are drawn through a makeup air port. The flow rates are each set with calibration filters and calibrated rotameter and are monitored with the same rotameter at each sample change.

Dioxins and furans were collected using Graseby GMW Model GPS1 PUF samplers. The sampler does not have a size-selective inlet, but does have a shelter top to prevent exposure of the media to material falling on it. It is thus a total suspended particles (TSP) collection process. The actual sampling train consists of a 10 cm glass fiber filter backed up by a cartridge of polyurethane foam (PUF). Samplers were calibrated with a calibrated orifice (Graseby GMW Model G40) prior to the beginning of the study.

In order to maximize the amount of sample collected for dioxin analysis, runs were scheduled on a day/day and night/night basis to yield a 24-hr. sampling period. Dioxin sampler flows were also maximized to approximately 24 standard cubic feet per minute (scfm) to increase sample collection. Flows in the Bore 4 outlet dioxin sampler had to be reduced to approximately 19 scfm in order to reduce clogging of the media and the concurrent severe reduction in sampler flow. In order to compensate for this problem, samplers were collocated at the Bore 4 outlet beginning with Run 3 and the collected

samples were combined for analysis. Even with the collocated samples, these samplers experienced considerable loading and the flow rates dropped over the sample periods. To compensate for this, after the first 12 hour sample period the flow was readjusted back up to the starting value for the second 12 hour period. Total volume collected was the sum of the two 12 hour periods, and for each period we used the average of the start and end flows to calculate the volume sampled. Flow data was not monitored continuously. Based on DRI's previous experience with this type of sampler, an error of ±5% is expected on the total volume calculated.

3.2 Dioxin and Furan Laboratory Methods

Following sampling, the filters and PUF media were shipped to Quanterra Environmental Services, Inc. (Sacramento, California) for analysis. Shipments were made by overnight carrier and the samples were packed in coolers with blue-ice packs to keep the samples cool. The general sampling and analysis approach followed was that of US EPA Method TO-9 (EPA, 1988), but employing the analytical improvements of Method 8290 (EPA, 1994b). Method TO-9 describes the air sampling protocol, including pre-cleaning of media and extraction and analysis for only four dioxins and no furans. Method 8290 is an analytical method only that expands the list of target compounds to include the full range of dioxin and furan congeners. As part of method 8290 samples are extracted, cleaned up and subjected to high resolution gas chromatography/high resolution mass spectrometry for identification and quantification of tetra- through octa-chlorinated dioxins and furans. The method allows for ppt and sub-ppt determination of 2,3,7,8-substituted PCDD/PCDF isomers.

3.2.1 Dioxin/Furan Method Summary

PUF and Filter Cleaning Procedures

PUFs and filters are subjected to a 16 hour soxhlet extraction with 200-300 ml of toluene. PUFs and filters are removed from the soxhlets and allowed to air dry in a hood until all traces of solvent have dissipated. After this first phase is complete a set of PUFs is selected from the batch to determine quality control. This subset of PUFs is spiked with dioxin and furan standards and is again subjected to a 16 hour soxhlet extraction. The extract is concentrated down to approximately 1 to 2 ml using a rotary vacuum evaporator (a heated bath approximately 60 degrees centigrade is used during this process). This step is followed by nitrogen blow down of the extract to a final volume of 20 µL. The extract is then analyzed per Quanterra's Standard Operating Procedures (SOP). This Quality Control (QC) procedure is used to determine that the PUFs are indeed free from contamination. If the PUFs pass the QC procedure, the information is documented and filed. All PUFs and filters are subsequently wrapped and stored in individual containers for shipment to the field.

Pre-Spiking Protocol

Ambient air media are prespiked with a single labeled isomer (^{37}Cl-2,3,7,8-TCDD). This spiking scheme is used to monitor sampling efficiency and/or breakthrough during the sampling period.

The spiking solution contains the single labeled isotope in isooctane. The concentration is set at 10 pg/µL and a syringe is used to introduce 200 µL of the solution directly into the PUF media. Precautions are used throughout these processes to eliminate contamination and/or misspike of the PUF prior to shipment to the field.

Blanks

Of the five method blank (MB) samples reported, only one had detectable levels of any congeners and these were, in general, well below the levels seen in the tunnel. The average blank detection limits, presented in Table 3-1, can be used to assess the method detection limits. However, as described later in this section, each sample's detection limits are calculated individually; therefore, those values presented in Table 3-1 may not be exactly those of the tunnel samples. Actual tunnel samples were not blank corrected.

Table 3-1. Summary of average (n=5) blank detection limits in pg/sample.

Congener	pg/sample
TCDDs (total)	3.1E+00
2,3,7,8-TCDD	2.5E+00
PeCDDs (total)	4.5E+00
1,2,3,7,8,-PeCDD	3.9E+00
HxCDDs (total)	3.6E+00
1,2,3,4,7,8-HxCDD	3.7E+00
1,2,3,6,7,8-HxCDD	3.7E+00
1,2,3,7,8,9-HxCDD	3.4E+00
HpCDDs (total)	5.1E+00
1,2,3,4,6,7,8-HpCDD	4.0E+00
OCDD	2.1E+01
TCDFs (total)	2.3E+00
2,3,7,8,-TCDF	2.3E+00
PeCDFs (total)	3.4E+00
1,2,3,7,8,-PeCDF	3.2E+00
2,3,4,7,8-PeCDF	2.7E+00
HxCDFs (total)	2.4E+00
1,2,3,4,7,8-HxCDF	1.3E+00
1,2,3,6,7,8-HxCDF	1.6E+00
2,3,4,6,7,8-HxCDF	1.7E+00
1,2,3,7,8,9-HxCDF	2.1E+00
HpCDFs (total)	3.9E+00
1,2,3,4,6,7,8-HpCDF	2.0E+00
1,2,3,4,7,8,9-HpCDF	3.5E+00
OCDF	5.6E+00

Extraction Protocol

All extraction equipment is washed with a detergent solution, and rinsed with water. This is followed by solvent rinsing with acetone, toluene, hexane and methylene chloride in sequence, to ensure removal of any contamination that might be present.

Extraction glassware is tracked throughout the analytical process and documentation is maintained to verify cleanliness of equipment and to prevent cross contamination of samples.

Field sample PUF and filters are maintained at 4 degrees centigrade until time of extraction. Precleaned apparatus that has gone through a 4 hour cleaning cycle is used for the extraction procedures. Each PUF and associated filter are loaded into the soxhlet body, and the collection vessel is charged with 200-300 ml of toluene.

Quality control is monitored by the addition of a method blank and a laboratory control sample (LCS), that are associated with a specific group of field samples. PUFs that were previously cleaned and passed QC are used as the matrix for the MB and LCS.

A set of nine ^{13}C-labeled standards are introduced into each of the samples including the QC samples. One thousand to 5000 pg per labeled analogue is placed in each sample. In addition, the LCS has a second solution introduced that contains all the 2,3,7,8 substituted target analytes of interest, at a concentration of 200-500 pg/isomer. Whereas the level of internal standards is below that seen in the actual samples, they are used to check the laboratory extraction and cleanup procedures. The LCS sample has spiking concentrations more on the order of the Bore 4 outlet concentrations, but higher than those seen at the inlets or vents.

When spiking is complete, refluxing of solvent through the PUF begins by the application of heating mantles to the collection vessel. The cycling of solvent is allowed to continue for a 16 hour period.

All Fort McHenry Tunnel samples were processed in this manner except for the Bore 4 outlet collocated samples. Each set of collocated samples was extracted together to make one sample. A larger soxhlet body was used and the solvent volume was increased to 600-800 ml of toluene. After concentration these samples were cleaned up as described below with no changes in protocol as a result of the combination of the collocated samples.

At the completion of the extraction cycle the vessel is allowed to cool, the apparatus is disassembled and the collection vessels with the extract are removed for further processing. Each extract is rotary evaporated under vacuum and heat. The extract is concentrated by removing excess solvent. Each extract is then brought up to a volume of 10 ml in toluene, and then split into two 5 ml portions. One portion will continue with clean up steps. The other portion is archived in the event of analytical problems.

A summary of both the internal standards and field surrogate spike-and-recovery data for this project is presented in Table 3-2. These values are for samples that went through the entire extraction and cleanup procedure. In this table the average of 60 experiments is presented along with the standard deviation and the percent relative standard deviation (RSD). Also presented are the highest and lowest recoveries reported for this study. The data show excellent consistency among the 60 recovery experiments conducted. The highest standard deviation was 16%, for both the heptachloro dioxin and heptachloro furan internal standards. It is important to note that the ^{37}Cl-labeled field surrogate showed excellent results with an average 105% recovery and only 7% relative standard deviation. This standard is added prior to the media going to the field and shows that the trapping and recovery of the compounds of interest should be excellent.

Cleanup Procedures

The EPA method allows for a variety of cleanup procedures to be utilized depending on the known or anticipated contaminants and interferences associated with the sample matrix.

All Fort McHenry Tunnel samples were treated with a silica column cleanup, an alumina column cleanup, followed by the carbon-on-silica column cleanup. Acid, base, and neutral silicas and aluminas, as well as carbon-on-silica substrate, are used to eliminate potential contaminates. Interferences such as PAHs, PCBs and others may be present in concentrations far greater than the level of target analytes of interest. These cleanup procedures have all been proven effective in eliminating most interferences and allowing for the collection of the compounds of interest.

After these rigorous cleanup procedures, the sample extract is concentrated down to a 1-2 ml portion by use of a Turbo-Vap. ^{13}C-labeled recovery standard is added and a final volume of 20 µL is achieved by slow evaporation under a dry stream of nitrogen gas in a concentrator. The extract is quantitatively transferred to an injector vial and the extract is ready for analysis.

Table 3-2. Summary of 60 spike and recovery experiments for the Fort McHenry Tunnel Dioxin study.

Internal Standards	Ave	Std Dev	RSD	High	Low
^{13}C-2,3,7,8-TCDF	114	11	10%	133	82
^{13}C-2,3,7,8-TCDD	101	14	14%	120	61
^{13}C-1,2,3,7,8-PeCDF	113	13	11%	134	76
^{13}C-1,2,3,7,8-PeCDD	127	15	12%	170	93
^{13}C-1,2,3,4,7,8-HxCDF	78	8	10%	93	55
^{13}C-1,2,3,4,7,8-HxCDD	87	8	9%	100	59
^{13}C-1,2,3,4,6,7,8-HpCDF	81	13	16%	102	51
^{13}C-1,2,3,4,6,7,8-HpCDD	88	14	16%	110	55
^{13}C-OCDD	76	10	13%	96	46
Field Surrogate					
^{37}Cl-2,3,7,8-TCDD	105	8	7%	129	86

Analysis

Instrumentation required to analyze dioxin and furans at trace levels is very specific with magnetic sector High Resolution Mass Spectrometer (HRMS) being the preferred instrument. Quanterra analyzed the samples using one of three VG-70 SE, and one VG Ultima in the Quanterra HRMS facility. All the instruments are devoted to high resolution dioxin analysis.

Instrument Criteria

The mass spectrometer is operated in the electron ionization mode. A static resolving power of at least 10,000 (10 percent valley definition) must be demonstrated at

appropriate masses before any analysis is performed. Corrective actions are implemented whenever the resolving power does not meet the requirement.

Using a perfluorokerosene (PFK) molecular ion peak, the instrument is tuned to meet minimum required resolving power of 10,000 (10 percent valley) at m/z 304.9824 (PFK) which is the reference signal close to m/z 303.9016 (from TCDF). By using the peak matching unit and the aforementioned PFK reference peak, the exact mass of m/z 380.9760 (PFK) is verified to be within 5 ppm of the required value. Note that the selection of the low- and high-mass ions must be such that they provide the largest voltage differential.

Documentation of the instrument resolving power must then be accomplished by recording the peak profile of the high-mass reference signal (m/z 380.9760) obtained during the above peak matching experiment by using the low-mass PFK ion at m/z 304.9824 as a reference. The minimum resolving power of 10,000 must be demonstrated on the high-mass ion while it is transmitted at a lower accelerating voltage than the low-mass reference ion, which is transmitted at full sensitivity. The format of the peak profile representation must allow manual determination of the resolution, i.e., the horizontal axis must be a calibrated mass scale (amu or ppm per division). The result of the peak width measurement (performed at 5 percent of the maximum, which corresponds to the 10-percent valley definition) must appear on the hard copy and cannot exceed 100 ppm at m/z 380.9760 (or 0.038 amu at that particular mass).

Prior to the initial calibration a Window Defining Mix (WDM) that contains the first and last eluting isomers in each chlorination level is injected into the GC to determine the proper switching times for the SIM descriptors. This solution also includes a Column Performance Solution Mixture (CPSM) used to determine the chromatographic separation between the 2,3,7,8-TCDD and the next closest eluting TCDD isomer. The peaks must be resolved with a valley of $\leq 25\%$.

A five point calibration curve containing all the labeled and unlabeled dioxin and furan isomers is used to calibrate the instrument. Relative response factors (RRF) are calculated for all natives relative to internal standards from a single set of injections. A % RSD for the mean response factors of ± 20% for natives and ± 30% for internal standards is used to evaluate the curve materials. In addition the signal to noise S/N ratio for GC signals present in every SICP must be ≥ 10, and the isotopic ratios must be within control limits.

Routine or Continuing Calibration

The mid point of the curve (CC-3) is used as a continuing calibration or daily standard. This standard is run at the beginning of each 12 hour analytical run. The RRF measured for the labeled and the unlabeled standards must be within ± 30%, and ± 20%, respectively, of the mean values established in the initial calibration.

All standards are purchased from certified vendors and come with documentation of authenticity. The standards are logged in and assigned an expiration date upon opening. Calibration and spiking solutions are created from these purchased materials, using Quanterra's standard operating procedures for the preparation of standards. Calibration solution concentrations are confirmed using a third party independent solution. When all standard operating conditions are satisfied, analyses are begun.

The recommended GC column used for dioxin furan analysis is the DB-5 or equivalent column. This column allows for the separation of most target analytes. In addition the method requires a secondary column (DB-225 or equivalent) to be utilized to verify a specific isomer (2,3,7,8-TCDF), if present.

GC conditions: Temperature Program: 190°C, increasing at a rate of 4°C per minute up to 240°C, and maintaining at this temperature until the last of the tetra-group has eluted from the column. (The total time required for this is approximately 25 minutes, depending on the length of the column.) The maintained temperature of 240°C is then increased to 320°C at the rate of 20°C per minute and held at this level until the last compound (octa-group) has eluted from the column.

Identification Criteria: For a gas chromatographic peak to be identified as a PCDD or PCDF, it must meet all of the following criteria:

Retention Times: For 2,3,7,8-substituted congeners, which have an isotopically labeled internal or recovery standard present in the sample extract (this represents a total of 10 congeners including OCDD), the retention time (at maximum peak height) of the sample components (i.e., the two ions used for quantitation purposes) must be within - 1 and + 3 seconds of the retention time of the peak for the isotopically labeled internal or recovery standard at m/z corresponding to the first characteristic ion (of the set of two) to obtain a positive identification of these nine 2,3,7,8-substituted PCDDs/PCDFs and OCDD.

For 2,3,7,8-substituted compounds that do not have an isotopically labeled internal standard present in the sample extract (this represents a total of six congeners), the relative retention time (relative to the appropriate internal standard) must fall within 0.005 relative retention time units of the relative retention times measured in the daily routine calibration. Identification of OCDF is based on its retention time relative to ^{13}C-OCDD as determined from the daily routine calibration results.

For non-2,3,7,8-substituted compounds (tetra through octa; totaling 119 congeners), the retention time must be within the corresponding homologous retention time windows established by analyzing the column performance check solution. The ion current responses for both ions used for quantitative purposes (e.g., for TCDDs: m/z 319.8465 and 321.8936) must reach a maximum simultaneously (± 2 seconds).

The ion current responses for both ions used for the labeled standards (e.g., for ^{13}C-TCDD: m/z 331.9368 and m/z 333.9339) must reach a maximum simultaneously (± 2 seconds).

Ion Abundance Ratios

The integrated ion current for the two ions used for quantitation purposes must have a ratio between the lower and upper limits established for the homologous series to which the peak is assigned.

Signal-To-Noise Ratio

All ion current intensities must be >2.5 times noise level for positive identification of the PCDD/PCDF compound or a group of coeluting isomers.

Polychlorinated Diphenyl Ether Interferences

In addition to the above criteria, the identification of a GC peak as a PCDF can be made only if no signal having a S/N >2.5 is detected, at the same retention time (± 2 seconds), in the corresponding polychlorinated diphenyl ether (PCDPE) channel.

Calculations

For gas chromatographic peaks that have met the criteria outlined, the concentration of the PCDD or PCDF compounds is calculated using the formula:

$$C_x = \frac{A_x \cdot Q_{is}}{A_{is} \cdot W \cdot RRF(n)}$$

where:

- C_x = concentration of unlabeled PCDD/PCDF congeners (or group of coeluting isomers within an homologous series) usually in pg/g or pg/L.
- A_x = sum of the integrated ion abundances of the quantitation ions for the unlabeled PCDDs/PCDFs.
- A_{is} = sum of the integrated ion abundances of the quantitation ions for the labeled internal standards.
- Q_{is} = quantity, in pg, of the internal standard added to the sample before extraction.
- W = sample size in grams. (Note: for air work we report the data as "pg/sample," therefore, a nominal value of 1 is used for this value.)
- RRF(n) = calculated mean relative response factor for the analyte.

Sample-Specific Estimated Detection Limit

The sample-specific estimated detection limit (EDL) is the concentration of a given analyte required to produce a signal with a peak height of at least 2.5 times the background signal level. An EDL is calculated for each 2,3,7,8-substituted congener that is not identified, regardless of whether or not other non-2,3,7,8- substituted isomers are present. Two methods of calculation can be used, as follows, depending on the type of response produced during the analysis of a particular sample.

Samples giving a response for both quantitation ions that is less than 2.5 times the background level will use the formula:

$$EDL(2,3,7,8-PCDD/PCDF) = \frac{2.5 \cdot H_x \cdot Q_{is}}{H_{is} \cdot W \cdot RRF(n)}$$

where:

- EDL = estimated detection limit for homologous 2,3,7,8-substituted PCDDs/PCDFs.
- H_x = height of the average noise for one of the quantitation ions for the unlabeled PCDDs/PCDFs.
- H_{is} = height of one of the quantitation ions for the labeled internal standards.
- Q_{is} = quantity in pg, of the internal standard added to the sample before extraction.

- W = Sample size in g. (Note: for air work we report the data as "pg/sample," therefore a nominal value of 1 is used for this value.)
- RRF(n) = Calculated mean relative response factor for the analyte.

For Fort McHenry dioxin samples, lower than normal threshold limits were used to denote positive values. Quanterra's normal convention is to use target detection limits of 10 pg/sample for the Tetra isomers; 50 pg/sample for penta, hexa, and hepta isomers; and 100 pg/sample for the octa isomer. These were lowered by approximately a factor of five by a thorough manual analysis of all peaks and measured instrument gain. An estimate of the detection limits for this study is provided by the blank samples presented in Table 3-1.

Data Review

Level I: Skilled analysts (with 5 or more years mass spectrometry experience) well versed in the operation and interpretation of dioxin data are responsible for first level review. They are able to make initial decisions regarding data and will, in a collaborative effort, determine corrective actions, if needed, to produce useable data.

Level II: The data are passed on for peer review, a second level review, that will allow a second analyst to evaluate the data generated by the initial analyst. A check list, outlining acceptance criteria, is reviewed along with the data and the second analyst signatures his agreement with the reviewed data.

Level III: Data are passed on for third level or final review. A senior analyst does a final technical review of the data to confirm that the data meet the client's data quality objectives.

Following the last data review, the data were packaged and reported to the DRI.

3.3 Methodology for Calculating Emission Factors

The method of calculating emission rates from tunnel measurements is described in detail in a series of papers by Pierson *et al.* (1983, 1990, 1996). Briefly, one samples simultaneously the tunnel outgoing air (air exiting the tunnel portal and any exhaust ducts) and the incoming air (the air coming in through the tunnel entrance and the supply ducts) and measures, using the methodology described in the previous part of this section, the concentrations of the species of interest in the sampled air. The mass of any given constituent produced by vehicles traveling through the tunnel can be determined from:

$$M = \sum_i (C_{out} V_{out})_i - \sum_j (C_{in} V_{in})_j \qquad (3\text{-}1)$$

where $(C_{out} V_{out})_i$ is the product of concentration C_{out} and volume of air V_{out} (m^3) for each of the "i" exit channels (exhaust ducts, exit portal), and similarly for $(C_{in} V_{in})_j$. For this study there was one outlet (the exit portal), since the exhaust fans were not in

operation, and three inlets (the two supply samples and the entrance portal). Thus for this study, the equation simplifies to:

$$M = (C_{outlet} V_{outlet}) - (C_{inlet} V_{inlet}) - (C_{E\,Vent} V_{E\,Vent}) - (C_{W\,Vent} V_{W\,Vent}) \qquad (3\text{-}2)$$

Given the traffic count "N" and the known length "L" of the tunnel, one can calculate the average emission rate "E" for a given sampling period as:

$$E = M / (N\,L). \qquad (3\text{-}3)$$

In the 1992 Fort McHenry study (Pierson *et al.*, 1996), LD and HD emissions were separated from the calculated emission rates by regression of the observed total fleet emissions against the fraction of HD vehicles. The intercepts of this regression, 0% HD and 100% HD, provided the LD and HD emission rates, respectively. The decision to go to 24 hr. sampling periods precluded choosing runs with large differences in the fraction of HD vehicles. This, in turn, did not allow for the mathematical separation of LD and HD emissions. Instead, we proposed to separate LD and HD emissions by measuring the LD emissions in Bore 3 and subtracting these from the mixed LD and HD emissions in Bore 4 to determine the HD emission rates. As discussed in Section 4, the Bore 3 emission rates were too low to be quantified in this experiment. Based on this low emission rate and the assumption that the HD emissions were much greater than the LD emissions (e.g. EPA 1994, Oehme *et al.*, 1991), we assumed all the observed Bore 4 emissions were due to the HD fraction of the fleet. This will cause an over-estimation of the emission rate from the HD fraction of the fleet, and thus the numbers determined this way should be considered an upper bound for the result from this experiment.

4.0 RESULTS - DIOXINS AND FURANS

This first part of this section details the observed dioxin and furan results at the six sampling locations, (in terms of mass per sample, mass/m^3, and TEQ-mass/m^3). Based on mass/m^3 and TEQ results, emission factors are calculated and presented in the second part of this section along with a comparison to other work.

4.1 Observed Concentrations

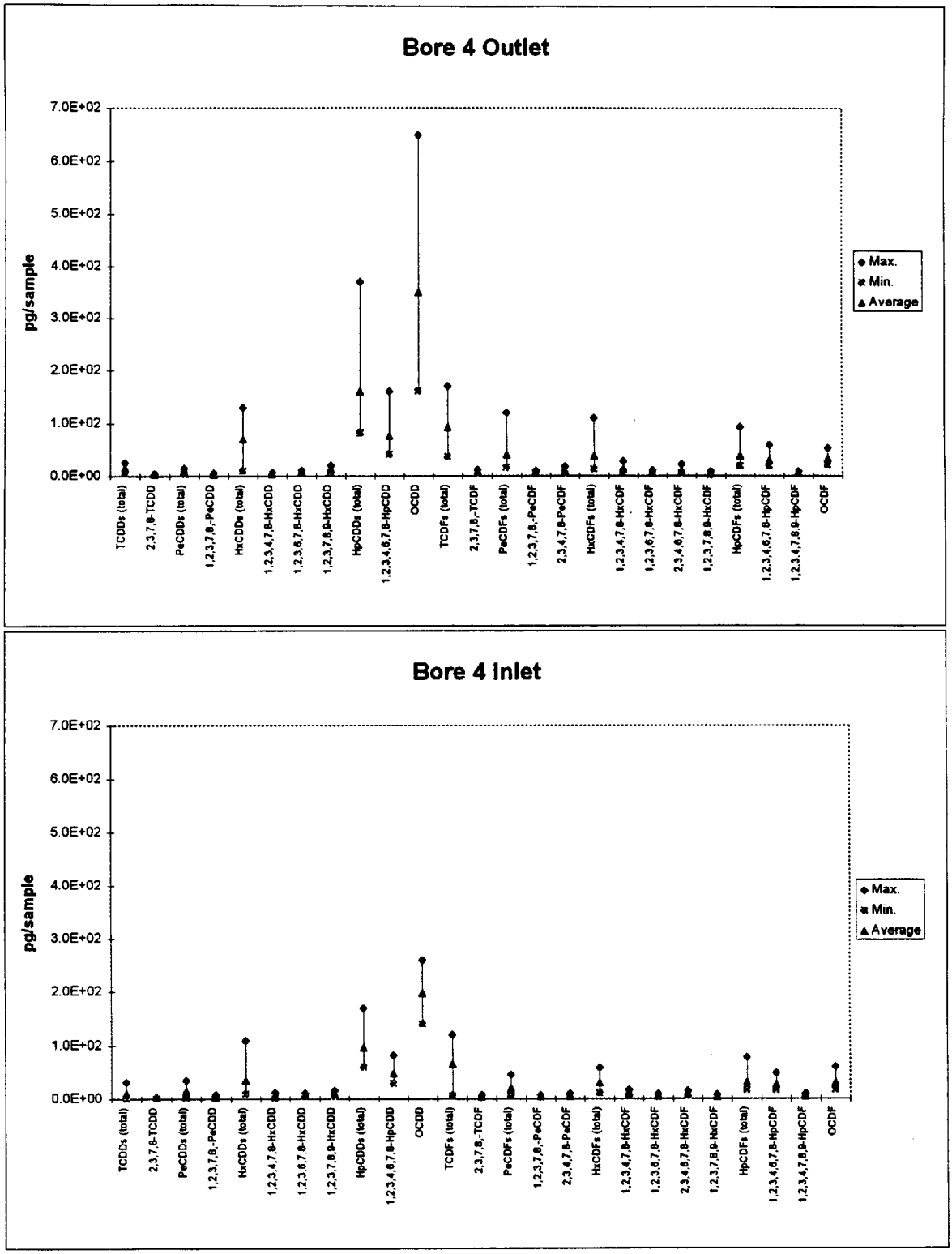
Following analysis of the dioxin samples by Quanterra, the data were reviewed and tabulated. The results of the sample analyses are summarized in Table 4-1; the complete data are in Appendix 1. Table 4-1 contains the pg/sample results from the six different sampling locations showing the highest, lowest and average values observed over the course of the study. A subset of these data is presented graphically in Figure 4-1, which shows the Bore 4 inlet and outlet high, low and average values observed. Note that the vertical scale in this figure is the same for the inlet and outlet to aid in interpreting the figure. It is clear from this figure that the outlet samples are more heavily loaded than the inlets. When reviewing Table 4-1, Appendix 1, and Figure 4-1, the following caveats are important to consider:

- These results do not take into account the sampler flow rates. The Bore 4 outlet dioxin samplers were run at slightly lower flow rates than the other samplers. This was necessary to reduce "plugging" of the sample filters by the large amount of particles collected over the 24-hr. sampling period.
- Beginning with Run 3, collocated sampling was performed at the Bore 4 outlet to increase the amount of dioxins and furans collected. The reported values are the combination of the two collocated samples. As part of the sample analysis, the collocated samples were combined to increase the mass of species analyzed and thus increase the sensitivity. This was done for all runs except Bore 4, Run 4 which was run on the individual outlet samples to test the importance of combining the samples. Based on the initial Bore 4, Run 4 results, we decided to combine the collocated samples.
- The Bore 3 and 4, Run 1 outlet results are low. One of the Fort McHenry Tunnel workers tripped the circuit breaker for the outlets into which the samplers were plugged during the course of the run. This run is therefore invalid for calculating emission factors because the samplers at the inlet and outlet did not for run the same time period.
- The filter on the dioxin sampler for the Run 10 East Supply sample was torn and the sample was not analyzed. The West Supply values were substituted since in most cases the two supply values were nearly identical and the vents had only a small impact on the calculated emission factors.

Table 4-1. Summary of Observed Sample Loadings (pg/sample).

Sample Location	West Vent			Bore 3 Inlet			Bore 4 Inlet			East Vent			Bore 3 Outlet			Bore 4 Outlet		
Value	Max.	Min.	Average	Max.	Min.	Average	Max.	Min.	Average	Max.	Min.	Average	Max.	Min.	Average	Max.	Min.	Average
TCDDs (total)	2.7E+01	4.0E+00	1.4E+01	8.9E+00	3.4E+00	5.9E+00	3.2E+01	9.4E-01	9.5E+00	2.1E+01	4.3E+00	8.8E+00	8.8E+00	3.9E+00	5.8E+00	2.6E+01	6.2E+00	1.6E+01
2,3,7,8-TCDD	6.9E+00	1.6E+00	3.6E+00	3.8E+00	2.5E+00	3.0E+00	4.7E+00	8.7E-01	2.9E+00	3.4E+00	1.6E+00	2.6E+00	3.7E+00	1.2E+00	2.5E+00	5.0E+00	1.8E+00	3.4E+00
PeCDDs (total)	2.8E+01	2.1E+00	8.8E+00	3.7E+01	1.9E+00	1.2E+01	3.5E+01	2.6E+00	1.4E+01	8.1E+00	3.9E+00	6.0E+00	5.9E+00	4.0E+00	4.7E+00	1.5E+01	4.5E+00	9.1E+00
1,2,3,7,8,-PeCDD	7.6E+00	1.9E+00	4.2E+00	6.9E+00	1.8E+00	3.4E+00	7.5E+00	1.6E+00	4.0E+00	4.0E+00	1.2E+00	2.8E+00	3.1E+00	2.2E+00	2.5E+00	5.9E+00	1.6E+00	3.4E+00
HxCDDs (total)	1.6E+02	8.5E+00	4.0E+01	5.0E+01	9.6E+00	2.8E+01	1.1E+02	1.0E+01	3.5E+01	1.8E+02	9.0E+00	5.5E+01	2.8E+01	8.3E+00	1.5E+01	1.3E+02	1.0E+01	7.0E+01
1,2,3,4,7,8-HxCDD	1.3E+01	1.3E+00	4.7E+00	9.4E+00	2.0E+00	4.2E+00	1.2E+01	1.6E+00	4.5E+00	8.1E+00	1.9E+00	4.0E+00	3.6E+00	2.1E+00	2.8E+00	7.0E+00	2.0E+00	4.1E+00
1,2,3,6,7,8-HxCDD	1.6E+01	3.2E+00	6.9E+00	8.9E+00	3.0E+00	6.1E+00	1.1E+01	3.5E+00	6.6E+00	1.4E+01	2.6E+00	6.4E+00	4.9E+00	2.8E+00	4.1E+00	1.1E+01	4.4E+00	7.8E+00
1,2,3,7,8,9-HxCDD	2.6E+01	4.2E+00	1.0E+01	9.5E+00	5.4E+00	7.6E+00	1.6E+01	4.5E+00	8.7E+00	2.9E+01	3.8E+00	1.1E+01	7.2E+00	3.9E+00	6.1E+00	2.0E+01	5.8E+00	1.2E+01
HpCDDs (total)	4.2E+02	5.6E+01	1.3E+02	9.6E+01	5.8E+01	7.5E+01	1.7E+02	5.9E+01	9.6E+01	6.8E+02	4.9E+01	2.0E+02	7.9E+01	5.0E+01	6.8E+01	3.7E+02	8.2E+01	1.6E+02
1,2,3,4,6,7,8-HpCDD	2.3E+02	2.8E+01	6.6E+01	4.4E+01	2.7E+01	3.6E+01	8.2E+01	2.9E+01	4.7E+01	2.9E+02	2.4E+01	8.8E+01	3.8E+01	2.4E+01	3.3E+01	1.6E+02	4.1E+01	7.6E+01
OCDD	1.4E+03	1.2E+02	3.1E+02	2.3E+02	1.3E+02	1.6E+02	2.6E+02	1.4E+02	2.0E+02	9.7E+02	9.7E+01	3.2E+02	1.6E+02	1.2E+02	1.4E+02	6.5E+02	1.6E+02	3.5E+02
TCDFs (total)	2.1E+02	3.1E+01	1.2E+02	1.3E+02	7.3E+00	8.1E+01	1.2E+02	5.8E+00	6.5E+01	1.9E+02	5.2E+01	1.1E+02	8.5E+01	7.2E+00	5.4E+01	1.7E+02	3.6E+01	9.2E+01
2,3,7,8,-TCDF	9.8E+00	1.9E+00	5.4E+00	6.9E+00	3.4E+00	5.1E+00	7.2E+00	2.4E+00	4.4E+00	7.6E+00	3.5E+00	5.5E+00	7.1E+00	2.1E+00	4.7E+00	1.2E+01	3.7E+00	7.6E+00
PeCDFs (total)	1.2E+02	4.7E+00	3.4E+01	5.5E+01	1.1E+01	2.3E+01	4.5E+01	7.1E+00	2.0E+01	8.6E+01	1.3E+01	3.3E+01	4.7E+01	1.1E+01	2.5E+01	1.2E+02	1.5E+01	4.0E+01
1,2,3,7,8,-PeCDF	8.9E+00	3.0E+00	5.4E+00	9.9E+00	2.9E+00	5.6E+00	7.3E+00	2.2E+00	5.2E+00	7.9E+00	2.0E+00	4.6E+00	5.2E+00	2.5E+00	4.1E+00	1.0E+01	3.1E+00	4.7E+00
2,3,4,7,8-PeCDF	1.2E+01	2.6E+00	6.0E+00	9.3E+00	2.4E+00	6.4E+00	9.9E+00	3.0E+00	6.0E+00	2.0E+01	2.5E+00	7.5E+00	1.0E+01	3.8E+00	6.5E+00	1.8E+01	3.7E+00	7.6E+00
HxCDFs (total)	1.6E+02	5.2E+00	4.0E+01	5.5E+01	1.1E+01	2.7E+01	5.8E+01	1.1E+01	3.0E+01	9.9E+01	9.8E+00	4.1E+01	6.7E+01	1.0E+01	3.1E+01	1.1E+02	1.3E+01	3.8E+01
1,2,3,4,7,8-HxCDF	2.5E+01	3.8E+00	1.1E+01	1.7E+01	4.0E+00	1.0E+01	1.7E+01	6.0E+00	1.0E+01	2.6E+01	5.0E+00	1.4E+01	2.0E+01	4.5E+00	1.1E+01	2.8E+01	7.0E+00	1.3E+01
1,2,3,6,7,8-HxCDF	1.9E+01	2.2E+00	6.9E+00	8.8E+00	4.5E+00	5.9E+00	8.8E+00	3.0E+00	5.8E+00	1.2E+01	2.6E+00	6.1E+00	9.5E+00	3.7E+00	6.2E+00	1.1E+01	3.2E+00	6.4E+00
2,3,4,6,7,8-HxCDF	2.1E+01	3.7E+00	1.0E+01	1.4E+01	5.5E+00	9.1E+00	1.5E+01	5.2E+00	9.4E+00	2.9E+01	4.0E+00	1.3E+01	1.7E+01	1.8E+00	9.3E+00	2.2E+01	5.1E+00	9.9E+00
1,2,3,7,8,9-HxCDF	2.0E+01	1.6E+00	6.3E+00	7.6E+00	1.3E+00	4.0E+00	7.6E+00	2.2E+00	3.6E+00	7.9E+00	1.3E+00	3.2E+00	6.4E+00	1.2E+00	3.1E+00	9.4E+00	1.1E+00	3.8E+00
HpCDFs (total)	6.1E+01	1.3E+01	3.5E+01	3.7E+01	1.7E+01	2.3E+01	7.8E+01	1.6E+01	3.1E+01	1.5E+02	1.2E+01	5.3E+01	6.6E+01	1.6E+01	3.4E+01	9.3E+01	1.8E+01	3.9E+01
1,2,3,4,6,7,8-HpCDF	8.0E+01	1.3E+01	3.2E+01	3.7E+01	1.7E+01	2.3E+01	4.8E+01	1.6E+01	2.6E+01	8.5E+01	1.2E+01	3.8E+01	4.3E+01	1.6E+01	2.7E+01	5.9E+01	1.8E+01	2.9E+01
1,2,3,4,7,8,9-HpCDF	1.3E+01	2.3E+00	6.7E+00	5.4E+00	1.6E+00	3.9E+00	9.5E+00	2.7E+00	4.8E+00	1.5E+01	2.0E+00	6.3E+00	7.9E+00	1.5E+00	4.6E+00	8.6E+00	2.7E+00	4.8E+00
OCDF	1.0E+02	1.7E+01	3.8E+01	4.0E+01	1.3E+01	2.5E+01	6.0E+01	1.7E+01	3.0E+01	9.6E+01	1.7E+01	4.3E+01	5.1E+01	1.4E+01	2.9E+01	5.3E+01	2.1E+01	3.4E+01

Figure 4-1. Comparison of pg/sample values for Bore 4 outlet (top) and inlet (bottom) sites. The figure shows the average, high and low values for each congener and homologue series.



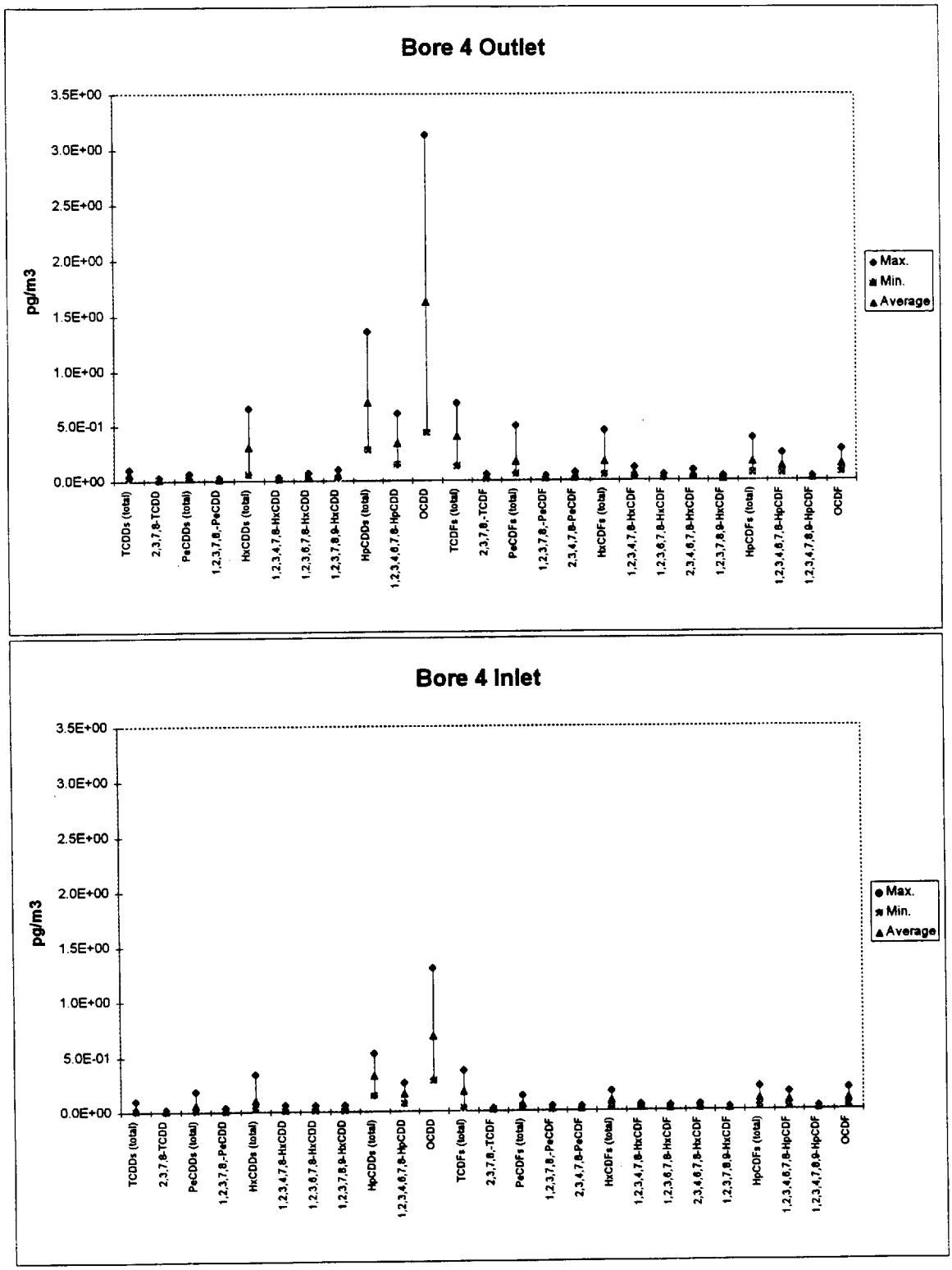
Based on the pg/sample results and the measured sampler flow rates, concentrations in pg/m^3 were calculated. These results are summarized in Table 4-2 and the complete set of data are in Appendix 2. This table contains the pg/m^3 results from the six different sampling locations showing the highest, lowest and average value observed over the course of the study. A subset of these data is presented graphically in Figure 4-2 which shows for Bore 4 inlet and outlet the high, low and average values observed. Note that the vertical scale in this figure is the same for the inlet and outlet to aid in interpreting the figure. Here again it is clear that the concentrations in the tunnel were higher at the outlet than at the inlet, which is to be expected if the vehicles in the tunnel are emitting dioxins and furans. Included in Tables 4-1 and 4-2, as well as Appendices 1 and 2, are the total concentrations for the homologues TCDDs, PeCDDs, HxCDDs, HpCDDs, TCDFs, PeCDFs, HxCDFs, and HpCDFs. These results, while not used in the emission factor calculation, provide a quick check of the ability of the experiment to detect emissions in the two bores. This check is as follows:

- For the valid runs are the outlet concentrations greater than the inlet concentrations? In other words, were emissions high enough to detect a difference and was this difference great enough to proceed with calculating speciated emission factors?
- In the case of the Bore 3 results, the outlet and inlet concentrations were similar. Vent concentrations also have an impact but for this check, they can be ignored for a first approximation. Since the vent air generally supplies approximately 20% of the total flow, if the ratio is not at least 1.2 (and the vent air is zero) we must assume the difference is too low to give a reasonable estimate of emissions. If the vent air contains any compound then the ratio must be even higher. The outlet to inlet ratio for TCDD varied between 0.7 and 1.3. The TCDF ratio varied between 0.8 and 1.0. The average ratio for all congeners varied between 0.8 and 1.5. Given the small difference between inlet and outlet concentrations, emission factors in Bore 3 cannot be estimated. This comparison is shown graphically for the homologues in Figures 4-3, 4-4 and 4-5. Figure 4-3 shows the average observed concentrations in Bore 3 from the inlet, outlet and both vent samples. It is fairly clear that there is very little difference among the four sampling sites. Figure 4-4 presents the same data that are in Figure 4-3 as a line plot showing the log of the observed concentration for each homologue. Again there is not enough difference between the inlets and outlets to determine an emission factor. Figures 4-3 and 4-4 showed the average concentrations. A specific case is presented in Figure 4-5 which shows the data for Run 1. Again, the inlet and outlet show very little difference and the vents are similar in concentration. The results are similar for all other runs (see data in Appendix 2).
- In the case of the Bore 4 results, the outlet and inlet concentrations were significantly different. The outlet concentrations were between a factor of 2.0 and 4.5 greater, on average for all species, than the inlet concentrations. Thus, we can estimate emission factors for the Bore 4 runs. A similar comparison as made for Bore 3 is presented in Figures 4-6, 4-7 and 4-8 for Bore 4. Figure 4-6 shows the average observed concentrations in Bore 4 for the inlet, outlet and both vent samples. In a striking contrast to Figure 4-3,

Table 4-2. Summary of Observed Concentrations (pg/m^3).

Sample Location	West Vent			Bore 3 Inlet			Bore 4 Inlet			East Vent			Bore 3 Outlet			Bore 4 Outlet		
Value	Max.	Min.	Average	Max.	Min.	Average	Max.	Min.	Average	Max.	Min.	Average	Max.	Min.	Average	Max.	Min.	Average
TCDDs (total)	4.8E-02	1.1E-02	2.7E-02	2.3E-02	1.1E-02	1.7E-02	9.9E-02	5.6E-03	2.8E-02	3.4E-02	7.4E-03	1.6E-02	2.8E-02	1.1E-02	2.1E-02	1.1E-01	2.6E-02	6.2E-02
2,3,7,8-TCDD	1.4E-02	2.8E-03	7.8E-03	1.3E-02	5.9E-03	8.9E-03	2.3E-02	2.4E-03	9.9E-03	6.3E-03	2.7E-03	4.9E-03	1.5E-02	2.9E-03	9.8E-03	3.3E-02	6.8E-03	1.6E-02
PeCDDs (total)	5.2E-02	6.5E-03	1.7E-02	9.4E-02	8.2E-03	3.1E-02	1.9E-01	8.6E-03	6.0E-02	1.7E-02	7.1E-03	1.1E-02	2.4E-02	1.1E-02	1.8E-02	6.7E-02	1.7E-02	3.8E-02
1,2,3,7,8,-PeCDD	1.6E-02	3.5E-03	8.7E-03	1.8E-02	4.2E-03	9.5E-03	4.1E-02	4.1E-03	1.5E-02	8.4E-03	2.0E-03	5.3E-03	1.4E-02	5.6E-03	9.4E-03	2.8E-02	6.1E-03	1.5E-02
HxCDDs (total)	3.3E-01	1.6E-02	8.0E-02	1.3E-01	2.3E-02	8.4E-02	3.4E-01	3.0E-02	1.0E-01	3.2E-01	1.6E-02	1.0E-01	1.1E-01	2.1E-02	5.9E-02	6.6E-01	5.7E-02	3.0E-01
1,2,3,4,7,8-HxCDD	2.4E-02	2.4E-03	9.7E-03	2.4E-02	4.7E-03	1.3E-02	6.5E-02	3.5E-03	1.7E-02	1.5E-02	3.3E-03	7.7E-03	1.6E-02	5.9E-03	1.1E-02	3.6E-02	7.6E-03	1.8E-02
1,2,3,6,7,8-HxCDD	3.3E-02	6.0E-03	1.4E-02	3.2E-02	7.1E-03	1.9E-02	6.0E-02	8.6E-03	2.3E-02	2.5E-02	4.2E-03	1.2E-02	2.2E-02	6.9E-03	1.6E-02	7.3E-02	1.7E-02	3.4E-02
1,2,3,7,8,9-HxCDD	5.4E-02	8.0E-03	2.1E-02	2.8E-02	1.3E-02	2.3E-02	6.0E-02	1.0E-02	2.9E-02	5.2E-02	6.2E-03	2.2E-02	3.5E-02	9.8E-03	2.3E-02	1.0E-01	2.2E-02	5.3E-02
HpCDDs (total)	8.7E-01	1.0E-01	2.8E-01	4.3E-01	1.4E-01	2.3E-01	5.3E-01	1.4E-01	3.2E-01	1.2E+00	8.6E-02	3.6E-01	3.7E-01	1.3E-01	2.6E-01	1.4E+00	2.8E-01	7.1E-01
1,2,3,4,6,7,8-HpCDD	4.8E-01	5.2E-02	1.4E-01	2.0E-01	6.9E-02	1.1E-01	2.6E-01	6.7E-02	1.6E-01	5.2E-01	4.1E-02	1.6E-01	1.8E-01	6.1E-02	1.3E-01	6.1E-01	1.4E-01	3.4E-01
OCDD	2.9E+00	2.2E-01	6.6E-01	1.0E+00	3.1E-01	5.1E-01	1.3E+00	2.8E-01	6.8E-01	1.7E+00	1.6E-01	5.9E-01	7.3E-01	3.0E-01	5.3E-01	3.1E+00	4.4E-01	1.6E+00
TCDFs (total)	3.9E-01	1.0E-01	2.3E-01	4.2E-01	3.3E-02	2.2E-01	3.7E-01	2.6E-02	1.8E-01	4.6E-01	8.7E-02	2.1E-01	3.9E-01	3.8E-02	1.9E-01	7.0E-01	1.3E-01	4.0E-01
2,3,7,8,-TCDF	2.0E-02	6.2E-03	1.1E-02	2.2E-02	8.3E-03	1.5E-02	2.2E-02	7.6E-03	1.4E-02	1.9E-02	5.7E-03	1.1E-02	2.6E-02	1.1E-02	1.6E-02	5.8E-02	1.1E-02	3.4E-02
PeCDFs (total)	2.5E-01	1.7E-02	6.8E-02	1.8E-01	3.7E-02	7.0E-02	1.4E-01	3.2E-02	6.0E-02	1.7E-01	2.3E-02	6.5E-02	2.2E-01	4.4E-02	9.6E-02	5.0E-01	5.7E-02	1.7E-01
1,2,3,7,8,-PeCDF	1.7E-02	6.7E-03	1.1E-02	2.5E-02	9.8E-03	1.6E-02	4.2E-02	6.0E-03	1.9E-02	2.1E-02	3.3E-03	9.3E-03	2.4E-02	9.3E-03	1.5E-02	4.1E-02	1.1E-02	2.1E-02
2,3,4,7,8-PeCDF	2.5E-02	5.0E-03	1.2E-02	3.0E-02	1.1E-02	1.8E-02	4.1E-02	8.0E-03	2.1E-02	3.9E-02	4.1E-03	1.5E-02	4.6E-02	1.3E-02	2.5E-02	7.4E-02	1.4E-02	3.4E-02
HxCDFs (total)	3.3E-01	1.6E-02	8.1E-02	1.8E-01	3.3E-02	7.8E-02	1.8E-01	3.0E-02	9.3E-02	1.9E-01	1.8E-02	7.7E-02	3.1E-01	3.3E-02	1.3E-01	4.5E-01	4.7E-02	1.7E-01
1,2,3,4,7,8-HxCDF	5.2E-02	8.2E-03	2.3E-02	5.5E-02	1.0E-02	3.0E-02	5.1E-02	1.6E-02	3.4E-02	5.0E-02	9.1E-03	2.6E-02	9.2E-02	1.1E-02	4.3E-02	1.2E-01	2.7E-02	5.6E-02
1,2,3,6,7,8-HxCDF	3.9E-02	4.1E-03	1.5E-02	2.8E-02	1.1E-02	1.8E-02	4.4E-02	7.3E-03	2.0E-02	2.0E-02	4.4E-03	1.2E-02	4.4E-02	1.2E-02	2.4E-02	5.5E-02	1.2E-02	2.9E-02
2,3,4,6,7,8-HxCDF	4.3E-02	6.9E-03	2.1E-02	4.5E-02	1.6E-02	2.7E-02	5.1E-02	1.2E-02	3.2E-02	4.9E-02	7.2E-03	2.5E-02	7.8E-02	4.5E-03	3.7E-02	9.1E-02	2.0E-02	4.3E-02
1,2,3,7,8,9-HxCDF	4.1E-02	3.0E-03	1.3E-02	1.9E-02	5.8E-03	1.1E-02	2.3E-02	4.3E-03	1.2E-02	1.3E-02	2.4E-03	6.0E-03	2.9E-02	3.0E-03	1.3E-02	3.9E-02	4.2E-03	1.7E-02
HpCDFs (total)	1.2E-01	2.4E-02	7.1E-02	1.2E-01	4.3E-02	6.9E-02	2.1E-01	3.1E-02	1.0E-01	2.5E-01	2.2E-02	9.4E-02	3.0E-01	4.0E-02	1.4E-01	3.8E-01	6.1E-02	1.6E-01
1,2,3,4,6,7,8-HpCDF	1.7E-01	2.4E-02	6.7E-02	1.2E-01	4.3E-02	6.9E-02	1.7E-01	3.1E-02	8.9E-02	1.4E-01	2.2E-02	6.8E-02	2.0E-01	4.0E-02	1.1E-01	2.4E-01	6.1E-02	1.3E-01
1,2,3,4,7,8,9-HpCDF	4.5E-02	4.3E-03	1.6E-02	1.6E-02	7.2E-03	1.1E-02	3.1E-02	4.5E-03	1.6E-02	2.5E-02	3.6E-03	1.1E-02	3.6E-02	3.8E-03	1.8E-02	3.6E-02	1.2E-02	2.1E-02
OCDF	2.1E-01	3.7E-02	7.9E-02	1.3E-01	3.3E-02	7.5E-02	2.0E-01	3.5E-02	1.0E-01	1.6E-01	3.1E-02	7.7E-02	2.0E-01	4.3E-02	1.1E-01	2.8E-01	7.1E-02	1.5E-01

Figure 4-2. Comparison of pg/m^3 values for Bore 4 outlet (top) and inlet (bottom) sites. The figure shows the average, high and low values for each congener and homologue series.



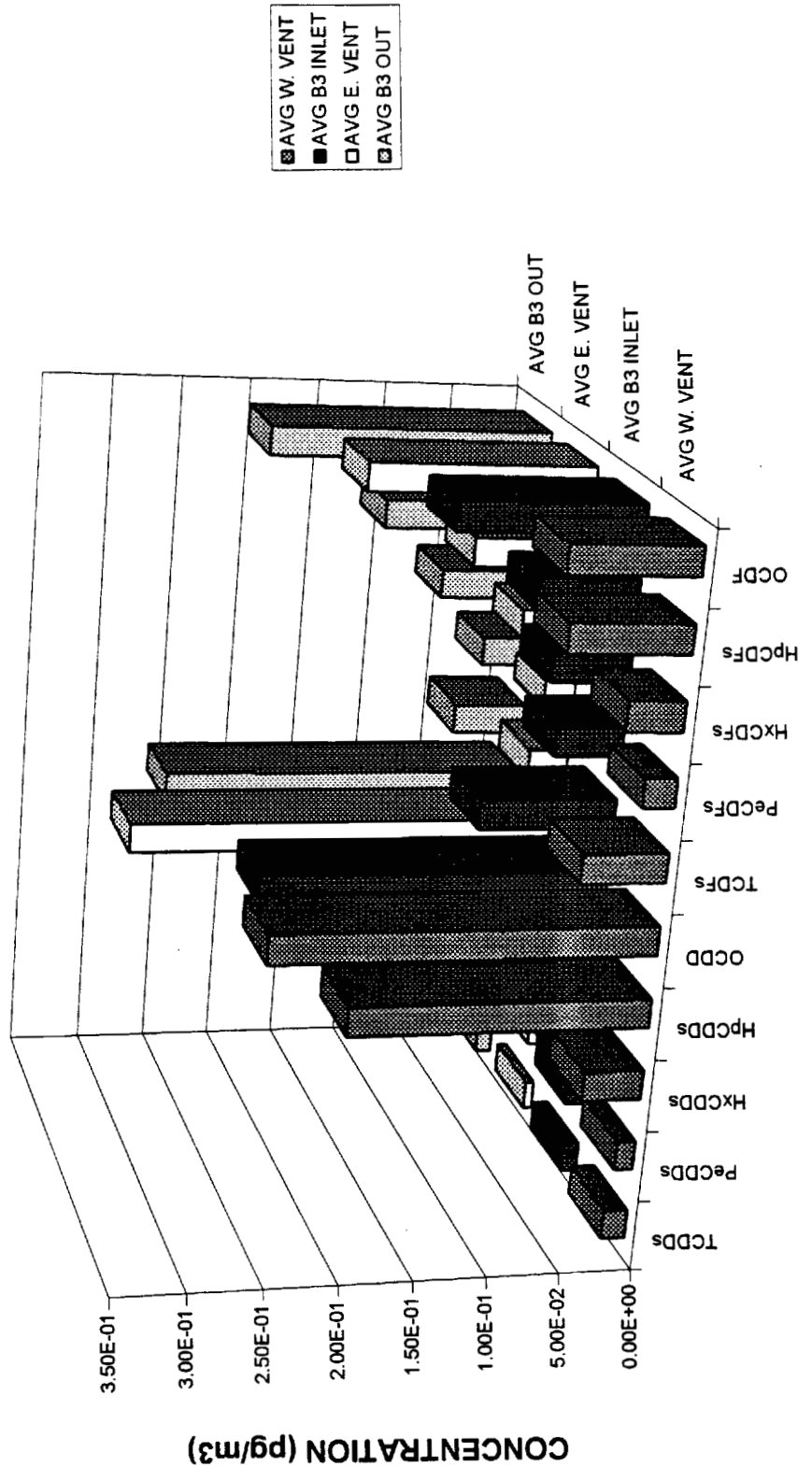


Figure 4-3. Bore 3 Observed Concentrations - Average.

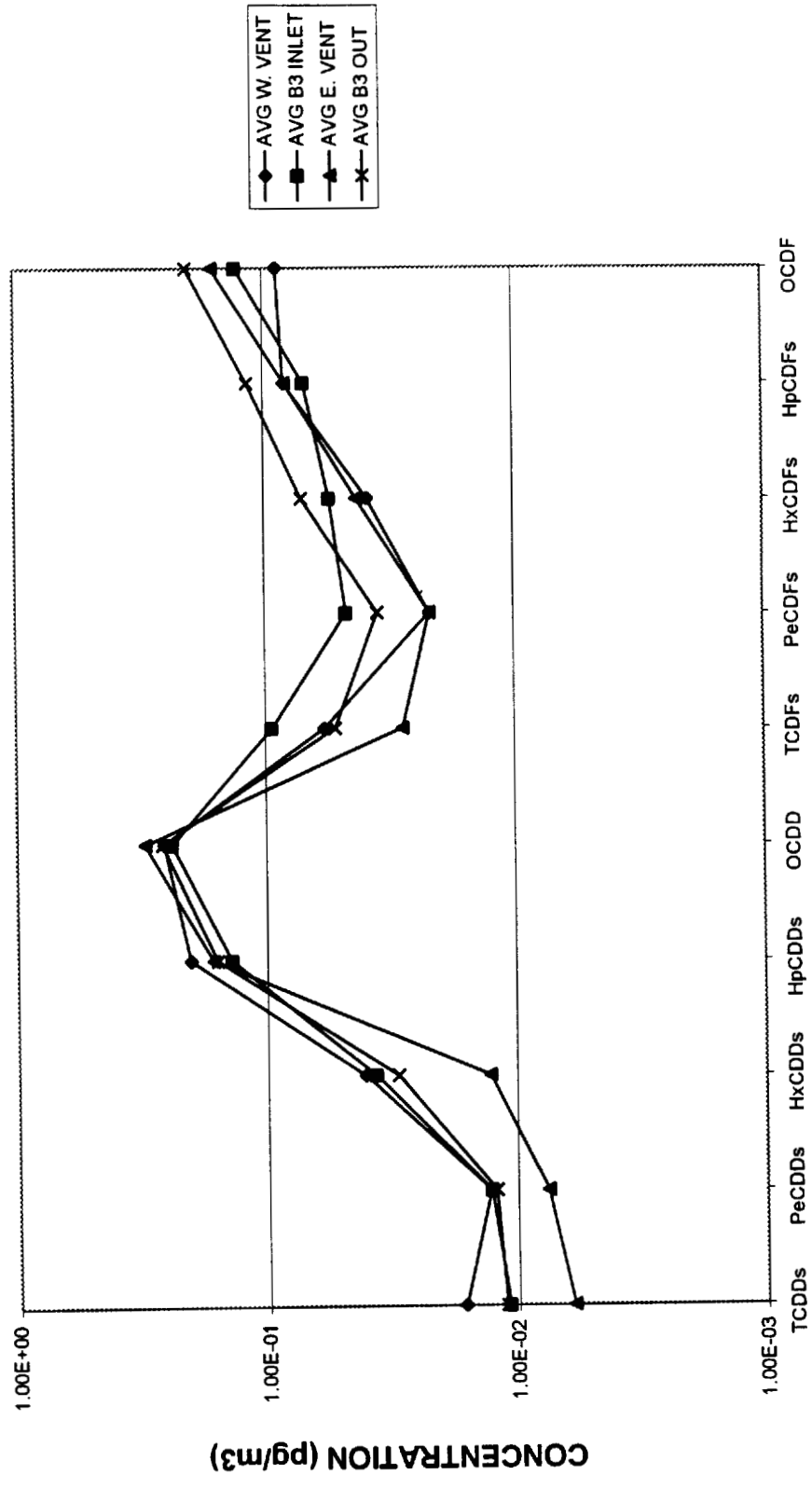


Figure 4-4. Bore 3 Observed Concentrations - Average.

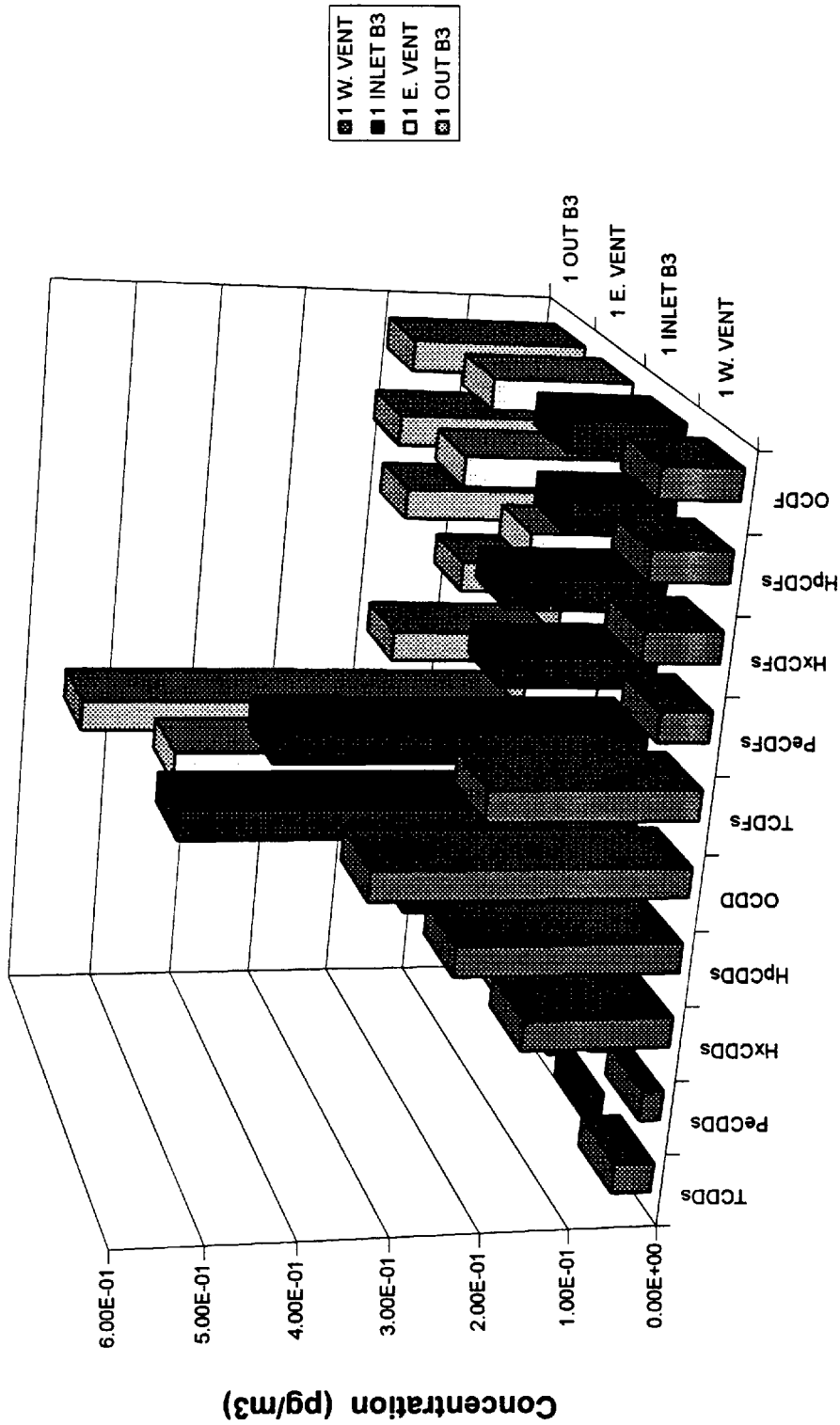


Figure 4-5. Bore 3 Observed Concentrations - Run 1.

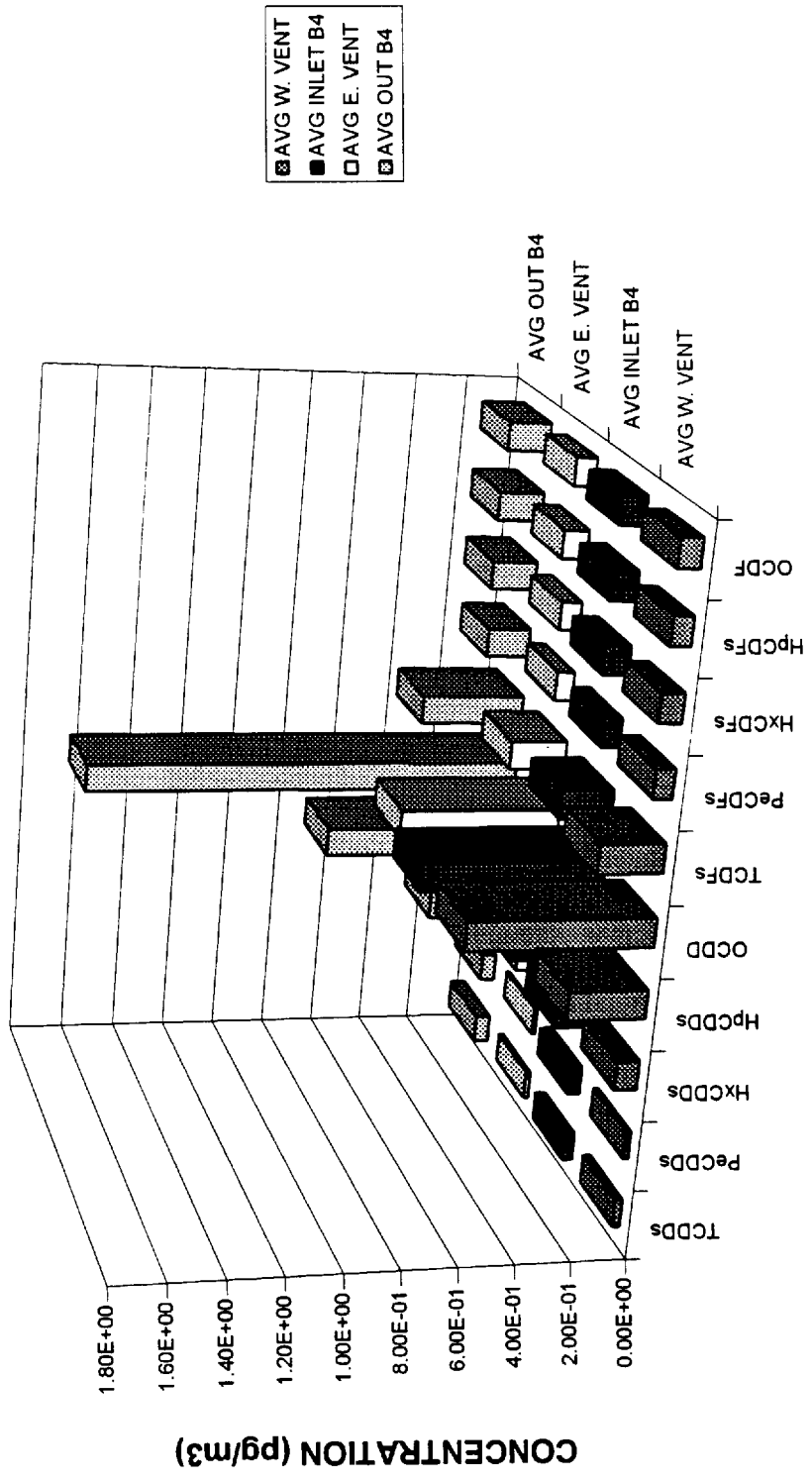


Figure 4-6. Bore 4 Observed Concentrations - Average.

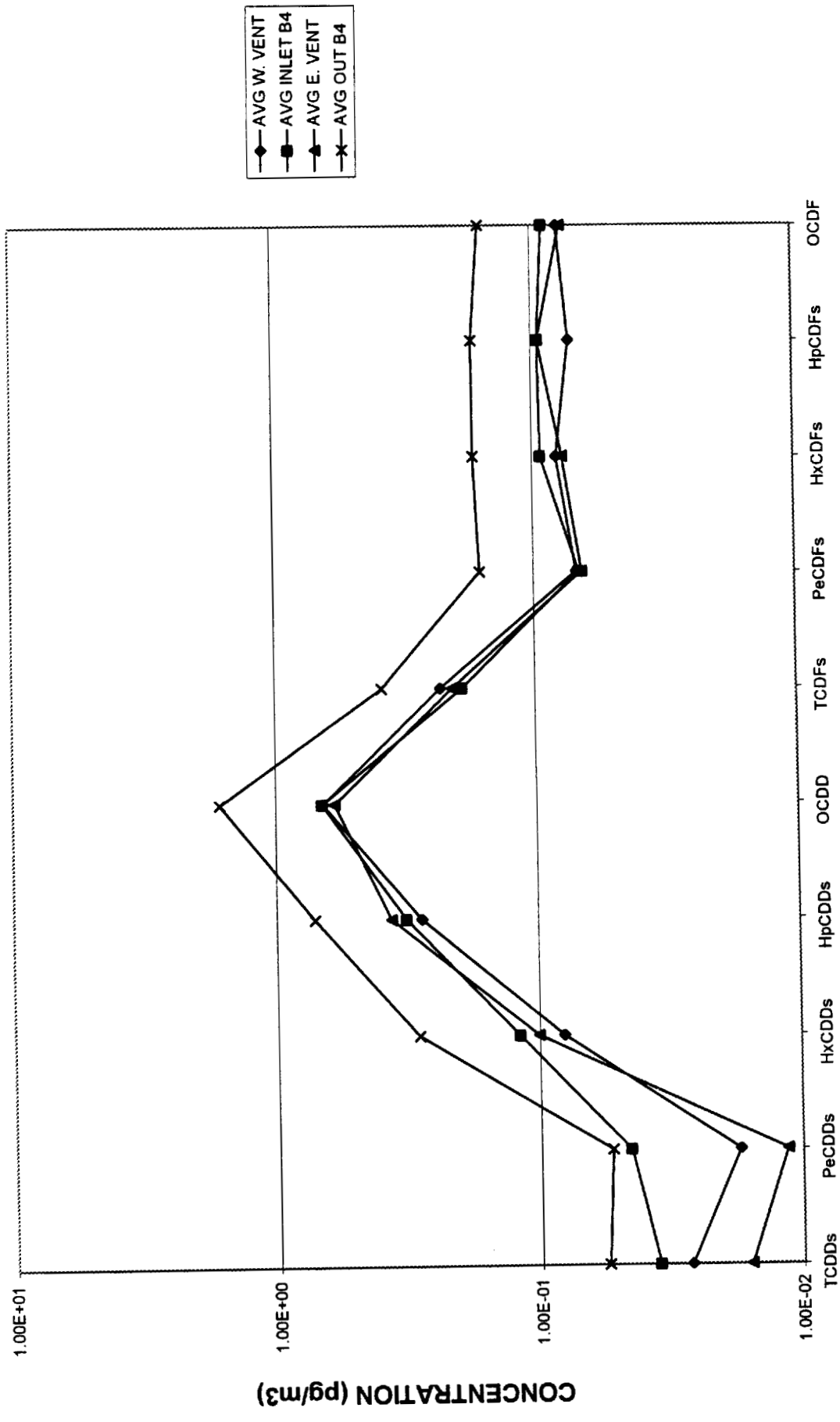


Figure 4-7. Bore 4 - Observed Concentrations - Average.

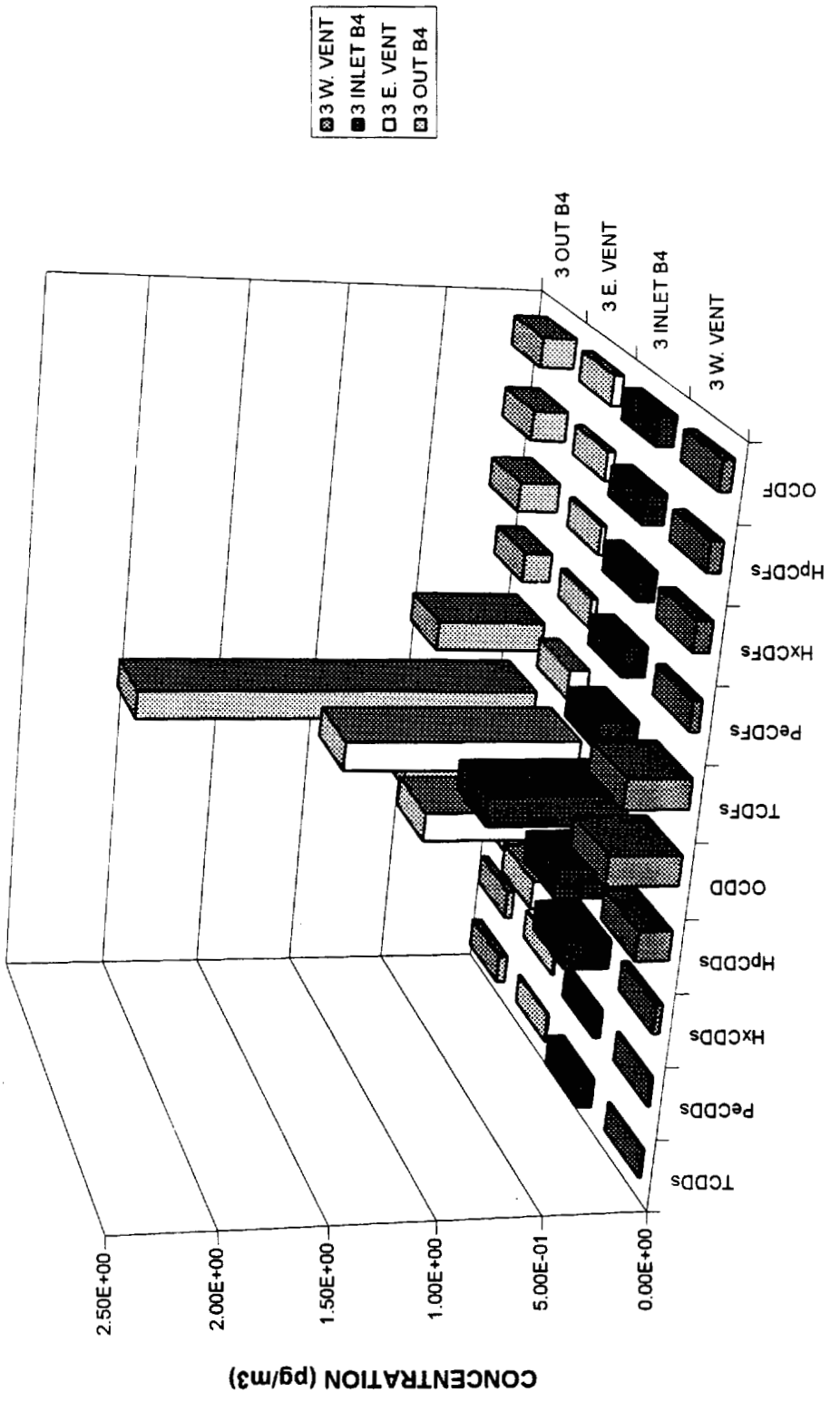


Figure 4-8. Bore 4 Observed Concentrations - Run 3.

one can now see a very clear difference in the Bore 4 outlet values being, on average, higher than the inlet or vent values. Figure 4-7 presents the same data that are in Figure 4-6 as a line plot of the log concentration for each congener group. In this case the outlet line remains clearly above the other sample locations for all congeners. Figures 4-6 and 4-7 show the average concentration. A specific case is presented in Figure 4-8, which shows the data for Run 3, a daytime run. As with the average of all runs, this run shows a clear difference between the outlet and the other locations. The results are similar for all other runs (see data in Appendix 2).

As can be seen in the preceding discussion, most of the mass emissions are accounted for by the OCDD and OCDF isomers. Since TEQ is the measurement of regulatory concern rather than mass (EPA, 1989), it is important to calculate a TEQ emission factor in addition to a mass emission factor. Prior to doing this, TEQ concentrations need to be calculated.

TEQ concentrations are determined by multiplying the pg/m^3 results (see Appendix 2 and summary in Table 4-2) by the appropriate TEQ factors to yield the TEQ concentrations ($pg\text{-}TEQ/m^3$) in the samples which are summarized in Table 4-3. Appendix 3 contains the complete data set along with the TEQ factors. The TEQ factors used in this study are from EPA, 1989. A subset of the data in Table 4-3 is presented graphically in Figure 4-9 which shows the Bore 4 inlet and outlet high, low and average values observed. Note that the vertical scale in this figure is the same for the inlet and outlet to aid in interpreting the figure. Here again it is clear that the TEQ concentrations in the tunnel were higher at the outlet than at the inlet, which is to be expected if the vehicles in the tunnel are sources of dioxins and furans. Comparing Figure 4-9 with Figure 4-2, one can clearly see the effect of the TEQ factors which is to increase the importance of some congeners, notably, 2,3,7,8-TCDD, 1,2,3,7,8-PeCDD, and 2,3,4,7,8-PeCDF. These three have the highest TEQ factors in the set at 1, 0.5, and 0.5, respectively. At the same time, the TEQ decreases the importance of some other isomers, most notably OCDD, which has a TEQ factor of 0.001.

4.2 Emission Factors

Using the results in Appendix 3 (and summarized in Table 4-3), the methodology discussed in Section 3, and the observed vehicle counts and tunnel flows (see Appendix 4), speciated and total mass and TEQ emission factors were calculated. The results for the valid runs are presented in Table 4-4 for the mass emission factors and Table 4-5 for the TEQ emission factors. Tables 4-4 and 4-5 do not have data for runs 1, 4, and 7. These runs were invalid for various reasons that will be discussed in this section.

Table 4-4 shows the mass emission factors for the congeners and homologues in units of ng/veh-mi. In this table, any negative emission factors that occurred have been set to zero. All zero values in this table are because they were set as such. At the bottom of Table 4-4 are the total emission factors for the entire fleet, the fraction of HD vehicles in each run, and the calculated emission factors for the sums of the individual

Table 4-3. Summary of Observed TEQ Concentrations (pg-TEQ/m^3).

Sample Location	West Vent			Bore 3 Inlet			Bore 4 Inlet			East Vent			Bore 3 Outlet			Bore 4 Outlet		
Value	Max.	Min	Average	Max.	Min	Average	Max	Min.	Average	Max.	Min.	Average	Max.	Min.	Average	Max.	Min	Average
2,3,7,8-TCDD	1.4E-02	2.8E-03	7.8E-03	1.3E-02	5.9E-03	8.9E-03	2.3E-02	2.4E-03	9.9E-03	6.3E-03	2.7E-03	4.9E-03	1.5E-02	2.9E-03	9.8E-03	3.3E-02	6.8E-03	1.6E-02
1,2,3,7,8,-PeCDD	7.9E-03	1.8E-03	4.4E-03	8.8E-03	2.1E-03	4.8E-03	2.0E-02	2.1E-03	7.5E-03	4.2E-03	9.8E-04	2.7E-03	7.1E-03	2.8E-03	4.7E-03	1.4E-02	3.0E-03	7.5E-03
1,2,3,4,7,8-HxCDD	2.4E-03	2.4E-04	9.7E-04	2.4E-03	4.7E-04	1.3E-03	6.5E-03	3.5E-04	1.7E-03	1.5E-03	3.3E-04	7.7E-04	1.6E-03	5.9E-04	1.1E-03	3.6E-03	7.6E-04	1.8E-03
1,2,3,6,7,8-HxCDD	3.3E-03	6.0E-04	1.4E-03	3.2E-03	7.1E-04	1.9E-03	6.0E-03	8.6E-04	2.3E-03	2.5E-03	4.2E-04	1.2E-03	2.2E-03	6.9E-04	1.6E-03	7.3E-03	1.7E-03	3.4E-03
1,2,3,7,8,9-HxCDD	5.4E-03	8.0E-04	2.1E-03	2.8E-03	1.3E-03	2.3E-03	6.0E-03	1.0E-03	2.9E-03	5.2E-03	6.2E-04	2.2E-03	3.5E-03	9.8E-04	2.3E-03	1.0E-02	2.2E-03	5.3E-03
1,2,3,4,6,7,8-HpCDD	4.8E-03	5.2E-04	1.4E-03	2.0E-03	6.9E-04	1.1E-03	2.6E-03	6.7E-04	1.6E-03	5.2E-03	4.1E-04	1.6E-03	1.8E-03	6.1E-04	1.3E-03	6.1E-03	1.4E-03	3.4E-03
OCDD	2.9E-03	2.2E-04	6.6E-04	1.0E-03	3.1E-04	5.1E-04	1.3E-03	2.8E-04	6.8E-04	1.7E-03	1.6E-04	5.9E-04	7.3E-04	3.0E-04	5.3E-04	3.1E-03	4.4E-04	1.6E-03
2,3,7,8,-TCDF	2.0E-03	6.2E-04	1.1E-03	2.2E-03	8.3E-04	1.5E-03	2.2E-03	7.6E-04	1.4E-03	1.9E-03	5.7E-04	1.1E-03	2.6E-03	1.1E-03	1.6E-03	5.8E-03	1.1E-03	3.4E-03
1,2,3,7,8,-PeCDF	8.6E-04	3.3E-04	5.6E-04	1.3E-03	4.9E-04	8.0E-04	2.1E-03	3.0E-04	9.4E-04	1.1E-03	1.6E-04	4.6E-04	1.2E-03	4.7E-04	7.5E-04	2.1E-03	5.7E-04	1.0E-03
2,3,4,7,8-PeCDF	1.2E-02	2.5E-03	6.2E-03	1.5E-02	5.4E-03	9.0E-03	2.1E-02	4.0E-03	1.0E-02	1.9E-02	2.0E-03	7.4E-03	2.3E-02	6.4E-03	1.2E-02	3.7E-02	7.0E-03	1.7E-02
1,2,3,4,7,8-HxCDF	5.2E-03	8.2E-04	2.3E-03	5.5E-03	1.0E-03	3.0E-03	5.1E-03	1.6E-03	3.4E-03	5.0E-03	9.1E-04	2.6E-03	9.2E-03	1.1E-03	4.3E-03	1.2E-02	2.7E-03	5.6E-03
1,2,3,6,7,8-HxCDF	3.9E-03	4.1E-04	1.5E-03	2.8E-03	1.1E-03	1.8E-03	4.4E-03	7.3E-04	2.0E-03	2.0E-03	4.4E-04	1.2E-03	4.4E-03	1.2E-03	2.4E-03	5.5E-03	1.2E-03	2.9E-03
2,3,4,6,7,8-HxCDF	4.3E-03	6.9E-04	2.1E-03	4.5E-03	1.6E-03	2.7E-03	5.1E-03	1.2E-03	3.2E-03	4.9E-03	7.2E-04	2.5E-03	7.8E-03	4.5E-04	3.7E-03	9.1E-03	2.0E-03	4.3E-03
1,2,3,7,8,9-HxCDF	4.1E-03	3.0E-04	1.3E-03	1.9E-03	5.8E-04	1.1E-03	2.3E-03	4.3E-04	1.2E-03	1.3E-03	2.4E-04	6.0E-04	2.9E-03	3.0E-04	1.3E-03	3.9E-03	4.2E-04	1.7E-03
1,2,3,4,6,7,8-HpCDF	1.7E-03	2.4E-04	6.7E-04	1.2E-03	4.3E-04	6.9E-04	1.7E-03	3.1E-04	8.9E-04	1.4E-03	2.2E-04	6.8E-04	2.0E-03	4.0E-04	1.1E-03	2.4E-03	6.1E-04	1.3E-03
1,2,3,4,7,8,9-HpCDF	4.5E-04	4.3E-05	1.6E-04	1.6E-04	7.2E-05	1.1E-04	3.1E-04	4.5E-05	1.6E-04	2.5E-04	3.6E-05	1.1E-04	3.6E-04	3.8E-05	1.8E-04	3.6E-04	1.2E-04	2.1E-04
OCDF	2.1E-04	3.7E-05	7.9E-05	1.3E-04	3.3E-05	7.5E-05	2.0E-04	3.5E-05	1.0E-04	1.6E-04	3.1E-05	7.7E-05	2.0E-04	4.3E-05	1.1E-04	2.8E-04	7.1E-05	1.5E-04
Total TEQ	7.6E-02	1.3E-02	3.5E-02	6.8E-02	2.3E-02	4.1E-02	1.1E-01	1.7E-02	5.0E-02	6.4E-02	1.1E-02	3.1E-02	8.5E-02	2.1E-02	4.9E-02	1.6E-01	3.2E-02	7.6E-02

Figure 4-9. Comparison of pg-TEQ/m^3 values for Bore 4 outlet (top) and inlet (bottom) sites. The figure shows the average, high and low values for each congener.

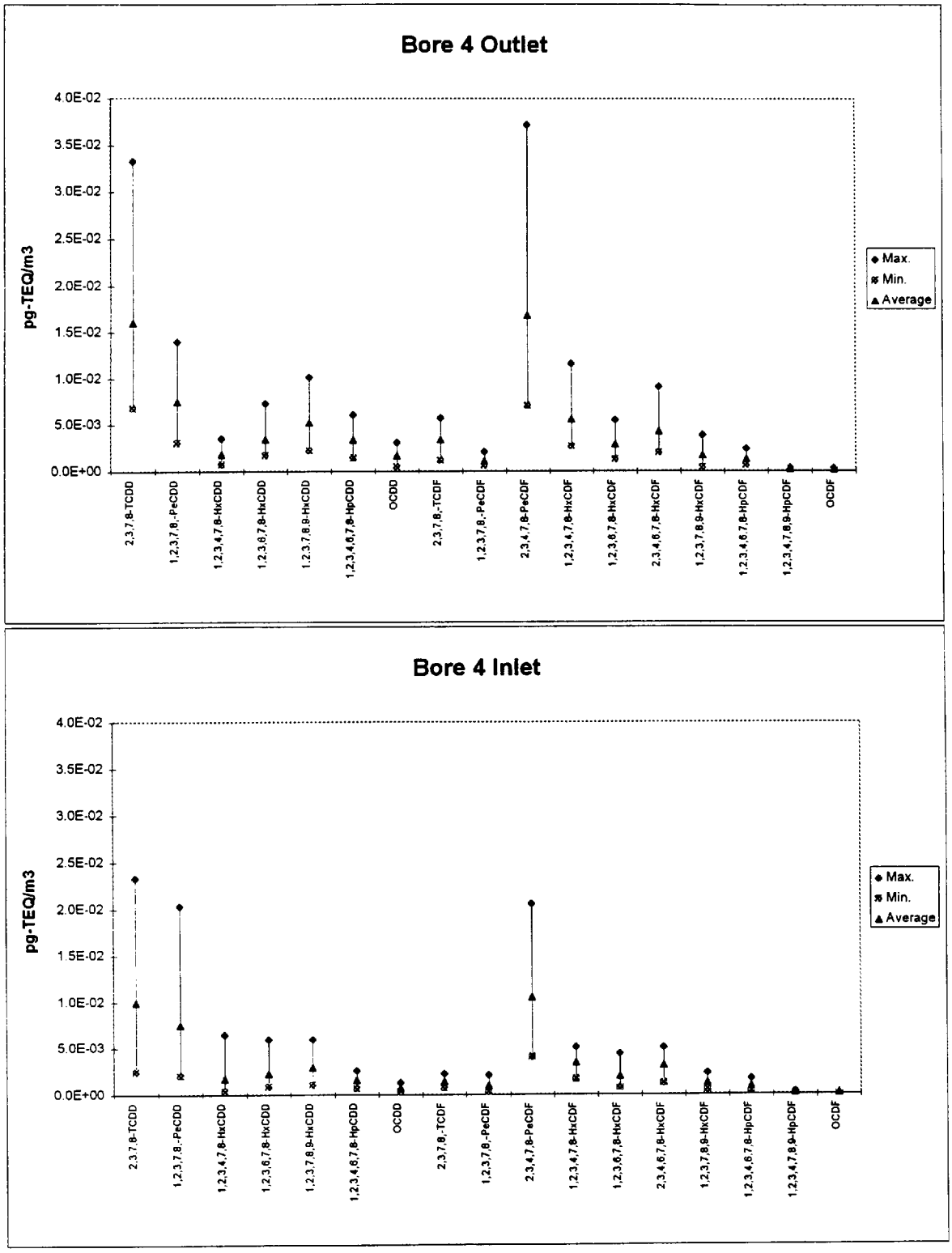


Table 4-4. Mass Emission Factors (ng/veh-mi). Negative emission factors set to zero. Runs 1, 4, and 7 were invalid for various reasons (see text).

Run	2	3	5	6	8	9	10
TCDDs (total)	8.35E-02	0.00E+00	5.08E-02	9.05E-02	1.44E-01	4.26E-02	4.29E-02
2,3,7,8-TCDD	8.37E-03	2.18E-02	0.00E+00	1.16E-02	1.75E-02	1.56E-02	2.42E-02
PeCDDs (total)	3.75E-02	7.75E-03	3.03E-02	1.95E-02	8.07E-02	0.00E+00	7.26E-02
1,2,3,7,8,-PeCDD	1.37E-02	7.30E-03	5.61E-03	3.06E-03	1.78E-02	0.00E+00	3.66E-02
HxCDDs (total)	2.31E-01	0.00E+00	2.74E-01	2.98E-02	9.31E-01	6.49E-01	1.31E+00
1,2,3,4,7,8-HxCDD	6.21E-03	8.92E-03	1.69E-02	4.56E-03	2.99E-02	0.00E+00	5.41E-02
1,2,3,6,7,8-HxCDD	1.28E-02	1.00E-02	2.34E-02	1.07E-02	7.10E-02	2.77E-02	8.20E-02
1,2,3,7,8,9-HxCDD	1.83E-02	2.00E-02	3.33E-02	2.65E-02	1.30E-01	4.90E-02	1.63E-01
HpCDDs (total)	0.00E+00	2.84E-01	5.45E-01	7.75E-02	2.64E+00	7.53E-01	1.93E+00
1,2,3,4,6,7,8-HpCDD	0.00E+00	1.42E-01	2.65E-01	6.09E-02	1.13E+00	3.75E-01	9.17E-01
OCDD	0.00E+00	1.19E+00	1.23E+00	6.13E-01	4.51E+00	2.27E+00	3.36E+00
TCDFs (total)	0.00E+00	3.19E-01	4.78E-01	3.59E-01	1.12E+00	3.92E-01	3.03E-01
2,3,7,8,-TCDF	0.00E+00	3.34E-02	2.46E-02	8.36E-02	7.22E-02	2.86E-02	2.72E-02
PeCDFs (total)	4.22E-02	4.22E-02	4.19E-01	4.29E-02	4.89E-01	1.10E-01	2.76E-01
1,2,3,7,8,-PeCDF	0.00E+00	1.73E-02	2.64E-02	1.29E-02	2.47E-02	0.00E+00	1.91E-02
2,3,4,7,8-PeCDF	8.35E-03	2.68E-02	4.75E-02	2.55E-02	3.94E-02	2.49E-02	4.78E-02
HxCDFs (total)	4.64E-02	1.13E-01	3.10E-01	3.70E-02	2.06E-01	2.80E-01	2.73E-01
1,2,3,4,7,8-HxCDF	5.25E-03	4.92E-02	7.43E-02	5.13E-02	5.75E-02	6.40E-02	7.30E-02
1,2,3,6,7,8-HxCDF	1.08E-04	2.66E-02	2.68E-02	2.79E-02	2.84E-02	2.12E-02	4.21E-02
2,3,4,6,7,8-HxCDF	5.19E-03	2.92E-02	5.52E-02	3.05E-02	4.31E-02	3.38E-02	4.91E-02
1,2,3,7,8,9-HxCDF	9.46E-03	5.23E-03	2.75E-02	0.00E+00	9.55E-03	1.45E-02	2.80E-02
HpCDFs (total)	0.00E+00	7.90E-02	2.96E-01	7.87E-02	2.38E-01	1.38E-01	2.81E-01
1,2,3,4,6,7,8-HpCDF	4.31E-03	9.93E-02	1.62E-01	8.44E-02	1.45E-01	1.38E-01	1.36E-01
1,2,3,4,7,8,9-HpCDF	0.00E+00	2.07E-02	2.21E-02	1.70E-02	1.16E-02	8.86E-04	1.54E-02
OCDF	0.00E+00	8.47E-02	1.46E-01	9.57E-02	1.93E-01	2.08E-01	1.63E-01
Mass EMF - Congeners	9.21E-02	1.80E+00	2.19E+00	1.16E+00	6.54E+00	3.27E+00	5.24E+00
Mass EMF - Homologues	4.41E-01	2.12E+00	3.78E+00	1.44E+00	1.06E+01	4.84E+00	8.01E+00
Fraction of HD	2.12E-01	2.20E-01	2.26E-01	3.40E-01	2.88E-01	2.42E-01	2.74E-01
HD EMF - Congeners	4.35E-01	8.17E+00	9.68E+00	3.41E+00	2.27E+01	1.35E+01	1.91E+01
HD EMF - Homologues	2.08E+00	9.66E+00	1.67E+01	4.24E+00	3.67E+01	2.00E+01	2.93E+01

Table 4-5. TEQ Emission Factors (ng-TEQ/veh-mi). Negative emission factors set to zero. Runs 1, 4, and 7 were invalid for various reasons (see text).

Run	2	3	5	6	8	9	10
2,3,7,8-TCDD	8.37E-03	2.18E-02	0.00E+00	1.16E-02	1.75E-02	1.56E-02	2.42E-02
1,2,3,7,8,-PeCDD	6.87E-03	3.65E-03	2.81E-03	1.53E-03	8.89E-03	0.00E+00	1.83E-02
1,2,3,4,7,8-HxCDD	6.21E-04	8.92E-04	1.69E-03	4.56E-04	2.99E-03	0.00E+00	5.41E-03
1,2,3,6,7,8-HxCDD	1.28E-03	1.00E-03	2.34E-03	1.07E-03	7.10E-03	2.77E-03	8.20E-03
1,2,3,7,8,9-HxCDD	1.83E-03	2.00E-03	3.33E-03	2.65E-03	1.30E-02	4.90E-03	1.63E-02
1,2,3,4,6,7,8-HpCDD	0.00E+00	1.42E-03	2.65E-03	6.09E-04	1.13E-02	3.75E-03	9.17E-03
OCDD	0.00E+00	1.19E-03	1.23E-03	6.13E-04	4.51E-03	2.27E-03	3.36E-03
2,3,7,8,-TCDF	0.00E+00	3.34E-03	2.46E-03	8.36E-03	7.22E-03	2.86E-03	2.72E-03
1,2,3,7,8,-PeCDF	0.00E+00	8.65E-04	1.32E-03	6.44E-04	1.23E-03	0.00E+00	9.55E-04
2,3,4,7,8-PeCDF	4.18E-03	1.34E-02	2.37E-02	1.28E-02	1.97E-02	1.24E-02	2.39E-02
1,2,3,4,7,8-HxCDF	5.25E-04	4.92E-03	7.43E-03	5.13E-03	5.75E-03	6.40E-03	7.30E-03
1,2,3,6,7,8-HxCDF	1.08E-05	2.66E-03	2.68E-03	2.79E-03	2.84E-03	2.12E-03	4.21E-03
2,3,4,6,7,8-HxCDF	5.19E-04	2.92E-03	5.52E-03	3.05E-03	4.31E-03	3.38E-03	4.91E-03
1,2,3,7,8,9-HxCDF	9.46E-04	5.23E-04	2.75E-03	0.00E+00	9.55E-04	1.45E-03	2.80E-03
1,2,3,4,6,7,8-HpCDF	4.31E-05	9.93E-04	1.62E-03	8.44E-04	1.45E-03	1.38E-03	1.36E-03
1,2,3,4,7,8,9-HpCDF	0.00E+00	2.07E-04	2.21E-04	1.70E-04	1.16E-04	8.86E-06	1.54E-04
OCDF	0.00E+00	8.47E-05	1.46E-04	9.57E-05	1.93E-04	2.08E-04	1.63E-04
TEQ-EMF	2.52E-02	6.19E-02	6.19E-02	5.23E-02	1.09E-01	5.95E-02	1.33E-01
Fraction of HD	2.12E-01	2.20E-01	2.26E-01	3.40E-01	2.88E-01	2.42E-01	2.74E-01
HD TEQ-EMF	1.19E-01	2.82E-01	2.74E-01	1.54E-01	3.79E-01	2.46E-01	4.87E-01

congeners and for the homologues, assuming all the emissions come from HD vehicles. A graphical summary of the results in Table 4-4 are presented in Figure 4-10 which shows the observed mass emission factor for each run as well as the average. As with the concentration plots (see, for example, Figures 4-2 and 4-7), this figure is dominated by the higher order chlorinated dioxins, especially OCDD.

Table 4-5 presents the TEQ emission factors for the individual congeners in units of ng-TEQ/veh-mi. As with Table 4-4, any negative emission factors that occurred have been set to zero, and these are the only zeros in the table. At the bottom of Table 4-5 are the total TEQ emission factors for the fleet, the fraction of HD vehicles in each run and the calculated emission factors for the total TEQ, assuming all the emissions come from HD vehicles. A graphical summary of the results in Table 4-5 is presented in Figure 4-11 which shows the observed TEQ emission factor for each run as well as the average. Contrasting Figure 4-10 with 4-11 one can again see the effect of the TEQ factors, which greatly enhances the importance of some of the isomers, most notably 2,3,7,8-TCDD.

In the foregoing discussion it was noted that if any congener's or homologue's calculated emission factor was negative it was set to zero. These cases were generally where the inlets and outlets were nearly the same and the negative values were very small. Uncertainties in the airflow or analytical results are responsible for these negative values. As described in Section 3.3, to obtain an emission factor one must subtract the total mass of any compound from the three inlets from the total mass at the outlet. Each of these values comes from the analytical value (mass/sample), the sampler flow rate (volume/sample), and the tunnel flow rate (volume/run) to determine the mass/run at each sampling location. There are errors associated with each of these measurements that can cause negative emission factors especially for low concentration compounds. The exact value effect of this adjustment can be seen in Table 4-6 where the effect on the average was less than a 1.5% difference.

Major uncertainties present in this study include analytical, sampler flow and tunnel volume flow measurement. These are the uncertainties that pertain to the values reported here as pg/sample, pg/m^3, and the emission factor, respectively. In this analysis, the uncertainty associated with the length of the tunnel, the number and type of vehicles, and the TEQ factors was assumed to be negligible.

The analytical uncertainty is that associated with the extraction and measurement of the samples. One of the best surrogates for this would be the field surrogate. ^{37}Cl-2,3,7,8-TCDD was spiked to the media prior to shipment to the field and then analyzed in the laboratory. The relative standard deviation of determination for this compound was ±7%. Based on our prior experience with the high volume PUF-type sampler, an error of ±5% is reasonable for the total volume sampled. Dividing the pg/sample by the sampler volume gives us the pg/m^3 value, thus these two errors would combine by the root-mean-square and give an error of ±8.6%. The error associated with the tunnel volumetric flows can be best assessed by looking at the flow balances in the tunnel (the air in *vs.* air out) which is ±9% on average. Since the concentration value is multiplied by the tunnel flow we will also incorporate this error by the root-mean-square to give an error of ±12.4%, which represents a reasonable estimate of the error in each emission estimate.

Table 4-6. Assessment of the effect of setting all negative emission factors to zero on the total TEQ emission factor for the HDD vehicles (ng-TEQ/veh-mi).

Run	All Values	No Negs.
2	1.17E-01	1.19E-01
3	2.82E-01	2.82E-01
5	2.67E-01	2.74E-01
6	1.54E-01	1.54E-01
8	3.79E-01	3.79E-01
9	2.24E-01	2.46E-01
10	4.87E-01	4.87E-01
Ave.	2.73E-01	2.77E-01

Again, a few caveats:

- The assumption that all the emissions come from the HD vehicles will, necessarily, result in an overestimation of the HD emissions.
- Based on the discussion in the previous section, emission factors could not be calculated for the Bore 3 runs.
- Emission factors for Runs 1 and 4 were not calculated. Run 1 was invalid due to the power shutdown. Run 4 was invalid since the outlet samples were used as a test of the analytical method, and the outlet concentrations were unusually low, as can be seen in Figure 4-12 which shows the concentrations at each of the sampling locations. Contrasting this figure to Figures 4-6 and 4-8, one can clearly see that this run was not typical of either the average or of a valid run.
- Run 7 was similarly invalidated by the presence of very high values in the West Vent sample as can be seen in Figure 4-13. The calculated factor for that run was 0.14 ng-TEQ/veh-mi – not very different from the other results; however, the profile of emissions was inconsistent with the other runs. Looking at the run descriptions (Table 2-1), Run 7 was unusual in that the Bore 4 vehicle counts were one-half the Bore 3 numbers. For all other day/day runs, the Bore 3 and Bore 4 total counts were similar. Reviewing the run counts, there were a number of periods of unusually low or absent traffic. For these reasons, the results have not been included in Table 4-4.

The average observed TEQ emission factor for the day/day runs (Runs 3, 5, and 9) was 0.27 ± 0.02 ng-TEQ/veh-mi, where the reported uncertainty is one standard deviation about the mean. For the night/night runs (Runs 2, 6, 8, and 10) the result was 0.29 ± 0.18 ng/TEQ/veh-mi. The average for the 7 runs was 0.28 ± 0.13 ng-TEQ/veh-mi, or 0.28 ng-TEQ/veh-mi ± 46%. The run-to-run variability represents the uncertainty in the fleet and is a good estimate of the uncertainty in the emissions. Incorporating the uncertainty of the emission factors (each of the seven runs were assumed to have an uncertainty of 12.4%) results in the emission factor uncertainty of 35.7%. Since these two values are similar the larger will be reported.

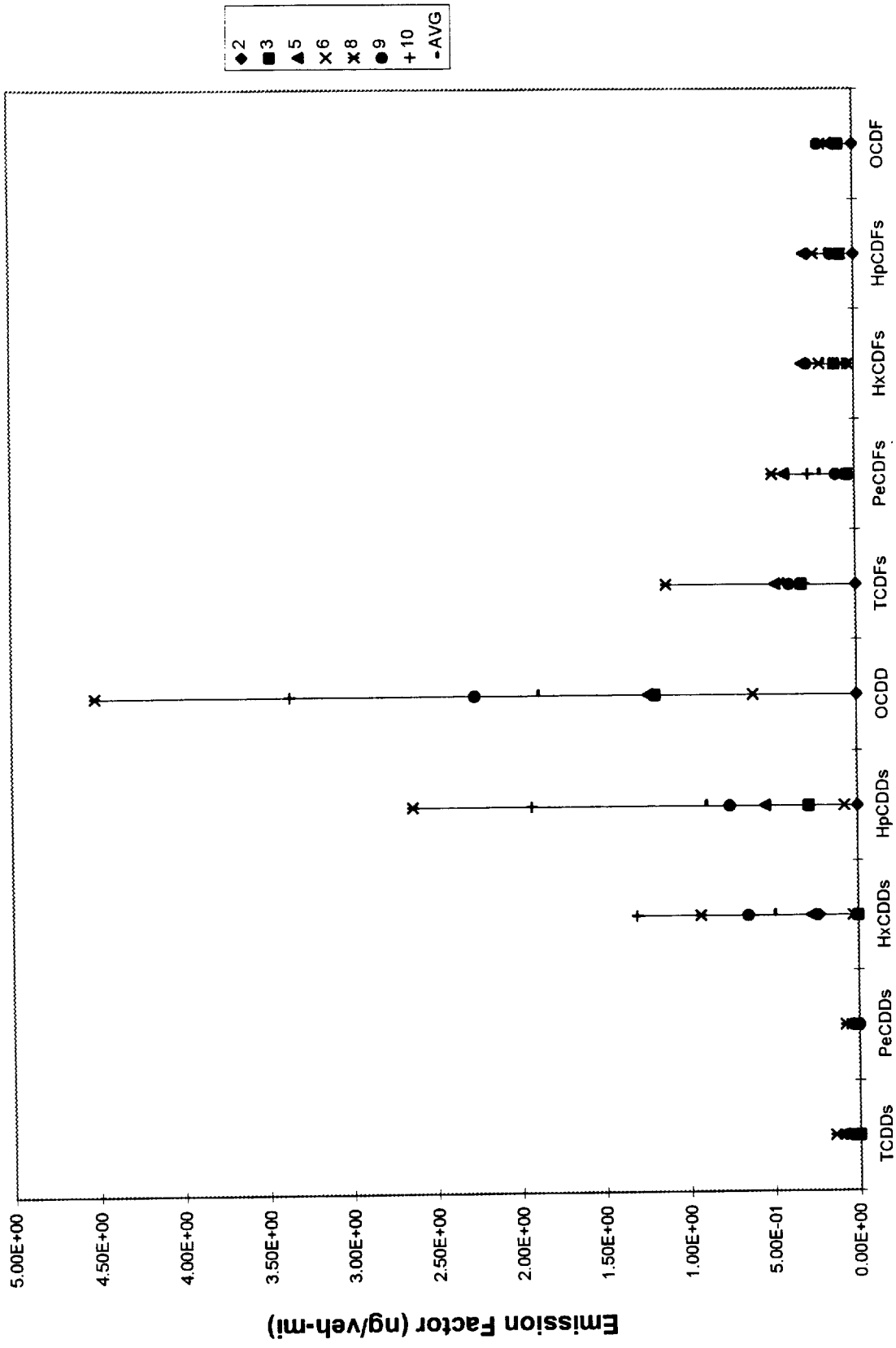


Figure 4-10. Bore 4 mass emission factors for the valid runs and the average.

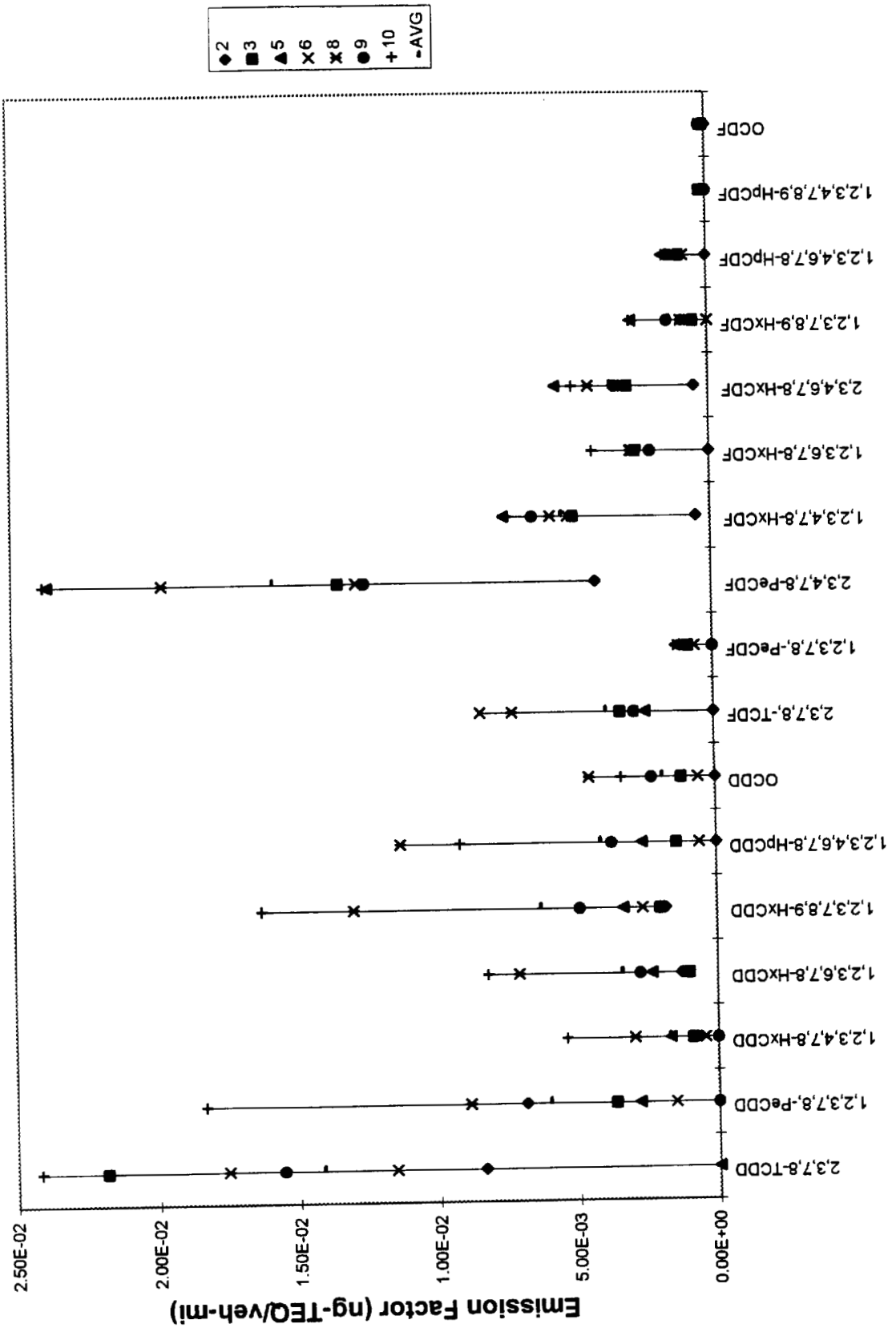


Figure 4-11. Bore 4 TEQ emission factors for the valid runs and the average.

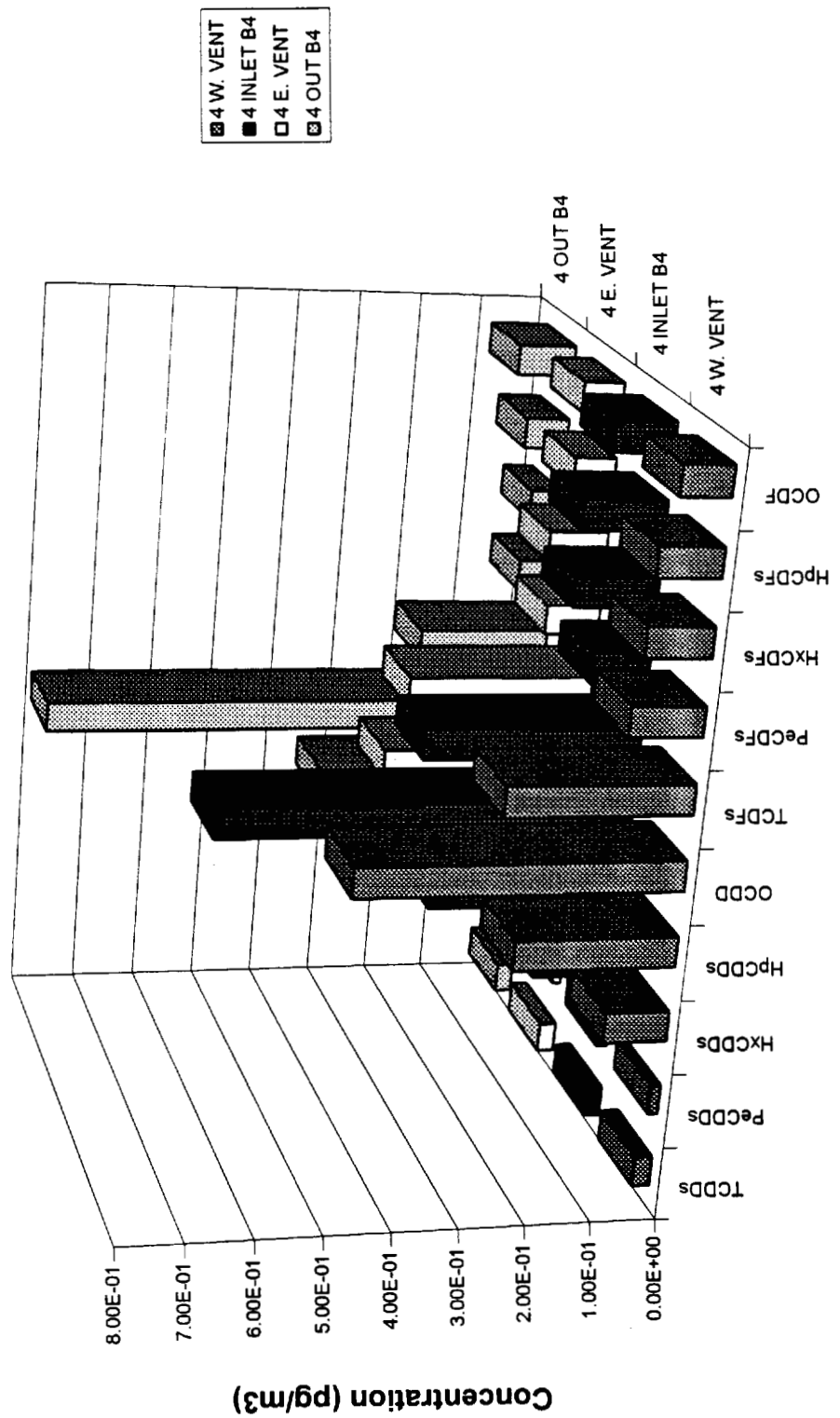


Figure 4-12. Observed concentrations, Bore 4, Run 4.

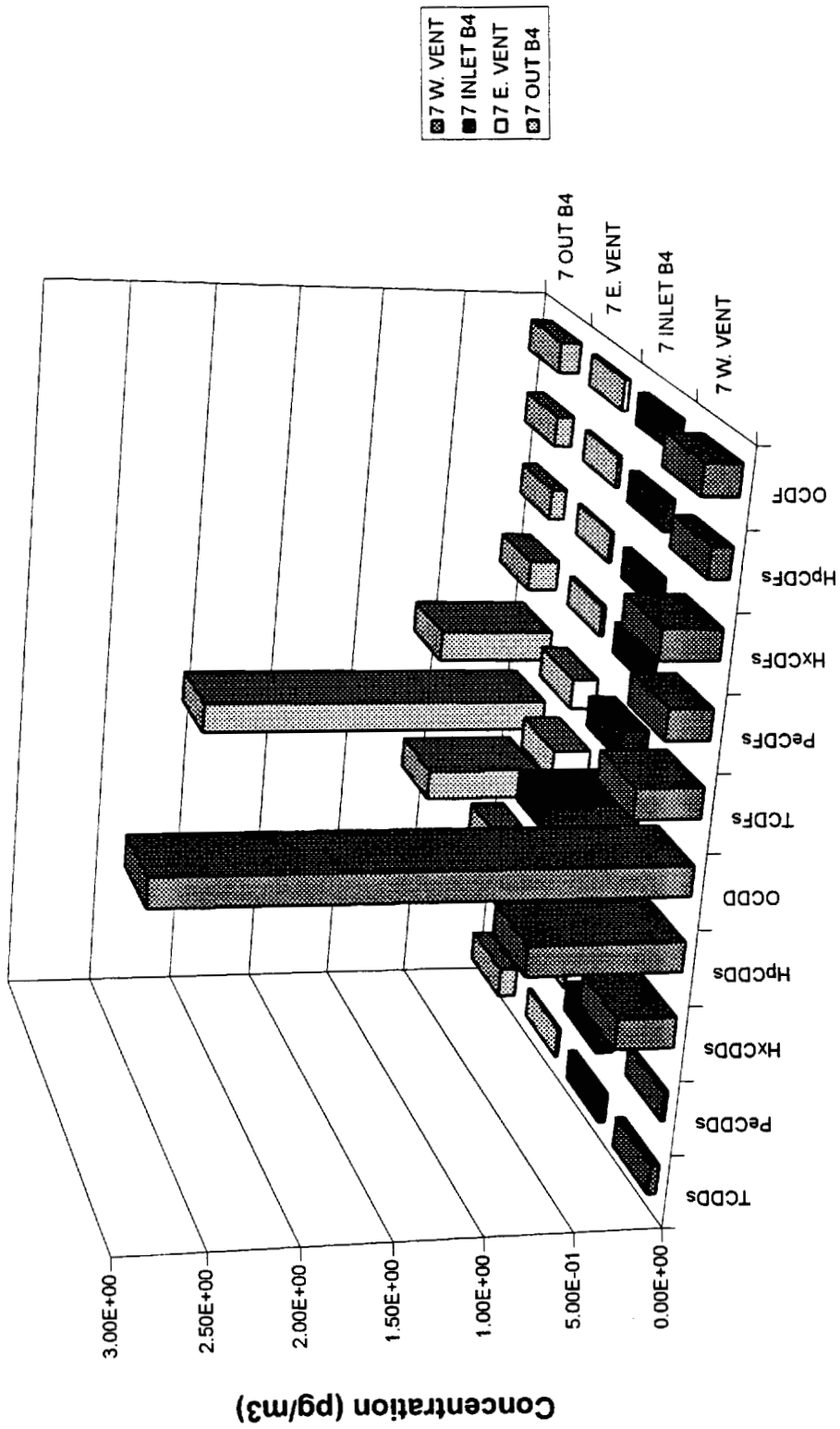


Figure 4-13. Observed concentrations Bore 4, Run 7. Note unusually high West Vent values.

4.3 Comparisons with Previous Studies

The results of this study can be compared to the previous work of Oehme, *et al.* (1991) and Hagenmaier, *et al.* (1990). In order to complete this analysis we must first develop normalized emission profiles from the present study.

4.3.1 Emission Profiles

The mass emission profile is presented in Table 4-7 and in Figure 4-14. To calculate the emission profile each part was divided by the total to show the contribution of each homologue. The mass profile is dominated by the OCDD isomer, as was the profile of concentrations seen in the tunnel.

Table 4-7. Normalized mass emission factors for the homologues. Valid runs only.

Homologue	Fraction
TCDDs	1.46E-02
PeCDDs	7.96E-03
HxCDDs	1.10E-01
HpCDDs	2.00E-01
OCDD	4.23E-01
TCDFs	9.53E-02
PeCDFs	4.55E-02
HxCDFs	4.06E-02
HpCDFs	3.56E-02
OCDF	2.85E-02

The TEQ emission profile is presented in Table 4-8 and in Figure 4-15. Again, to calculate the emission profile each part was divided by the total to show the contribution of each congener. The shift in emphasis away from OCDD to some other congeners is clear when comparing Figure 4-15 with Figure 4-14.

Considering the mass results, approximately half of the mass is accounted for by the OCDD and OCDF emissions. While these species are high in the mass profile, they have relatively low TEQ values. In terms of the TEQ profile, the contribution is weighted by the TEQ factor. The three highest factors are for 2,3,7,8-TCDD, 1,2,3,7,8-PeCDD, and 2,3,4,7,8-PeCDF. Thus, even though their mass emissions are low, they dominate the TEQ profile. Since OCDD and OCDF have low TEQ factors, their contributions are reduced.

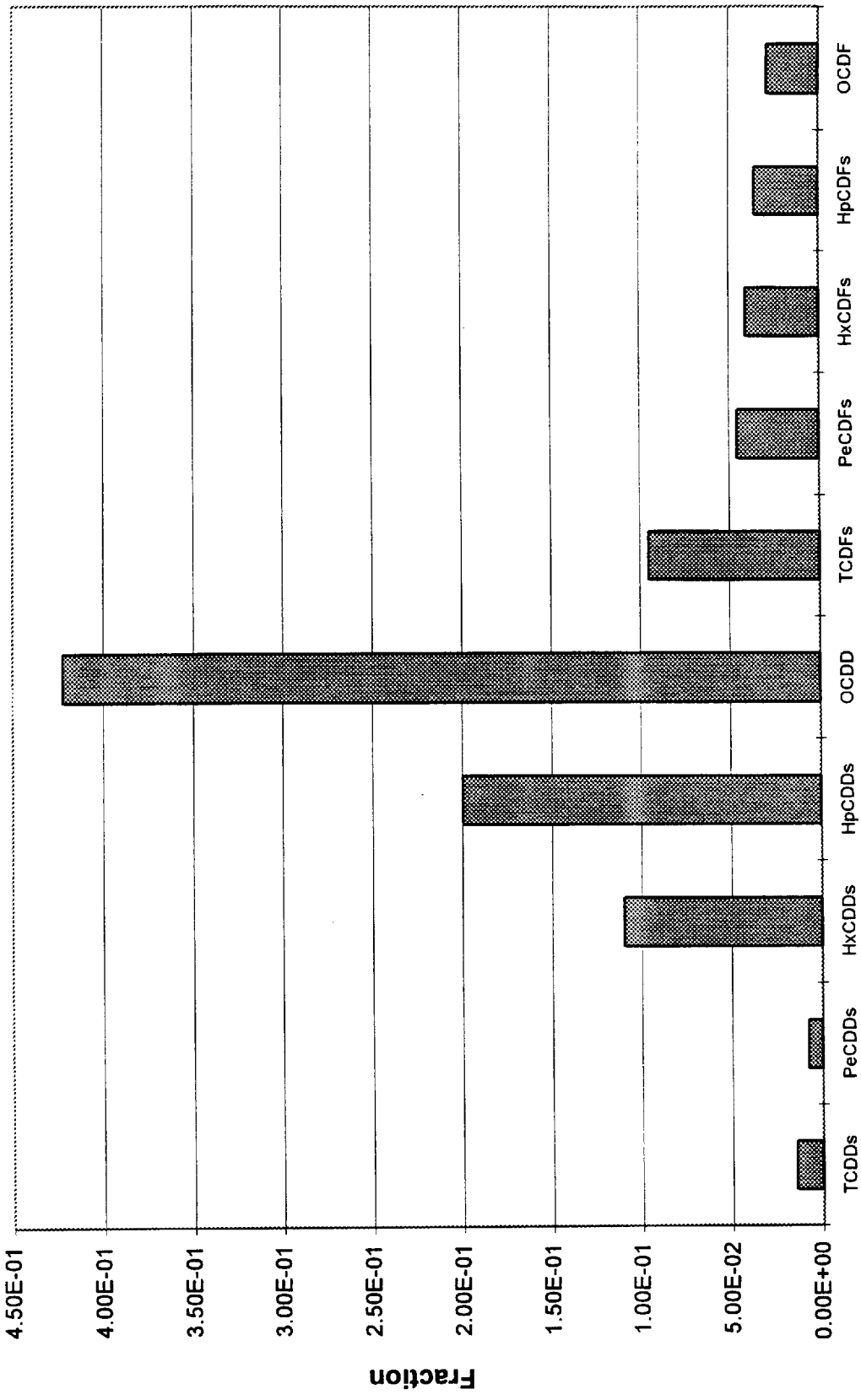


Figure 4-14. Normalized mass emission profile.

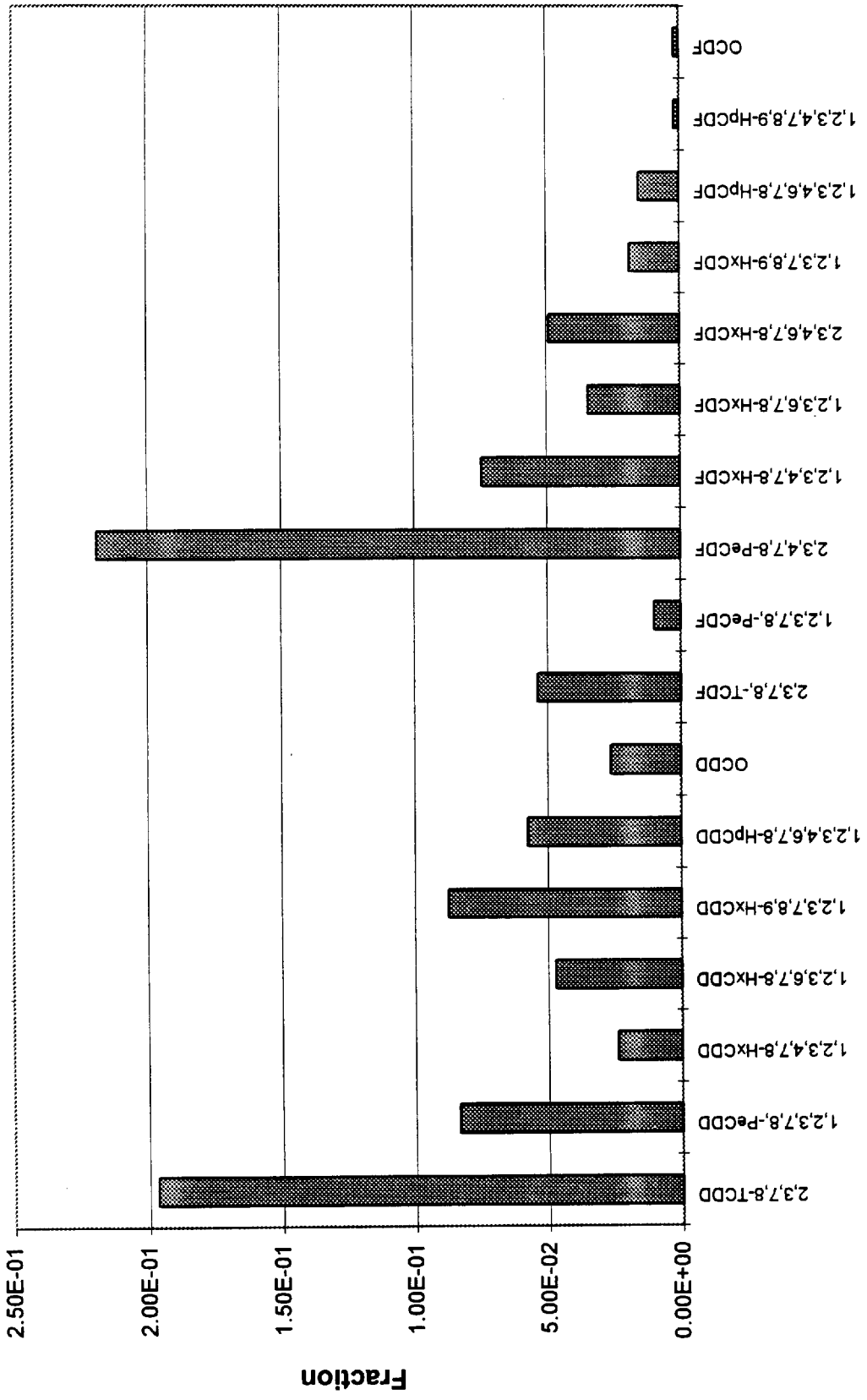


Figure 4-15. Normalized TEQ emission profile.

Table 4-8. Normalized TEQ emission factors for each congener.

Congener	Fraction
2,3,7,8-TCDD	1.97E-01
1,2,3,7,8,-PeCDD	8.36E-02
1,2,3,4,7,8-HxCDD	2.39E-02
1,2,3,6,7,8-HxCDD	4.72E-02
1,2,3,7,8,9-HxCDD	8.74E-02
1,2,3,4,6,7,8-HpCDD	5.74E-02
OCDD	2.62E-02
2,3,7,8,-TCDF	5.36E-02
1,2,3,7,8,-PeCDF	9.97E-03
2,3,4,7,8-PeCDF	2.19E-01
1,2,3,4,7,8-HxCDF	7.44E-02
1,2,3,6,7,8-HxCDF	3.44E-02
2,3,4,6,7,8-HxCDF	4.89E-02
1,2,3,7,8,9-HxCDF	1.87E-02
1,2,3,4,6,7,8-HpCDF	1.53E-02
1,2,3,4,7,8,9-HpCDF	1.74E-03
OCDF	1.77E-03

4.3.2 Comparison with Oehme, *et al.*

The results presented in Section 4.2 are approximately 29 times lower than the estimate 8.2 ng-TEQ/veh-mi which is the average of the uphill and downhill emission factors from Oehme *et al.* (1991). There are a number of possible explanations for the difference:

- The study by Oehme *et al.* (1991) was conducted separately in the uphill and downhill tubes of the tunnel. The factor used by the EPA (EPA, 1994) as part of its estimate of emissions was an average of the uphill and downhill values. Since it is likely that the vehicles in the uphill direction were different from those in the downhill direction, the averaging of these two adds uncertainty. The current Fort McHenry study measured combined emissions from both the downhill and uphill sections of the tunnel by the same fleet.
- The Norwegian HDD fraction was between 3 and 15%, with the lower fraction occurring on the weekends. The results were then extrapolated to 100% HDD. We looked at a case where there were up to 34% HDD vehicles in each run and all runs were performed during the week. The greater fraction of HDD vehicles gives less uncertainty in estimating their emissions.
- The Norwegian results were also complicated by the fact the majority of the LD fleet was running on leaded gasoline which was a significant source of dioxin and furan emissions. The LD US fleet was running on unleaded fuel and emissions from the LD vehicles were undetectable in this experiment.
- There are also likely to be technology and fuel differences between Norwegian and US HDD vehicles.

- It is impossible to determine the load on each vehicle in the tunnel, and it is possible that there was a difference in load between the Norwegian tunnel and the Fort McHenry Tunnel.

4.3.3 Comparison with Hagenmaier, *et al.*

We can compare the relative concentrations of the dioxin and furan homologues with those reported by Hagenmaier *et al.* (1990). Although Hagenmaier *et al.* looked at engine emissions on an engine dynamometer while this study looked at on-road emissions measured in a roadway tunnel, the results of these two studies compare reasonably well when we look at the normalized profiles.

The two emissions profiles are presented in Figure 4-16 as a bar chart.

While the agreement is reasonably good we do notice that the Hagenmaier *et al.* (1990) profile contains higher furans, notably the HpCDFs and OCDF, and our profile contains higher amounts of HxCDDs and HpCDDs. While there are these differences, overall the two profiles look reasonably similar.

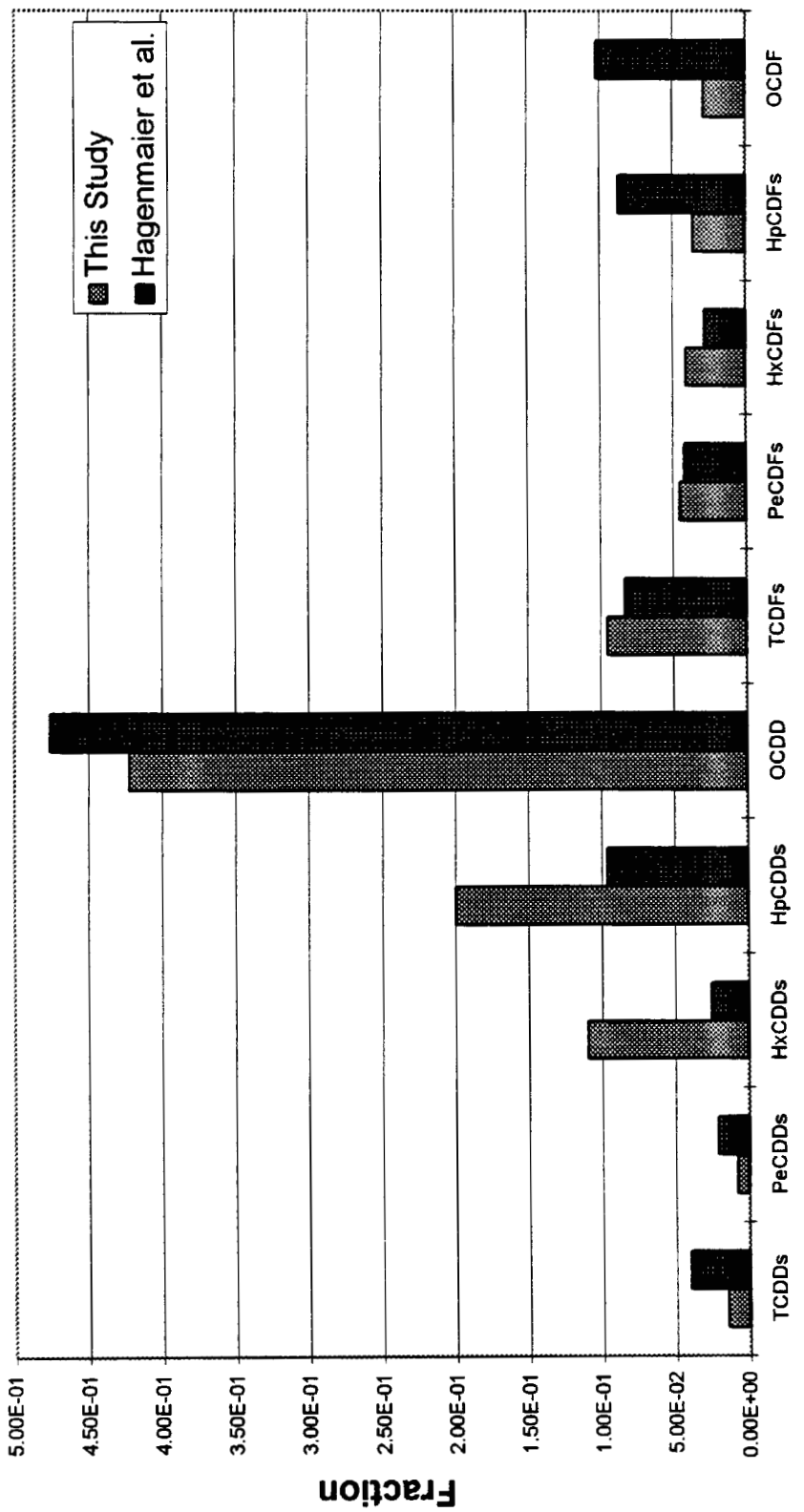


Figure 4-16. Comparison of diesel profiles.

5.0 RESULTS - PM_{10} AND RESUSPENDED ROAD DUST

PM_{10} and road dust samples were collected only in Bore 4. There were two reasons for making this measurement. The first was to compare the PM_{10} mass emission factor in this study with previous studies. The second was to determine the contribution of resuspended road dust to the observed dioxin and furan emission factors. We were also able to use these data to look for the impact of ambient chloride levels on dioxin and furan mass emission factors.

5.1 PM_{10} Analysis Methods

Samples were collected as described in Section 3.2. Analysis of the collected filter samples was performed at the DRI Environmental Analysis Facility. The Teflon® filters were weighed on a Cahn 31 Electro-Microbalance before and after sampling to determine mass concentrations. Chemical analyses were also performed on the Bore 4 outlet samples in order to determine the contribution from resuspended road dust. Teflon® filters were analyzed for elements (Na, Mg, Al, Si, P, S, Cl, K, Ca, Ti, V Cr, Mn, Fe, Co, Ni, Cu, Zn, Ga, As, Se, Br, Rb, Sr, Y, Zr, Mo, Pd, Ag, Cd, In, Sn, Sb, Ba, La, Au, Hg, Tl, Pb, and U) by x-ray fluorescence using a Kevex 700/800 analyzer. One-half of the quartz filter was extracted with distilled-deionized water. The extract was analyzed for chloride, nitrate, and sulfate ions by ion chromatography using a Dionex 4000i ion chromatograph, for ammonium ion by automated colorimetry using a TRAACS 800 Technicon auto analyzer, and for sodium and potassium by a Perkin-Elmer Model 2380 Double Beam Atomic Absorption Spectrometer. Organic and elemental carbon were measured by thermal/optical reflectance using a DRI/OGC thermal/optical carbon analyzer (Chow *et al.*, 1993) on 0.5 cm^2 punches taken from the remaining half of the quartz filter. The chemical analysis methods applied in this study are described by Watson and Chow (1994).

5.2 Particulate Mass Results

Following chemical analysis, total mass emission factors (g/veh-mi) were calculated using the methodology described in Section 3, by assuming all of the PM_{10} emissions came from HDD vehicles. Mass emission factors are contained in Table 5-1. The mass emission factors for Runs 9 and 10 are questionable. The observed Run 9 inlet mass is too high and the Run 10 outlet mass is too low. Visual inspection of the filters did not indicate any filters had been mislabeled (i.e., the outlet filters were darker than the inlet filters and both were darker than the vent filters). Switching the Run 9 inlet mass with the Run 10 outlet mass yields emission factors of 0.49 and 0.39 g/veh-mi for Runs 9 and 10, respectively. Given we have no valid reason for switching the results and the results as they stand are unreasonable, the reported average in Table 5-1 does not include the results for Runs 9 and 10.

Table 5-1. PM_{10} mass emission factors (EMF) in g/veh-mi. The reported average is for runs 1 through 8 only since the rates for runs 9 and 10 are suspect (see text).

Run	EMF
1	0.129
2	0.279
3	0.415
4	0.351
5	0.489
6	0.325
7	0.323
8	0.272
9	0.002
10	-0.045
Avg (1-8)	0.323

The average emission factor of the first eight runs reported in Table 5-1 is 0.32 g/veh-mi. The standard deviation was 0.11 g/veh-mi. In the 1993 experiment (Gertler *et al.*, 1995b) we reported a result of 0.67 ± 0.13 g/veh-mi for HD vehicles in Fort McHenry. These results were obtained for 1-hr. sampling periods with varying fleet composition and a weighted regression analysis (weighted by the number of vehicles in each run) was performed to separate LD and HD emission rates. Using an unweighted regression analysis method, similar to the approach taken in this study, the observed HD emission rate was 0.54 ± 0.12 g/veh-mi.

While the results of the 1993 and 1995 experiments agree within the experimental uncertainty (0.32 ± 0.11 vs. 0.54 ± 0.12 g/veh-mi), it is important to discuss why the 1993 result may be greater. In the present study 24-hr. sampling periods are used while in the 1993 study all runs were 1-hr. in duration. Given the significantly different sampling times and the much lower overall fraction of HDD (maximum of 34%) in this study as opposed to the 1993 study, the ability to detect the emissions against the general background may have been reduced. Also, the shorter run periods led to lower filter mass loadings and a greater analytical uncertainty. The 1993 experiment consisted of 32 runs of one hour duration. The regression analysis was dominated by 5 runs with emission factors three times greater than the average for all runs. This would lead to a high bias of the result. The greater analytical uncertainty inherent in the 1-hr. measurements and the uncertainty associated with the regression analysis as well as the significantly different sampling time may account for the observed difference.

5.3 Estimate of Contribution from Resuspended Road Dust

In order to quantify the dioxin and furan contribution from resuspended road dust, the Bore 4 outlet filters were chemically analyzed (see Section 5.1) and road dust samples were collected and analyzed for inorganic species and dioxins and furans. The approach consists of three parts:

1. Quantify the dioxin and furan composition in tunnel road dust.

2. Determine the contribution of resuspended road dust to the PM_{10} loadings.
3. Given a knowledge of the contribution of resuspended road dust and the amount of dioxins and furans in the road dust, estimate the contribution to the observed emissions from the resuspended dioxins and furans that may have been present in the road dust.

Two road dust samples were collected, one at the Bore 4 inlet and one at the Bore 4 outlet. Samples were collected by sweeping up dust along the side of the tunnel roadway. Approximately half a kilogram was collected at each site, stored in polyethylene containers, and refrigerated for transport back to DRI. Samples were resuspended and collected using a PM_{10} inlet to size fractionate the PM_{10} component of the road dust. The collected sample was split with one part analyzed at DRI for inorganic species and the second part analyzed by Quanterra for dioxins and furans. For description of the resuspension and analysis methods, see Chow *et al.*, 1994.

5.3.1 Dioxin and Furan Composition in Tunnel Road Dust

Results of the analysis of the PM_{10} fraction of the road dust for dioxins and furans are presented in Table 5-2 and in Figure 5-1. In Figure 5-1 the values for OCDD are reduced by a factor of 10 to fit on the scale. Outlet composition (pg/g) of dioxins and furans is greater in the outlet sample than in the inlet sample. This is indicative of production of these species by vehicles traversing the tunnel coupled with deposition and is what one would expect to see. In addition, the ratios between the isomers are very nearly constant (for detected species) between the two samples as shown in Figure 5-2. This figure shows the linear regression between the inlet and outlet samples. The similarity between these two samples is due to the observed dioxins and furans in both the inlet and outlet samples coming from the same source type, i.e., mobile sources.

Regression of the outlet and inlet composition (Figure 5-2) yields a slope of 8.2 and r^2 of 0.953, again indicating the similarity of the sources and increase in composition of dioxins and furans in the outlet sample.

Table 5-2. Composition of dioxins and furans in Bore 4 inlet and outlet road dust samples. Non-detects have been set to zero.

Homologue	Inlet (pg/g)	Outlet (pg/g)
TCDDs	4.3E+00	4.0E+01
PeCDDs	0.0E+00	6.1E+01
HxCDDs	3.6E+01	3.7E+02
HpCDDs	9.2E+01	7.1E+02
OCDD	1.1E+03	9.1E+03
TCDFs	3.4E+01	2.0E+02
PeCDFs	1.9E+01	1.6E+02
HxCDFs	2.2E+01	1.8E+02
HpCDFs	5.7E+01	5.1E+02
OCDF	7.0E+01	7.4E+02

5.3.2 Results of CMB Modeling

The results of the inorganic analysis of the outlet filters are contained in Table 5-3, and presented graphically in Figure 5-3. Results of the analysis of the resuspended road dust samples were used to create a source profile for road dust. Chemical Mass Balance (CMB) modeling was then conducted to determine the road dust contribution to the total observed mass on the outlet filters. (For a description of CMB, see Watson *et al.*, 1990.)

Briefly, the CMB constructs a least-squares solution to a set of linear equations which expresses each receptor concentration of a chemical species as a linear sum of products of source profile species weighted as source contributions. The source profile species (i.e., the road dust) and the receptor concentrations (i.e., the PM_{10} samples), each with uncertainties determined by the measurement limits of the analytical analyses combined with laboratory background measurements, serve as input data to the CMB model. The output consists of the contributions from the source type to the total ambient aerosol mass, as well as to individual chemical species concentrations.

The results of the CMB showed that 15.5 ± 3.3 % of the measured mass at the outlet of the tunnel was resuspended road dust. The balance of the mass was due to other sources (tailpipe particulate emissions).

As described in Section 5.2, the average PM_{10} emission factor from the HDD vehicles was 0.32 g/mile. Thus 15.5% of this or 0.05 g/mile was due to resuspended road dust. The total of all homologues in the PM_{10} fraction of the outlet tunnel dust was 1.2×10^4 pg/g. Multiplying these two together we get a value for the total of the dioxin and furan homologues of 0.59 ng/mile for the contribution to the emissions from resuspended road dust. This is approximately 4% of the observed total emission of all dioxin and furan homologues and provides an estimate of the contribution of resuspended road dust to our observed dioxin and furan emission factors. This analysis is complicated since the dioxin and furan air samples were not collected with PM_{10} size faction inlets; however, this should still provide a reasonable estimate of the contribution of resuspended road dust.

5.3.3 Impact of Ambient PM_{10} Chlorine on Dioxin and Furan Emissions

Since the level of ambient chlorine has been suggested to be a key ingredient in dioxin and furan production, the results of the inorganic analysis of the outlet filters can be used to estimate the magnitude of this effect on the observed emissions. Using the inorganic data (Table 5-3) and the HD mass emission factors for dioxins and furans (Table 4-6), we can regress the observed emissions and ambient PM_{10} chloride concentrations. This is shown in Figure 5-4. No correlation is observed. This result implies that the ambient PM_{10} chloride levels in the tunnel had no observable effect on the observed dioxin and furan emissions.

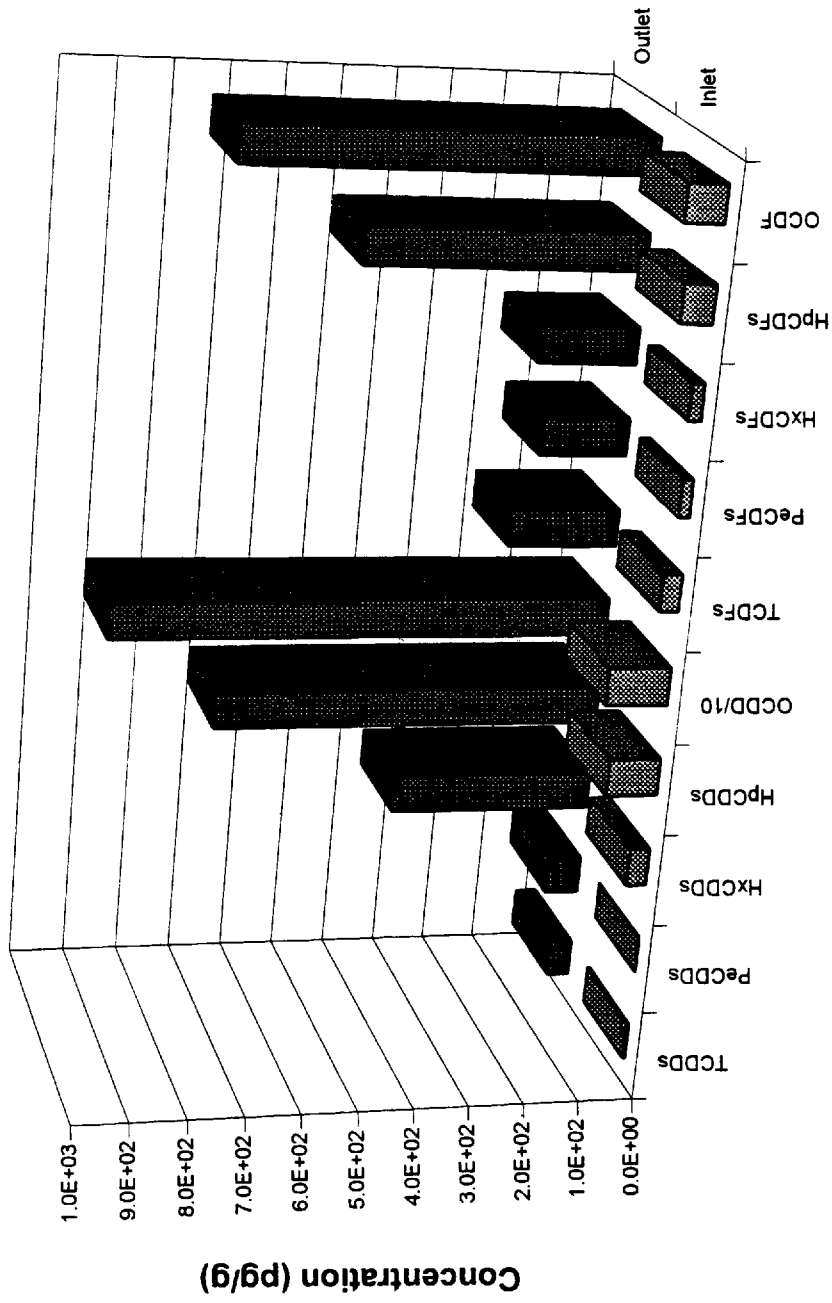


Figure 5-1. Concentration of dioxins and furans in road dust from the inlet and outlet of the Ft. McHenry Tunnel. Note OCDD is reduced by a factor of 10 to fit on scale.

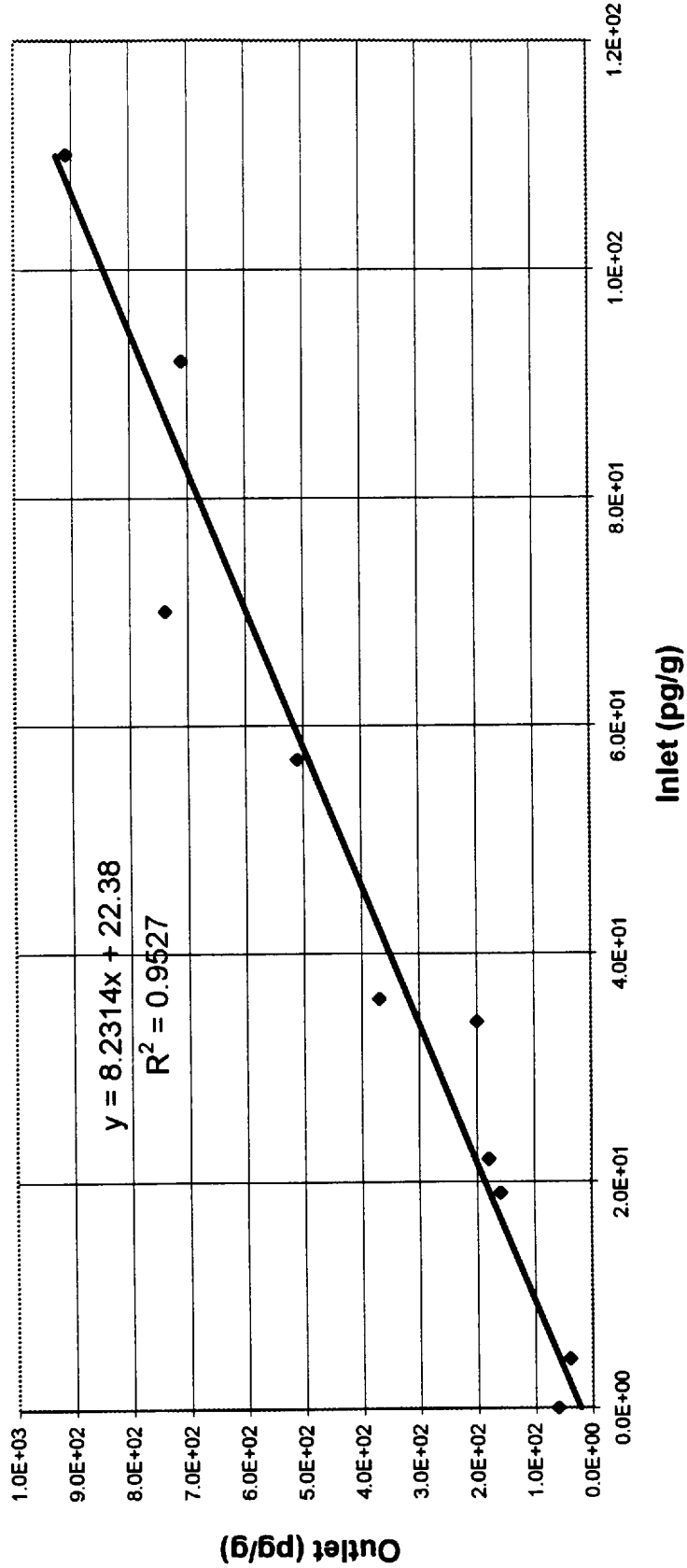


Figure 5-2. Comparison of concentrations of dioxins and furans in road dust samples at the inlet and outlet of the Ft. McHenry Tunnel. The equation shows the linear least squares regression. OCDD is reduced by a factor of 10.

Table 5-3. Average concentrations (μg/m^3) of the measured species in the Bore 4 outlet filters.

Species	Average
Mass	1.37E+02
Sum of Species	1.09E+02
Organic Carbon	4.13E+01
Elemental Carbon	4.17E+01
Total Carbon	8.29E+01
Chloride ion	5.36E-01
Nitrate ion	2.27E+00
Sulfate ion	6.35E+00
Ammonium ion	2.44E+00
Sodium by AA	3.45E-01
Potassium by AA	2.08E-01
Sodium by XRF	7.06E-02
Magnesium	2.62E-01
Aluminum	9.96E-01
Silicon	3.93E+00
Phosphorus	1.36E-01
Sulfur	2.54E+00
Chlorine	7.68E-01
Potassium	4.97E-01
Calcium	2.89E+00
Titanium	6.25E-02
Vanadium	4.39E-03
Chromium	1.75E-02
Manganese	5.09E-02
Iron	4.39E+00

Species (cont'd)	Average
Cobalt	8.48E-03
Nickel	4.42E-03
Copper	6.54E-02
Zinc	2.34E-01
Gallium	1.00E-04
Arsenic	6.10E-04
Selenium	2.76E-03
Bromine	1.10E-02
Rubidium	8.40E-04
Strontium	1.75E-02
Yttrium	1.00E-04
Zirconium	3.13E-03
Molybdenum	5.54E-03
Palladium	4.10E-04
Silver	5.00E-05
Cadmium	1.48E-03
Iodine	1.50E-04
Tin	1.59E-03
Antimony	3.89E-03
Barium	6.66E-01
Lanthanum	2.32E-03
Gold	9.00E-05
Mercury	9.00E-05
Thallium	0.00E+00
Lead	2.89E-02
Uranium	4.00E-04

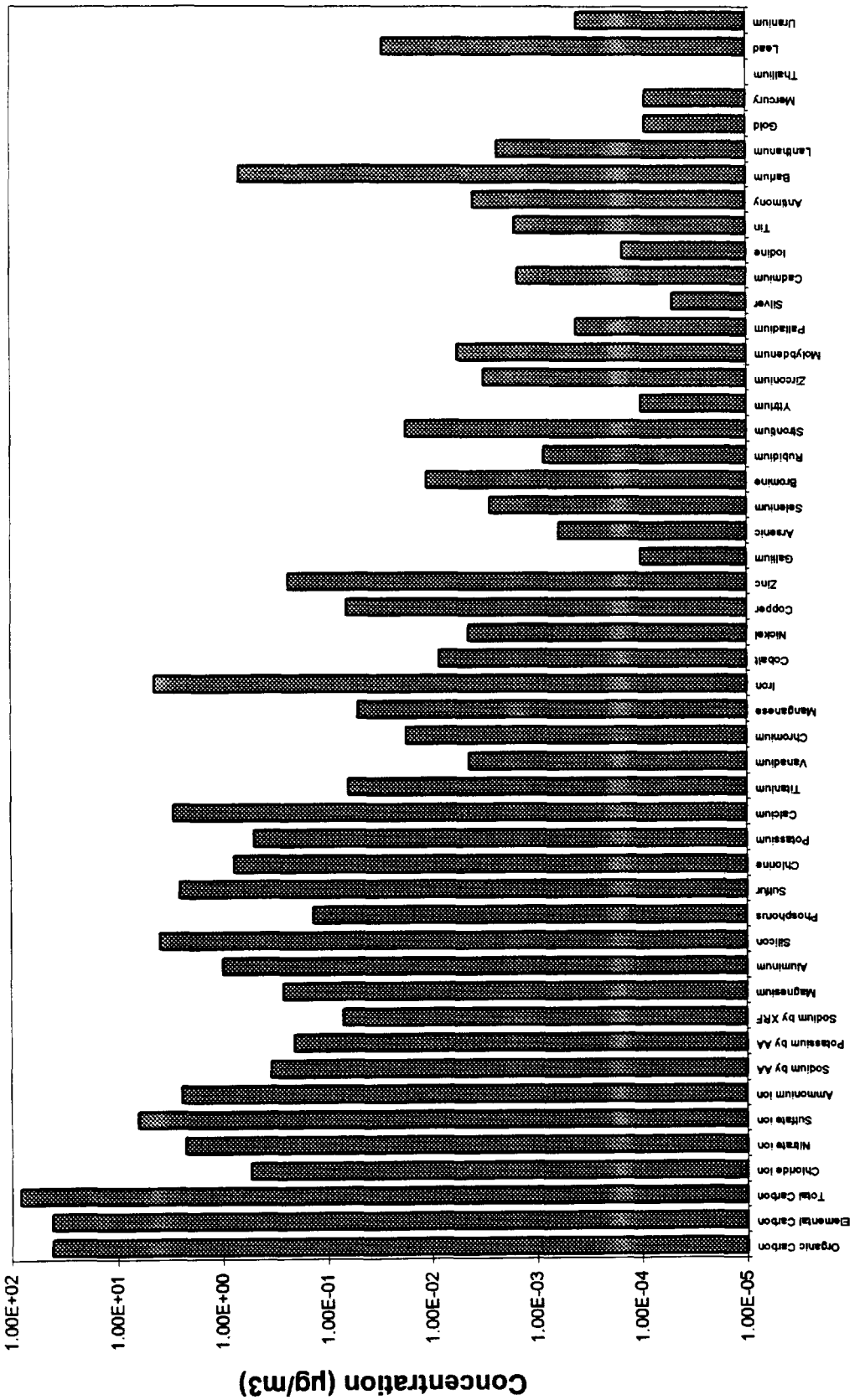


Figure 5-3. Chemical Concentration of the Bore 4 PM_{10} outlet filters.

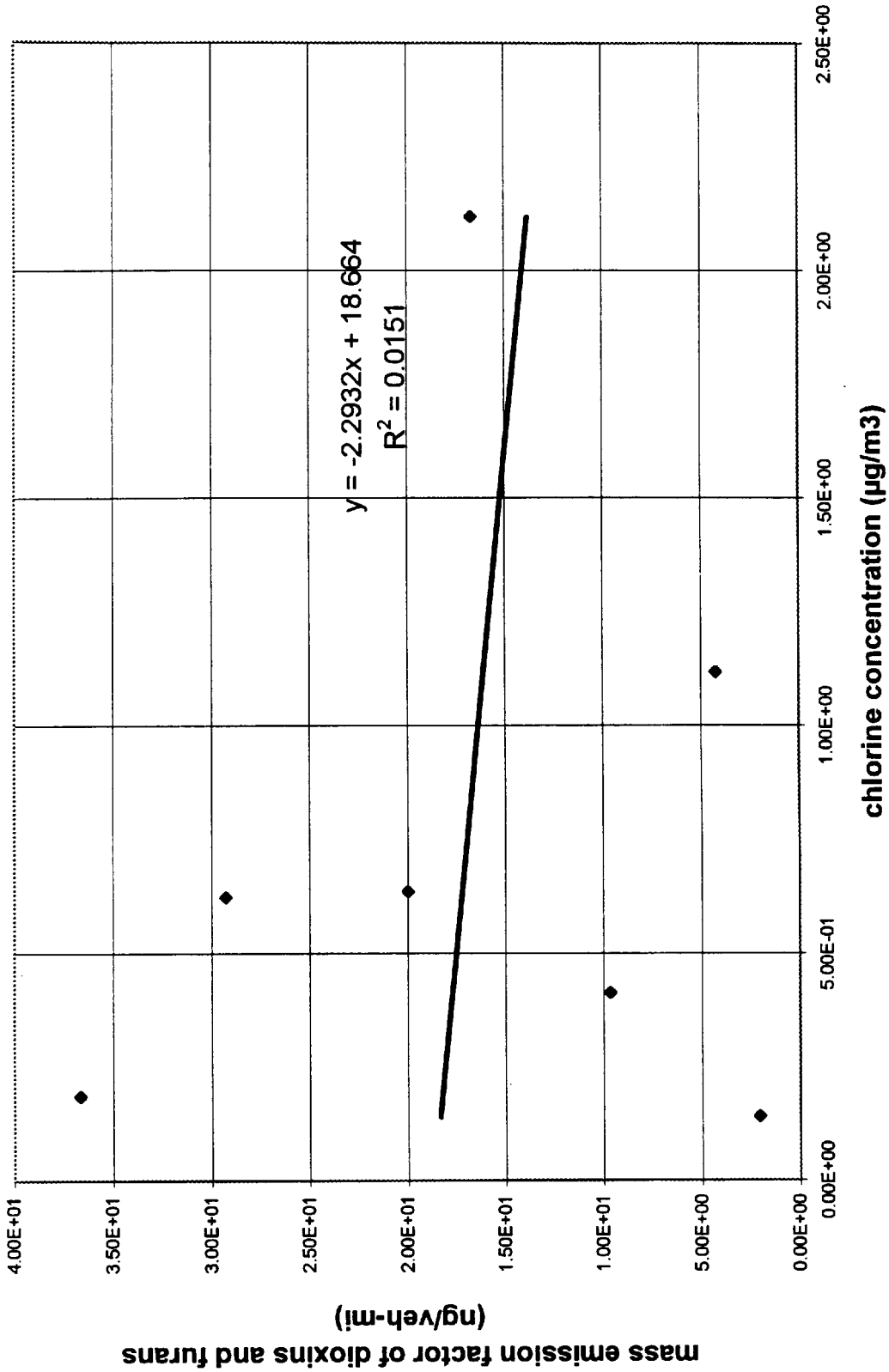


Figure 5-4. Relationship between chlorine and mass emissions of dioxins and furans.

6.0 SUMMARY

The primary objective of this work was to develop on-road emission factors of dioxins and furans from in-use vehicles with an emphasis on the HDD fraction of the fleet. The approach taken was to measure mobile source emissions in a tunnel. Measurements were performed in Baltimore's Fort McHenry Tunnel, a four-bore tunnel, two lanes per bore, carrying Interstate 95 east-west under the Baltimore Harbor. This study was conducted in Bores 3 and 4, the eastbound bores. Trucks are directed into Bore 4 with the result that the traffic in the LD-only Bore 3 generally contained less than 2% HDD vehicles, while Bore 4 contained, on average, 24 to 25% HDD vehicles.

Ten measurement runs were performed in Bore 4 and five measurement runs were performed in Bore 3. Sample periods were 24 hours long, consisting of two 12-hour periods, and ran approximately on a day/day and night/night schedule in Bore 4 and day/day schedule in Bore 3.

Dioxins and furans were collected using high volume samplers with filters backed up by polyurethane foam (PUF) at the inlet and outlet portals of the tunnel and the two fresh air supply inlets. Speciated dioxin analyses were performed by Quanterra Environmental Services (Sacramento, CA).

For Bore 3, the difference between the outlet and inlet concentrations was too small to estimate emission factors. This precluded directly separating the LD component from the Bore 4 results to obtain HDD emission factors. Given the large fraction of HDD vehicles in Bore 4 and the assumption that HDD dioxin and furan emissions are significantly greater than LD dioxin and furan emissions, all observed emissions in Bore 4 were attributed to the HDD fleet. This means the resulting estimate will be an upper bound for the actual emission factor. The average for the 7 valid runs in Bore 4 was 0.28 ± 0.13 ng-TEQ/veh-mi.

These results are approximately a factor of three lower than the EPA's estimate of 0.8 ng-TEQ/veh-mi and 29 times lower than the estimate of 8.2 ng-TEQ/veh-mi based on a Norwegian tunnel study (Oehme *et al.*, 1991) on which the EPA's estimate is partially based. Possible explanations for the difference with the Norwegian study include: the HDD fraction in the Norwegian study was between 3 and 15% of the total fleet and the results were extrapolated to 100% HDD, the LD fleet was operating using leaded fuel, a source of dioxins, and there are likely to be technology and fuel differences between Norwegian and US HDD vehicles.

Emission profiles were also compared with the results of German dynamometer tests conducted by Hagenmaier *et al.* (1990). Given the differences in the methodologies, the mass profiles are in reasonable agreement.

PM_{10} emission factors were also estimated as part of this work. The observed HDD emission factor of 0.32 ± 0.11 g/veh-mi was lower than the 0.54 ± 0.12 g/veh-mi obsrved in a 1993 study (Gertler *et al.*, 1995). Although the results agree to within the experimental uncertainty, possible reasons for the apparent difference may be due to

the shorter run periods (1-hr.) and subsequent greater uncertainty in the 1993 results coupled with the dominance of 5 high emission factor runs in the 1993 experiment.

CMB modeling was also conducted on the Bore 4 outlet PM_{10} filters. Resuspended road dust was found to account for 15.5 ± 3.3 % of the measured PM_{10} mass. Dioxins were present in the road dust at the outlet at approximately $1.2x10^4$ pg/g, thus the resuspended road dust dioxins could account for approximately 4% of the observed dioxin emission factor.

The results of the inorganic analyses were used to determine the impact of ambient PM_{10} chlorine levels on dioxin and furan mass emission factors. An analysis of these data indicated there was no correlation between ambient PM_{10} chlorine and dioxin and furan emissions.

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APPENDICES

Appendix 1. Observed Sample Loadings (pg/sample) by run and location.

Appendix 2. Observed Concentrations (pg/m^3) by run and location.

Appendix 3. Observed TEQ Concentrations (pg-TEQ/m^3) by run and location.

Appendix 4. Volumetric flows in the Fort McHenry Tunnel.

Appendix 1. Observed Sample Loadings (pg/sample).

Run	1						2			
INLET\OUTLET	INLET				OUTLET		INLET			OUTLET
SAMPLE PLACEMENT	W. VENT	B3	B4	E. VENT	B3	B4	W. VENT	B4	E. VENT	B4
TCDDs (total)	2.7E+01	5.6E+00	3.2E+01	5.0E+00	5.4E+00	9.4E-01	9.2E+00	7.7E+00	4.4E+00	2.6E+01
2,3,7,8-TCDD	3.6E+00	2.5E+00	4.0E+00	1.6E+00	3.7E+00	9.4E-01	2.8E+00	2.8E+00	3.4E+00	4.4E+00
PeCDDs (total)	1.4E+01	7.4E+00	1.5E+01	5.6E+00	5.9E+00	3.0E+01	5.8E+00	7.8E+00	5.0E+00	1.5E+01
1,2,3,7,8,-PeCDD	5.9E+00	2.5E+00	6.5E+00	2.6E+00	2.4E+00	5.0E+00	2.7E+00	3.3E+00	2.4E+00	5.9E+00
HxCDDs (total)	1.0E+02	4.1E+01	1.1E+02	1.7E+01	2.8E+01	1.2E+01	1.4E+01	5.9E+01	6.0E+01	1.0E+02
1,2,3,4,7,8-HxCDD	6.0E+00	3.4E+00	3.8E+00	3.8E+00	3.6E+00	3.0E+00	3.4E+00	4.3E+00	2.7E+00	4.9E+00
1,2,3,6,7,8-HxCDD	9.6E+00	5.1E+00	8.4E+00	5.0E+00	4.8E+00	3.5E+00	4.0E+00	7.4E+00	5.3E+00	8.8E+00
1,2,3,7,8,9-HxCDD	1.6E+01	8.0E+00	1.6E+01	7.9E+00	7.2E+00	4.5E+00	6.7E+00	1.4E+01	8.0E+00	1.5E+01
HpCDDs (total)	1.5E+02	8.0E+01	1.4E+02	1.1E+02	7.3E+01	5.9E+01	9.4E+01	1.7E+02	1.0E+02	1.2E+02
1,2,3,4,6,7,8-HpCDD	6.9E+01	3.8E+01	6.7E+01	5.5E+01	3.5E+01	3.0E+01	4.8E+01	8.2E+01	5.3E+01	6.0E+01
OCDD	2.1E+02	1.6E+02	2.3E+02	2.9E+02	1.4E+02	1.4E+02	1.9E+02	2.6E+02	2.0E+02	1.6E+02
TCDFs (total)	1.4E+02	1.3E+02	1.2E+02	5.2E+01	4.9E+01	1.2E+01	1.1E+02	9.3E+01	1.3E+02	4.8E+01
2,3,7,8,-TCDF	5.9E+00	6.9E+00	7.2E+00	4.5E+00	4.1E+00	3.4E+00	5.7E+00	4.6E+00	6.6E+00	4.2E+00
PeCDFs (total)	3.4E+01	5.5E+01	4.5E+01	3.3E+01	3.0E+01	7.1E+00	2.2E+01	2.2E+01	2.6E+01	2.9E+01
1,2,3,7,8,-PeCDF	4.0E+00	6.7E+00	6.2E+00	3.8E+00	4.6E+00	7.1E+00	4.4E+00	5.1E+00	5.1E+00	4.2E+00
2,3,4,7,8-PeCDF	6.2E+00	9.3E+00	9.9E+00	7.3E+00	7.5E+00	6.9E+00	5.5E+00	7.0E+00	9.6E+00	8.0E+00
HxCDFs (total)	5.1E+01	5.5E+01	5.8E+01	5.9E+01	4.9E+01	1.5E+01	4.0E+01	5.6E+01	7.9E+01	5.9E+01
1,2,3,4,7,8-HxCDF	1.4E+01	1.7E+01	1.6E+01	1.7E+01	1.4E+01	8.6E+00	1.2E+01	1.7E+01	2.6E+01	1.6E+01
1,2,3,6,7,8-HxCDF	7.8E+00	8.8E+00	8.8E+00	9.9E+00	7.6E+00	3.0E+00	6.4E+00	8.4E+00	1.2E+01	7.3E+00
2,3,4,6,7,8-HxCDF	1.4E+01	1.4E+01	1.5E+01	2.0E+01	1.5E+01	7.2E+00	1.3E+01	1.5E+01	2.9E+01	1.5E+01
1,2,3,7,8,9-HxCDF	4.0E+00	3.8E+00	4.5E+00	5.5E+00	2.1E+00	2.2E+00	6.1E+00	2.4E+00	7.9E+00	5.1E+00
HpCDFs (total)	5.3E+01	3.7E+01	4.0E+01	1.1E+02	5.3E+01	2.8E+01	6.1E+01	7.8E+01	1.5E+02	6.9E+01
1,2,3,4,6,7,8-HpCDF	4.5E+01	3.7E+01	4.0E+01	6.8E+01	4.1E+01	2.8E+01	3.7E+01	4.8E+01	8.5E+01	4.4E+01
1,2,3,4,7,8,9-HpCDF	6.6E+00	5.1E+00	5.6E+00	1.1E+01	6.7E+00	3.5E+00	6.4E+00	9.5E+00	1.5E+01	6.3E+00
OCDF	5.3E+01	4.0E+01	4.6E+01	9.6E+01	5.1E+01	3.3E+01	5.7E+01	6.0E+01	9.1E+01	5.3E+01

Appendix 1 (cont.). Observed Sample Loadings (pg/sample).

Note: Run 4 Bore 4 Outlet not valid due to changes in analytical procedure, see text.

RUN	3						4			
INLET\OUTLET	INLET				OUTLET		INLET			OUTLET
SAMPLE PLACEMENT	W. VENT	B3	B4	E. VENT	B3	B4	W. VENT	B4	E. VENT	B4
TCDDs (total)	5.6E+00	6.6E+00	2.5E+01	4.4E+00	4.5E+00	6.2E+00	1.5E+01	8.4E+00	1.7E+01	6.9E+00
2,3,7,8-TCDD	2.9E+00	3.1E+00	2.9E+00	2.2E+00	1.2E+00	4.7E+00	1.6E+00	8.7E-01	2.5E+00	1.8E+00
PeCDDs (total)	5.3E+00	8.1E+00	1.0E+01	5.4E+00	4.4E+00	4.9E+00	8.2E+00	5.7E+00	8.1E+00	4.5E+00
1,2,3,7,8,-PeCDD	2.3E+00	3.8E+00	4.6E+00	3.9E+00	2.3E+00	2.9E+00	2.7E+00	1.6E+00	2.3E+00	1.6E+00
HxCDDs (total)	1.5E+01	5.0E+01	7.2E+01	8.7E+01	1.3E+01	1.0E+01	5.5E+01	4.7E+01	5.5E+01	1.5E+01
1,2,3,4,7,8-HxCDD	3.5E+00	2.6E+00	4.3E+00	8.1E+00	2.4E+00	3.2E+00	3.6E+00	2.9E+00	3.0E+00	2.0E+00
1,2,3,6,7,8-HxCDD	4.2E+00	6.2E+00	7.2E+00	9.4E+00	2.8E+00	4.4E+00	8.0E+00	6.3E+00	6.1E+00	5.2E+00
1,2,3,7,8,9-HxCDD	7.3E+00	9.5E+00	1.2E+01	2.0E+01	6.7E+00	8.0E+00	1.1E+01	7.5E+00	8.6E+00	5.8E+00
HpCDDs (total)	7.9E+01	8.0E+01	1.0E+02	4.0E+02	6.8E+01	9.2E+01	1.4E+02	1.1E+02	1.1E+02	9.4E+01
1,2,3,4,6,7,8-HpCDD	4.0E+01	4.0E+01	4.9E+01	1.7E+02	3.4E+01	4.5E+01	7.4E+01	5.7E+01	5.7E+01	4.6E+01
OCDD	1.7E+02	1.4E+02	2.2E+02	6.3E+02	1.4E+02	2.9E+02	2.8E+02	2.3E+02	2.1E+02	2.1E+02
TCDFs (total)	1.5E+02	7.9E+01	6.0E+01	5.3E+01	6.4E+01	7.8E+01	1.6E+02	1.2E+02	1.9E+02	5.5E+01
2,3,7,8,-TCDF	5.8E+00	3.4E+00	5.2E+00	3.9E+00	4.5E+00	7.5E+00	5.0E+00	3.9E+00	5.8E+00	3.7E+00
PeCDFs (total)	2.2E+01	1.5E+01	3.6E+01	1.6E+01	1.8E+01	2.0E+01	6.3E+01	3.2E+01	5.6E+01	1.5E+01
1,2,3,7,8,-PeCDF	4.8E+00	4.0E+00	4.6E+00	3.3E+00	3.8E+00	4.6E+00	5.4E+00	4.9E+00	4.6E+00	3.1E+00
2,3,4,7,8-PeCDF	6.0E+00	5.2E+00	6.3E+00	4.8E+00	6.1E+00	6.8E+00	7.0E+00	5.1E+00	7.9E+00	3.7E+00
HxCDFs (total)	3.7E+01	1.4E+01	2.7E+01	1.3E+01	1.6E+01	2.9E+01	5.7E+01	4.6E+01	6.0E+01	1.3E+01
1,2,3,4,7,8-HxCDF	1.2E+01	9.4E+00	1.0E+01	8.9E+00	9.3E+00	1.2E+01	1.6E+01	1.2E+01	1.5E+01	7.0E+00
1,2,3,6,7,8-HxCDF	7.5E+00	6.1E+00	5.4E+00	4.4E+00	5.0E+00	6.5E+00	7.2E+00	5.5E+00	6.9E+00	3.2E+00
2,3,4,6,7,8-HxCDF	1.1E+01	8.5E+00	8.7E+00	7.7E+00	8.2E+00	8.2E+00	1.3E+01	1.1E+01	1.4E+01	5.2E+00
1,2,3,7,8,9-HxCDF	4.6E+00	2.7E+00	3.5E+00	1.8E+00	2.9E+00	2.2E+00	4.7E+00	3.7E+00	2.1E+00	1.1E+00
HpCDFs (total)	2.9E+01	1.9E+01	3.2E+01	2.0E+01	2.0E+01	2.5E+01	5.5E+01	4.6E+01	4.2E+01	1.8E+01
1,2,3,4,6,7,8-HpCDF	2.9E+01	1.9E+01	2.2E+01	2.0E+01	2.0E+01	2.5E+01	3.9E+01	3.2E+01	4.2E+01	1.8E+01
1,2,3,4,7,8,9-HpCDF	5.4E+00	4.1E+00	4.3E+00	4.0E+00	3.9E+00	5.1E+00	6.5E+00	4.0E+00	6.4E+00	3.6E+00
OCDF	2.6E+01	2.2E+01	2.6E+01	2.6E+01	2.1E+01	2.4E+01	4.3E+01	3.3E+01	4.1E+01	2.4E+01

Appendix 1 (cont.). Observed Sample Loadings (pg/sample).

RUN	5						6			
INLET\OUTLET	INLET				OUTLET		INLET			OUTLET
SAMPLE PLACEMENT	W. VENT	B3	B4	E. VENT	B3	B4	W. VENT	B4	E. VENT	B4
TCDDs (total)	8.8E+00	4.8E+00	4.7E+00	7.5E+00	6.2E+00	1.6E+01	2.1E+01	6.3E+00	6.3E+00	1.4E+01
2,3,7,8-TCDD	3.4E+00	2.5E+00	4.7E+00	2.6E+00	2.2E+00	2.6E+00	4.7E+00	2.3E+00	2.8E+00	2.5E+00
PeCDDs (total)	6.8E+00	3.5E+00	2.6E+00	7.9E+00	5.0E+00	9.6E+00	2.8E+01	6.5E+00	5.9E+00	6.3E+00
1,2,3,7,8,-PeCDD	6.8E+00	1.8E+00	2.6E+00	4.0E+00	3.1E+00	3.3E+00	6.8E+00	3.0E+00	3.3E+00	1.9E+00
HxCDDs (total)	1.0E+01	9.6E+00	1.2E+01	6.2E+01	1.5E+01	7.8E+01	1.3E+01	4.6E+01	1.8E+02	2.9E+01
1,2,3,4,7,8-HxCDD	3.2E+00	2.0E+00	1.6E+00	4.0E+00	3.4E+00	5.4E+00	1.3E+01	2.1E+00	8.0E+00	2.4E+00
1,2,3,6,7,8-HxCDD	4.0E+00	3.0E+00	3.7E+00	7.6E+00	4.9E+00	8.4E+00	1.2E+01	7.1E+00	1.4E+01	5.0E+00
1,2,3,7,8,9-HxCDD	4.5E+00	5.4E+00	5.2E+00	1.4E+01	6.0E+00	1.2E+01	1.2E+01	7.6E+00	2.9E+01	7.8E+00
HpCDDs (total)	6.0E+01	6.0E+01	6.1E+01	1.8E+02	7.9E+01	1.8E+02	1.0E+02	9.2E+01	6.8E+02	8.2E+01
1,2,3,4,6,7,8-HpCDD	2.9E+01	3.1E+01	2.9E+01	8.0E+01	3.8E+01	8.7E+01	4.8E+01	4.7E+01	2.9E+02	4.1E+01
OCDD	1.2E+02	1.3E+02	1.7E+02	2.2E+02	1.6E+02	4.2E+02	1.9E+02	1.7E+02	9.7E+02	1.9E+02
TCDFs (total)	8.4E+01	1.0E+02	7.1E+01	1.8E+02	8.5E+01	1.7E+02	2.1E+02	1.2E+02	6.7E+01	9.6E+01
2,3,7,8,-TCDF	9.1E+00	5.5E+00	5.6E+00	7.6E+00	5.7E+00	1.0E+01	5.3E+00	5.6E+00	4.9E+00	1.2E+01
PeCDFs (total)	2.5E+01	1.7E+01	2.0E+01	8.6E+01	4.7E+01	1.2E+02	3.2E+01	2.9E+01	1.5E+01	1.7E+01
1,2,3,7,8,-PeCDF	7.4E+00	4.4E+00	4.9E+00	7.9E+00	5.2E+00	1.0E+01	8.9E+00	4.2E+00	2.6E+00	3.5E+00
2,3,4,7,8-PeCDF	7.0E+00	6.2E+00	8.9E+00	2.0E+01	1.0E+01	1.8E+01	7.8E+00	5.7E+00	3.1E+00	5.4E+00
HxCDFs (total)	1.5E+01	4.0E+01	4.9E+01	9.9E+01	6.7E+01	1.1E+02	1.8E+01	2.5E+01	1.1E+01	1.4E+01
1,2,3,4,7,8-HxCDF	9.7E+00	1.2E+01	1.4E+01	2.6E+01	2.0E+01	2.8E+01	5.4E+00	1.0E+01	6.5E+00	9.8E+00
1,2,3,6,7,8-HxCDF	4.3E+00	4.7E+00	6.6E+00	8.2E+00	9.5E+00	1.1E+01	7.4E+00	4.4E+00	2.6E+00	5.2E+00
2,3,4,6,7,8-HxCDF	9.3E+00	1.1E+01	1.2E+01	2.5E+01	1.7E+01	2.2E+01	8.5E+00	7.8E+00	5.0E+00	6.8E+00
1,2,3,7,8,9-HxCDF	1.6E+00	4.7E+00	4.1E+00	1.9E+00	6.4E+00	9.4E+00	1.0E+01	2.6E+00	3.3E+00	1.5E+00
HpCDFs (total)	2.5E+01	2.5E+01	2.7E+01	6.9E+01	6.6E+01	9.3E+01	1.8E+01	1.9E+01	3.2E+01	1.8E+01
1,2,3,4,6,7,8-HpCDF	2.5E+01	2.5E+01	2.7E+01	5.2E+01	4.3E+01	5.9E+01	1.8E+01	1.9E+01	2.0E+01	1.8E+01
1,2,3,4,7,8,9-HpCDF	2.3E+00	5.4E+00	4.7E+00	6.8E+00	7.9E+00	8.6E+00	5.5E+00	2.7E+00	4.5E+00	3.4E+00
OCDF	2.1E+01	2.9E+01	2.5E+01	3.6E+01	4.4E+01	5.3E+01	2.1E+01	2.1E+01	3.6E+01	2.1E+01

Appendix 1 (cont.). Observed Sample Loadings (pg/sample).

RUN	7						8			
INLET\OUTLET	INLET				OUTLET		INLET			OUTLET
SAMPLE PLACEMENT	W. VENT	B3	B4	E. VENT	B3	B4	W. VENT	B4	E. VENT	B4
TCDDs (total)	2.3E+01	8.9E+00	1.3E+01	9.4E+00	8.8E+00	2.2E+01	1.8E+01	1.4E+01	2.1E+01	2.6E+01
2,3,7,8-TCDD	6.9E+00	3.8E+00	3.0E+00	3.3E+00	2.8E+00	2.1E+00	4.0E+00	2.5E+00	3.2E+00	3.6E+00
PeCDDs (total)	1.1E+01	3.7E+01	3.3E+01	3.9E+00	4.3E+00	8.0E+00	3.5E+00	5.3E+00	7.6E+00	1.3E+01
1,2,3,7,8,-PeCDD	7.6E+00	6.9E+00	7.1E+00	2.7E+00	2.2E+00	2.0E+00	1.9E+00	1.9E+00	1.2E+00	3.2E+00
HxCDDs (total)	1.6E+02	1.1E+01	1.0E+01	9.0E+00	8.3E+00	4.2E+01	8.5E+00	2.4E+01	1.1E+01	1.3E+02
1,2,3,4,7,8-HxCDD	7.7E+00	9.4E+00	1.0E+01	1.9E+00	2.4E+00	2.4E+00	1.3E+00	2.0E+00	2.0E+00	4.8E+00
1,2,3,6,7,8-HxCDD	1.6E+01	8.9E+00	9.5E+00	3.4E+00	4.4E+00	5.5E+00	3.2E+00	4.0E+00	2.6E+00	1.1E+01
1,2,3,7,8,9-HxCDD	2.6E+01	8.8E+00	9.4E+00	4.5E+00	3.9E+00	6.3E+00	4.3E+00	4.8E+00	3.8E+00	1.9E+01
HpCDDs (total)	4.2E+02	5.8E+01	6.7E+01	4.9E+01	5.0E+01	1.4E+02	5.6E+01	6.5E+01	5.3E+01	3.7E+02
1,2,3,4,6,7,8-HpCDD	2.3E+02	2.7E+01	2.9E+01	2.4E+01	2.4E+01	6.8E+01	2.8E+01	3.1E+01	2.5E+01	1.6E+02
OCDD	1.4E+03	1.3E+02	1.7E+02	1.2E+02	1.2E+02	4.3E+02	1.2E+02	1.5E+02	9.7E+01	6.5E+02
TCDFs (total)	1.8E+02	8.8E+01	4.9E+01	8.2E+01	6.6E+01	1.4E+02	5.4E+01	5.1E+01	6.2E+01	1.7E+02
2,3,7,8,-TCDF	9.8E+00	5.8E+00	4.3E+00	7.0E+00	7.1E+00	1.2E+01	3.3E+00	3.5E+00	3.5E+00	1.1E+01
PeCDFs (total)	1.2E+02	1.9E+01	1.4E+01	1.3E+01	1.8E+01	3.6E+01	1.3E+01	1.5E+01	1.4E+01	7.0E+01
1,2,3,7,8,-PeCDF	8.3E+00	9.9E+00	6.9E+00	6.2E+00	4.2E+00	4.6E+00	4.3E+00	2.8E+00	2.0E+00	4.6E+00
2,3,4,7,8-PeCDF	1.2E+01	8.7E+00	3.2E+00	5.1E+00	5.1E+00	6.1E+00	2.7E+00	3.7E+00	2.5E+00	6.8E+00
HxCDFs (total)	1.6E+02	1.3E+01	1.3E+01	9.8E+00	1.3E+01	1.8E+01	8.5E+00	1.4E+01	1.2E+01	3.3E+01
1,2,3,4,7,8-HxCDF	2.5E+01	4.0E+00	6.7E+00	5.0E+00	4.5E+00	7.6E+00	4.4E+00	7.6E+00	7.2E+00	1.1E+01
1,2,3,6,7,8-HxCDF	1.9E+01	5.4E+00	5.4E+00	2.8E+00	5.1E+00	4.6E+00	2.2E+00	4.0E+00	2.7E+00	5.5E+00
2,3,4,6,7,8-HxCDF	2.1E+01	6.3E+00	6.3E+00	4.0E+00	1.8E+00	5.1E+00	3.7E+00	5.5E+00	5.9E+00	8.2E+00
1,2,3,7,8,9-HxCDF	2.0E+01	7.6E+00	7.6E+00	1.3E+00	1.2E+00	3.1E+00	4.6E+00	2.5E+00	3.1E+00	2.6E+00
HpCDFs (total)	5.6E+01	1.7E+01	1.7E+01	1.2E+01	1.6E+01	2.1E+01	1.3E+01	1.7E+01	2.1E+01	3.9E+01
1,2,3,4,6,7,8-HpCDF	8.0E+01	1.7E+01	1.7E+01	1.2E+01	1.6E+01	2.1E+01	1.3E+01	1.7E+01	2.1E+01	2.7E+01
1,2,3,4,7,8,9-HpCDF	1.0E+01	3.5E+00	2.7E+00	2.0E+00	1.5E+00	2.7E+00	2.3E+00	6.0E+00	3.3E+00	4.2E+00
OCDF	1.0E+02	1.3E+01	1.7E+01	1.7E+01	1.7E+01	2.5E+01	2.0E+01	2.5E+01	2.5E+01	3.7E+01

Appendix 1 (cont.). Observed Sample Loadings (pg/sample).

RUN	9						10			
INLET\OUTLET	INLET				OUTLET		INLET			OUTLET
SAMPLE PLACEMENT	W. VENT	B3	B4	E. VENT	B3	B4	W. VENT	B4	E. VENT	B4
TCDDs (total)	4.3E+00	3.4E+00	4.3E+00	4.3E+00	3.9E+00	8.8E+00	4.0E+00	3.2E+00		6.4E+00
2,3,7,8-TCDD	2.9E+00	2.9E+00	4.3E+00	1.8E+00	2.7E+00	5.0E+00	3.1E+00	3.2E+00		4.6E+00
PeCDDs (total)	2.1E+00	1.9E+00	3.5E+01	4.9E+00	4.0E+00	1.0E+01	3.0E+00	3.6E+00		9.2E+00
1,2,3,7,8,-PeCDD	2.1E+00	1.9E+00	7.5E+00	2.4E+00	2.3E+00	4.2E+00	3.0E+00	1.6E+00		4.7E+00
HxCDDs (total)	1.1E+01	2.6E+01	1.2E+01	1.4E+01	1.2E+01	9.6E+01	1.5E+01	1.6E+01		1.3E+02
1,2,3,4,7,8-HxCDD	2.2E+00	3.8E+00	1.2E+01	2.7E+00	2.1E+00	4.6E+00	2.8E+00	2.8E+00		7.0E+00
1,2,3,6,7,8-HxCDD	3.8E+00	7.2E+00	1.1E+01	4.3E+00	3.8E+00	1.1E+01	4.0E+00	4.9E+00		1.1E+01
1,2,3,7,8,9-HxCDD	4.2E+00	6.3E+00	1.1E+01	7.0E+00	6.6E+00	1.4E+01	7.6E+00	6.9E+00		2.0E+01
HpCDDs (total)	9.0E+01	9.6E+01	9.8E+01	7.5E+01	7.0E+01	1.7E+02	1.0E+02	1.0E+02		2.5E+02
1,2,3,4,6,7,8-HpCDD	4.4E+01	4.4E+01	4.8E+01	3.6E+01	3.5E+01	8.4E+01	5.0E+01	4.9E+01		1.2E+02
OCDD	1.9E+02	2.3E+02	2.4E+02	1.4E+02	1.4E+02	4.7E+02	1.9E+02	2.1E+02		4.6E+02
TCDFs (total)	3.1E+01	7.3E+00	7.5E+00	1.3E+02	7.2E+00	6.4E+01	3.9E+01	5.8E+00		3.6E+01
2,3,7,8,-TCDF	1.9E+00	4.1E+00	3.1E+00	5.4E+00	2.1E+00	6.1E+00	2.6E+00	2.4E+00		4.3E+00
PeCDFs (total)	4.7E+00	1.1E+01	8.7E+00	3.8E+01	1.1E+01	2.2E+01	9.2E+00	7.9E+00		3.1E+01
1,2,3,7,8,-PeCDF	3.2E+00	2.9E+00	7.3E+00	6.0E+00	2.5E+00	4.5E+00	3.0E+00	2.2E+00		3.5E+00
2,3,4,7,8-PeCDF	2.6E+00	2.4E+00	6.4E+00	7.6E+00	3.8E+00	7.8E+00	3.1E+00	3.0E+00		6.6E+00
HxCDFs (total)	5.2E+00	1.1E+01	1.1E+01	2.7E+01	1.0E+01	4.6E+01	1.1E+01	1.1E+01		3.3E+01
1,2,3,4,7,8-HxCDF	3.8E+00	7.5E+00	6.0E+00	1.1E+01	6.1E+00	1.3E+01	9.2E+00	6.7E+00		1.2E+01
1,2,3,6,7,8-HxCDF	2.4E+00	4.5E+00	8.1E+00	5.8E+00	3.7E+00	8.3E+00	5.1E+00	3.4E+00		6.6E+00
2,3,4,6,7,8-HxCDF	4.2E+00	5.5E+00	9.4E+00	8.7E+00	4.5E+00	1.1E+01	6.1E+00	5.2E+00		8.5E+00
1,2,3,7,8,9-HxCDF	3.3E+00	1.3E+00	4.0E+00	2.3E+00	2.9E+00	4.7E+00	3.9E+00	2.8E+00		4.8E+00
HpCDFs (total)	1.5E+01	1.7E+01	1.6E+01	1.9E+01	1.6E+01	3.0E+01	2.1E+01	1.9E+01		4.0E+01
1,2,3,4,6,7,8-HpCDF	1.5E+01	1.7E+01	1.6E+01	1.9E+01	1.6E+01	3.0E+01	2.1E+01	1.9E+01		2.7E+01
1,2,3,4,7,8,9-HpCDF	8.6E+00	1.6E+00	5.7E+00	3.5E+00	2.8E+00	4.2E+00	1.3E+01	3.2E+00		5.1E+00
OCDF	1.7E+01	2.0E+01	2.0E+01	1.7E+01	1.4E+01	4.2E+01	2.1E+01	2.0E+01		3.0E+01

Appendix 2. Observed Concentrations (pg/m^3).

Run	1						2			
INLET\OUTLET	INLET				OUTLET		INLET			OUTLET
SAMPLE PLACEMENT	W. VENT	B3	B4	E. VENT	B3	B4	W. VENT	B4	E. VENT	B4
TCDDs (total)	4.50E-02	1.80E-02	9.93E-02	8.36E-03	2.15E-02	5.60E-03	1.88E-02	2.08E-02	7.37E-03	7.07E-02
2,3,7,8-TCDD	6.00E-03	8.04E-03	1.24E-02	2.67E-03	1.48E-02	5.60E-03	5.73E-03	7.57E-03	5.69E-03	1.20E-02
PeCDDs (total)	2.33E-02	2.38E-02	4.66E-02	9.36E-03	2.35E-02	1.79E-01	1.19E-02	2.11E-02	8.37E-03	4.08E-02
1,2,3,7,8,-PeCDD	9.83E-03	8.04E-03	2.02E-02	4.34E-03	9.57E-03	2.98E-02	5.52E-03	8.92E-03	4.02E-03	1.60E-02
HxCDDs (total)	1.67E-01	1.32E-01	3.41E-01	2.84E-02	1.12E-01	7.14E-02	2.86E-02	1.60E-01	1.00E-01	2.72E-01
1,2,3,4,7,8-HxCDD	9.99E-03	1.09E-02	1.18E-02	6.35E-03	1.44E-02	1.79E-02	6.96E-03	1.16E-02	4.52E-03	1.33E-02
1,2,3,6,7,8-HxCDD	1.60E-02	1.64E-02	2.61E-02	8.36E-03	1.91E-02	2.08E-02	8.18E-03	2.00E-02	8.87E-03	2.39E-02
1,2,3,7,8,9-HxCDD	2.66E-02	2.57E-02	4.97E-02	1.32E-02	2.87E-02	2.68E-02	1.37E-02	3.79E-02	1.34E-02	4.08E-02
HpCDDs (total)	2.50E-01	2.57E-01	4.35E-01	1.84E-01	2.91E-01	3.51E-01	1.92E-01	4.60E-01	1.67E-01	3.26E-01
1,2,3,4,6,7,8-HpCDD	1.15E-01	1.22E-01	2.08E-01	9.19E-02	1.40E-01	1.79E-01	9.82E-02	2.22E-01	8.87E-02	1.63E-01
OCDD	3.50E-01	5.14E-01	7.14E-01	4.85E-01	5.58E-01	8.33E-01	3.89E-01	7.03E-01	3.35E-01	4.35E-01
TCDFs (total)	2.33E-01	4.18E-01	3.72E-01	8.69E-02	1.95E-01	7.14E-02	2.25E-01	2.51E-01	2.18E-01	1.31E-01
2,3,7,8,-TCDF	9.83E-03	2.22E-02	2.23E-02	7.52E-03	1.64E-02	2.02E-02	1.17E-02	1.24E-02	1.10E-02	1.14E-02
PeCDFs (total)	5.66E-02	1.77E-01	1.40E-01	5.51E-02	1.20E-01	4.23E-02	4.50E-02	5.95E-02	4.35E-02	7.89E-02
1,2,3,7,8,-PeCDF	6.66E-03	2.15E-02	1.92E-02	6.35E-03	1.84E-02	4.23E-02	9.00E-03	1.38E-02	8.54E-03	1.14E-02
2,3,4,7,8-PeCDF	1.03E-02	2.99E-02	3.07E-02	1.22E-02	2.99E-02	4.11E-02	1.13E-02	1.89E-02	1.61E-02	2.18E-02
HxCDFs (total)	8.49E-02	1.77E-01	1.80E-01	9.86E-02	1.95E-01	8.93E-02	8.18E-02	1.51E-01	1.32E-01	1.60E-01
1,2,3,4,7,8-HxCDF	2.33E-02	5.47E-02	4.97E-02	2.84E-02	5.58E-02	5.12E-02	2.45E-02	4.60E-02	4.35E-02	4.35E-02
1,2,3,6,7,8-HxCDF	1.30E-02	2.83E-02	2.73E-02	1.65E-02	3.03E-02	1.79E-02	1.31E-02	2.27E-02	2.01E-02	1.99E-02
2,3,4,6,7,8-HxCDF	2.33E-02	4.50E-02	4.66E-02	3.34E-02	5.98E-02	4.29E-02	2.66E-02	4.06E-02	4.85E-02	4.08E-02
1,2,3,7,8,9-HxCDF	6.66E-03	1.22E-02	1.40E-02	9.19E-03	8.38E-03	1.31E-02	1.25E-02	6.49E-03	1.32E-02	1.39E-02
HpCDFs (total)	8.83E-02	1.19E-01	1.24E-01	1.84E-01	2.11E-01	1.67E-01	1.25E-01	2.11E-01	2.51E-01	1.88E-01
1,2,3,4,6,7,8-HpCDF	7.49E-02	1.19E-01	1.24E-01	1.14E-01	1.64E-01	1.67E-01	7.57E-02	1.30E-01	1.42E-01	1.20E-01
1,2,3,4,7,8,9-HpCDF	1.10E-02	1.64E-02	1.74E-02	1.84E-02	2.67E-02	2.08E-02	1.31E-02	2.57E-02	2.51E-02	1.71E-02
OCDF	8.83E-02	1.29E-01	1.43E-01	1.60E-01	2.03E-01	1.96E-01	1.17E-01	1.62E-01	1.52E-01	1.44E-01

Appendix 2 (cont.). Observed Concentrations (pg/m^3).

Note: Run 4 Bore 4 Outlet not valid due to changes in analytical procedure, see text.

RUN	3						4			
INLET\OUTLET	INLET				OUTLET		INLET			OUTLET
SAMPLE PLACEMENT	W. VENT	B3	B4	E. VENT	B3	B4	W. VENT	B4	E. VENT	B4
TCDDs (total)	1.13E-02	1.62E-02	7.74E-02	8.21E-03	1.10E-02	4.36E-02	2.62E-02	2.32E-02	2.60E-02	2.62E-02
2,3,7,8-TCDD	5.87E-03	7.60E-03	8.97E-03	4.13E-03	2.94E-03	3.31E-02	2.79E-03	2.40E-03	3.82E-03	6.84E-03
PeCDDs (total)	1.07E-02	1.99E-02	3.09E-02	1.01E-02	1.08E-02	3.45E-02	1.43E-02	1.57E-02	1.24E-02	1.71E-02
1,2,3,7,8,-PeCDD	4.65E-03	9.32E-03	1.42E-02	7.28E-03	5.64E-03	2.04E-02	4.71E-03	4.41E-03	3.52E-03	6.08E-03
HxCDDs (total)	3.04E-02	1.23E-01	2.23E-01	1.62E-01	3.19E-02	7.04E-02	9.59E-02	1.30E-01	8.41E-02	5.70E-02
1,2,3,4,7,8-HxCDD	7.08E-03	6.38E-03	1.33E-02	1.51E-02	5.89E-03	2.25E-02	6.28E-03	7.99E-03	4.59E-03	7.60E-03
1,2,3,6,7,8-HxCDD	8.50E-03	1.52E-02	2.23E-02	1.75E-02	6.87E-03	3.10E-02	1.39E-02	1.74E-02	9.32E-03	1.97E-02
1,2,3,7,8,9-HxCDD	1.48E-02	2.33E-02	3.71E-02	3.73E-02	1.64E-02	5.63E-02	1.92E-02	2.07E-02	1.31E-02	2.20E-02
HpCDDs (total)	1.60E-01	1.96E-01	3.09E-01	7.47E-01	1.67E-01	6.47E-01	2.44E-01	3.03E-01	1.68E-01	3.57E-01
1,2,3,4,6,7,8-HpCDD	8.09E-02	9.81E-02	1.52E-01	3.17E-01	8.34E-02	3.17E-01	1.29E-01	1.57E-01	8.71E-02	1.75E-01
OCDD	3.44E-01	3.43E-01	6.81E-01	1.18E+00	3.44E-01	2.04E+00	4.88E-01	6.34E-01	3.21E-01	7.98E-01
TCDFs (total)	3.04E-01	1.94E-01	1.86E-01	9.89E-02	1.57E-01	5.49E-01	2.79E-01	3.31E-01	2.90E-01	2.09E-01
2,3,7,8,-TCDF	1.17E-02	8.34E-03	1.61E-02	7.28E-03	1.10E-02	5.28E-02	8.72E-03	1.07E-02	8.87E-03	1.41E-02
PeCDFs (total)	4.45E-02	3.68E-02	1.11E-01	2.99E-02	4.42E-02	1.41E-01	1.10E-01	8.82E-02	8.56E-02	5.70E-02
1,2,3,7,8,-PeCDF	9.71E-03	9.81E-03	1.42E-02	6.16E-03	9.33E-03	3.24E-02	9.42E-03	1.35E-02	7.03E-03	1.18E-02
2,3,4,7,8-PeCDF	1.21E-02	1.28E-02	1.95E-02	8.96E-03	1.50E-02	4.78E-02	1.22E-02	1.41E-02	1.21E-02	1.41E-02
HxCDFs (total)	7.49E-02	3.43E-02	8.36E-02	2.43E-02	3.93E-02	2.04E-01	9.94E-02	1.27E-01	9.17E-02	4.94E-02
1,2,3,4,7,8-HxCDF	2.43E-02	2.31E-02	3.09E-02	1.66E-02	2.28E-02	8.44E-02	2.79E-02	3.31E-02	2.29E-02	2.66E-02
1,2,3,6,7,8-HxCDF	1.52E-02	1.50E-02	1.67E-02	8.21E-03	1.23E-02	4.57E-02	1.26E-02	1.52E-02	1.05E-02	1.22E-02
2,3,4,6,7,8-HxCDF	2.23E-02	2.09E-02	2.69E-02	1.44E-02	2.01E-02	5.77E-02	2.27E-02	3.03E-02	2.14E-02	1.97E-02
1,2,3,7,8,9-HxCDF	9.31E-03	6.62E-03	1.08E-02	3.36E-03	7.12E-03	1.55E-02	8.20E-03	1.02E-02	3.21E-03	4.18E-03
HpCDFs (total)	5.87E-02	4.66E-02	9.90E-02	3.73E-02	4.91E-02	1.76E-01	9.59E-02	1.27E-01	6.42E-02	6.84E-02
1,2,3,4,6,7,8-HpCDF	5.87E-02	4.66E-02	6.81E-02	3.73E-02	4.91E-02	1.76E-01	6.80E-02	8.82E-02	6.42E-02	6.84E-02
1,2,3,4,7,8,9-HpCDF	1.09E-02	1.01E-02	1.33E-02	7.47E-03	9.57E-03	3.59E-02	1.13E-02	1.10E-02	9.78E-03	1.37E-02
OCDF	5.26E-02	5.40E-02	8.05E-02	4.85E-02	5.15E-02	1.69E-01	7.50E-02	9.10E-02	6.27E-02	9.12E-02

Appendix 2 (cont.). Observed Concentrations (pg/m^3).

RUN	5						6			
INLET\OUTLET	INLET				OUTLET		INLET			OUTLET
SAMPLE PLACEMENT	W. VENT	B3	B4	E. VENT	B3	B4	W. VENT	B4	E. VENT	B4
TCDDs (total)	1.65E-02	1.13E-02	1.56E-02	1.45E-02	2.84E-02	6.61E-02	3.93E-02	1.04E-02	1.13E-02	4.75E-02
2,3,7,8-TCDD	6.39E-03	5.89E-03	1.56E-02	5.01E-03	1.01E-02	1.07E-02	8.79E-03	3.81E-03	5.04E-03	8.48E-03
PeCDDs (total)	1.28E-02	8.24E-03	8.61E-03	1.52E-02	2.29E-02	3.96E-02	5.24E-02	1.08E-02	1.06E-02	2.14E-02
1,2,3,7,8,-PeCDD	1.28E-02	4.24E-03	8.61E-03	7.71E-03	1.42E-02	1.36E-02	1.27E-02	4.96E-03	5.94E-03	6.44E-03
HxCDDs (total)	1.88E-02	2.26E-02	3.97E-02	1.19E-01	6.88E-02	3.22E-01	2.43E-02	7.61E-02	3.24E-01	9.84E-02
1,2,3,4,7,8-HxCDD	6.01E-03	4.71E-03	5.30E-03	7.71E-03	1.56E-02	2.23E-02	2.43E-02	3.47E-03	1.44E-02	8.14E-03
1,2,3,6,7,8-HxCDD	7.52E-03	7.07E-03	1.23E-02	1.46E-02	2.25E-02	3.47E-02	2.24E-02	1.17E-02	2.52E-02	1.70E-02
1,2,3,7,8,9-HxCDD	8.46E-03	1.27E-02	1.72E-02	2.70E-02	2.75E-02	4.96E-02	2.24E-02	1.26E-02	5.22E-02	2.65E-02
HpCDDs (total)	1.13E-01	1.41E-01	2.02E-01	3.47E-01	3.62E-01	7.43E-01	1.87E-01	1.52E-01	1.22E+00	2.78E-01
1,2,3,4,6,7,8-HpCDD	5.45E-02	7.30E-02	9.60E-02	1.54E-01	1.74E-01	3.59E-01	8.98E-02	7.78E-02	5.22E-01	1.39E-01
OCDD	2.25E-01	3.06E-01	5.63E-01	4.24E-01	7.34E-01	1.73E+00	3.55E-01	2.81E-01	1.75E+00	6.44E-01
TCDFs (total)	1.58E-01	2.36E-01	2.35E-01	3.47E-01	3.90E-01	7.02E-01	3.93E-01	1.99E-01	1.21E-01	3.26E-01
2,3,7,8,-TCDF	1.71E-02	1.30E-02	1.85E-02	1.46E-02	2.61E-02	4.13E-02	9.91E-03	9.27E-03	8.82E-03	4.07E-02
PeCDFs (total)	4.70E-02	4.00E-02	6.62E-02	1.66E-01	2.15E-01	4.96E-01	5.99E-02	4.80E-02	2.70E-02	5.77E-02
1,2,3,7,8,-PeCDF	1.39E-02	1.04E-02	1.62E-02	1.52E-02	2.38E-02	4.13E-02	1.66E-02	6.95E-03	4.68E-03	1.19E-02
2,3,4,7,8-PeCDF	1.32E-02	1.46E-02	2.95E-02	3.85E-02	4.58E-02	7.43E-02	1.46E-02	9.43E-03	5.58E-03	1.83E-02
HxCDFs (total)	2.82E-02	9.42E-02	1.62E-01	1.91E-01	3.07E-01	4.54E-01	3.37E-02	4.14E-02	1.98E-02	4.75E-02
1,2,3,4,7,8-HxCDF	1.82E-02	2.83E-02	4.64E-02	5.01E-02	9.17E-02	1.16E-01	1.01E-02	1.65E-02	1.17E-02	3.32E-02
1,2,3,6,7,8-HxCDF	8.08E-03	1.11E-02	2.19E-02	1.58E-02	4.36E-02	4.54E-02	1.38E-02	7.28E-03	4.68E-03	1.76E-02
2,3,4,6,7,8-HxCDF	1.75E-02	2.59E-02	3.97E-02	4.82E-02	7.79E-02	9.08E-02	1.59E-02	1.29E-02	9.00E-03	2.31E-02
1,2,3,7,8,9-HxCDF	3.01E-03	1.11E-02	1.36E-02	3.66E-03	2.93E-02	3.88E-02	1.87E-02	4.30E-03	5.94E-03	5.09E-03
HpCDFs (total)	4.70E-02	5.89E-02	8.94E-02	1.33E-01	3.03E-01	3.84E-01	3.37E-02	3.14E-02	5.76E-02	6.11E-02
1,2,3,4,6,7,8-HpCDF	4.70E-02	5.89E-02	8.94E-02	1.00E-01	1.97E-01	2.44E-01	3.37E-02	3.14E-02	3.60E-02	6.11E-02
1,2,3,4,7,8,9-HpCDF	4.32E-03	1.27E-02	1.56E-02	1.31E-02	3.62E-02	3.55E-02	1.03E-02	4.47E-03	8.10E-03	1.15E-02
OCDF	3.95E-02	6.83E-02	8.28E-02	6.94E-02	2.02E-01	2.19E-01	3.93E-02	3.47E-02	6.48E-02	7.12E-02

Appendix 2 (cont.). Observed Concentrations (pg/m^3).

RUN	7						8			
INLET\OUTLET	INLET				OUTLET		INLET			OUTLET
SAMPLE PLACEMENT	W. VENT	B3	B4	E. VENT	B3	B4	W. VENT	B4	E. VENT	B4
TCDDs (total)	4.76E-02	2.27E-02	3.91E-02	1.70E-02	2.22E-02	1.06E-01	3.36E-02	3.02E-02	3.42E-02	9.57E-02
2,3,7,8-TCDD	1.43E-02	9.69E-03	9.03E-03	5.98E-03	7.07E-03	1.01E-02	7.46E-03	5.40E-03	5.21E-03	1.32E-02
PeCDDs (total)	2.28E-02	9.44E-02	9.93E-02	7.06E-03	1.09E-02	3.85E-02	6.53E-03	1.14E-02	1.24E-02	4.78E-02
1,2,3,7,8,-PeCDD	1.57E-02	1.76E-02	2.14E-02	4.89E-03	5.55E-03	9.62E-03	3.54E-03	4.10E-03	1.96E-03	1.18E-02
HxCDDs (total)	3.31E-01	2.81E-02	3.01E-02	1.63E-02	2.10E-02	2.02E-01	1.59E-02	5.18E-02	1.79E-02	4.78E-01
1,2,3,4,7,8-HxCDD	1.59E-02	2.40E-02	3.01E-02	3.44E-03	6.06E-03	1.15E-02	2.42E-03	4.32E-03	3.26E-03	1.77E-02
1,2,3,6,7,8-HxCDD	3.31E-02	2.27E-02	2.86E-02	6.16E-03	1.11E-02	2.64E-02	5.97E-03	8.63E-03	4.24E-03	4.05E-02
1,2,3,7,8,9-HxCDD	5.38E-02	2.24E-02	2.83E-02	8.15E-03	9.85E-03	3.03E-02	8.02E-03	1.04E-02	6.19E-03	6.99E-02
HpCDDs (total)	8.69E-01	1.48E-01	2.02E-01	8.87E-02	1.26E-01	6.73E-01	1.04E-01	1.40E-01	8.64E-02	1.36E+00
1,2,3,4,6,7,8-HpCDD	4.76E-01	6.89E-02	8.73E-02	4.35E-02	6.06E-02	3.27E-01	5.22E-02	6.69E-02	4.07E-02	5.89E-01
OCDD	2.90E+00	3.32E-01	5.12E-01	2.17E-01	3.03E-01	2.07E+00	2.24E-01	3.24E-01	1.58E-01	2.39E+00
TCDFs (total)	3.73E-01	2.24E-01	1.48E-01	1.48E-01	1.67E-01	6.73E-01	1.01E-01	1.10E-01	1.01E-01	6.26E-01
2,3,7,8,-TCDF	2.03E-02	1.48E-02	1.29E-02	1.27E-02	1.79E-02	5.77E-02	6.16E-03	7.55E-03	5.70E-03	4.05E-02
PeCDFs (total)	2.48E-01	4.85E-02	4.21E-02	2.35E-02	4.54E-02	1.73E-01	2.42E-02	3.24E-02	2.28E-02	2.58E-01
1,2,3,7,8,-PeCDF	1.72E-02	2.52E-02	2.08E-02	1.12E-02	1.06E-02	2.21E-02	8.02E-03	6.04E-03	3.26E-03	1.69E-02
2,3,4,7,8-PeCDF	2.48E-02	2.22E-02	9.63E-03	9.24E-03	1.29E-02	2.93E-02	5.04E-03	7.99E-03	4.07E-03	2.50E-02
HxCDFs (total)	3.31E-01	3.32E-02	3.91E-02	1.77E-02	3.28E-02	8.65E-02	1.59E-02	3.02E-02	1.96E-02	1.21E-01
1,2,3,4,7,8-HxCDF	5.17E-02	1.02E-02	2.02E-02	9.05E-03	1.14E-02	3.65E-02	8.21E-03	1.64E-02	1.17E-02	4.05E-02
1,2,3,6,7,8-HxCDF	3.93E-02	1.38E-02	1.63E-02	5.07E-03	1.29E-02	2.21E-02	4.10E-03	8.63E-03	4.40E-03	2.02E-02
2,3,4,6,7,8-HxCDF	4.35E-02	1.61E-02	1.90E-02	7.24E-03	4.54E-03	2.45E-02	6.90E-03	1.19E-02	9.61E-03	3.02E-02
1,2,3,7,8,9-HxCDF	4.14E-02	1.94E-02	2.29E-02	2.35E-03	3.03E-03	1.49E-02	8.58E-03	5.40E-03	5.05E-03	9.57E-03
HpCDFs (total)	1.16E-01	4.34E-02	5.12E-02	2.17E-02	4.04E-02	1.01E-01	2.42E-02	3.67E-02	3.42E-02	1.44E-01
1,2,3,4,6,7,8-HpCDF	1.66E-01	4.34E-02	5.12E-02	2.17E-02	4.04E-02	1.01E-01	2.42E-02	3.67E-02	3.42E-02	9.94E-02
1,2,3,4,7,8,9-HpCDF	2.07E-02	8.93E-03	8.13E-03	3.62E-03	3.79E-03	1.30E-02	4.29E-03	1.29E-02	5.38E-03	1.55E-02
OCDF	2.07E-01	3.32E-02	5.12E-02	3.08E-02	4.29E-02	1.20E-01	3.73E-02	5.40E-02	4.07E-02	1.36E-01

Appendix 2 (cont.). Observed Concentrations (pg/m^3).

RUN #	9						10			
INLET\OUTLET	INLET				OUTLET		INLET			OUTLET
SAMPLE PLACEMENT	W. VENT	B3	B4	E. VENT	B3	B4	W. VENT	B4	E. VENT	B4
TCDDs (total)	1.51E-02	1.53E-02	2.33E-02	1.51E-02	2.05E-02	5.86E-02	1.40E-02	1.44E-02		3.26E-02
2,3,7,8-TCDD	1.02E-02	1.30E-02	2.33E-02	6.34E-03	1.42E-02	3.33E-02	1.08E-02	1.44E-02		2.34E-02
PeCDDs (total)	7.39E-03	8.54E-03	1.90E-01	1.72E-02	2.10E-02	6.65E-02	1.05E-02	1.62E-02		4.68E-02
1,2,3,7,8,-PeCDD	7.39E-03	8.54E-03	4.07E-02	8.45E-03	1.21E-02	2.80E-02	1.05E-02	7.19E-03		2.39E-02
HxCDDs (total)	3.87E-02	1.17E-01	6.51E-02	4.93E-02	6.30E-02	6.39E-01	5.24E-02	7.19E-02		6.61E-01
1,2,3,4,7,8-HxCDD	7.75E-03	1.71E-02	6.51E-02	9.50E-03	1.10E-02	3.06E-02	9.78E-03	1.26E-02		3.56E-02
1,2,3,6,7,8-HxCDD	1.34E-02	3.24E-02	5.96E-02	1.51E-02	1.99E-02	7.32E-02	1.40E-02	2.20E-02		5.60E-02
1,2,3,7,8,9-HxCDD	1.48E-02	2.83E-02	5.96E-02	2.46E-02	3.46E-02	9.32E-02	2.65E-02	3.10E-02		1.02E-01
HpCDDs (total)	3.17E-01	4.32E-01	5.31E-01	2.64E-01	3.67E-01	1.13E+00	3.49E-01	4.49E-01		1.27E+00
1,2,3,4,6,7,8-HpCDD	1.55E-01	1.98E-01	2.60E-01	1.27E-01	1.84E-01	5.59E-01	1.75E-01	2.20E-01		6.10E-01
OCDD	6.69E-01	1.03E+00	1.30E+00	4.93E-01	7.35E-01	3.13E+00	6.63E-01	9.44E-01		2.34E+00
TCDFs (total)	1.09E-01	3.28E-02	4.07E-02	4.58E-01	3.78E-02	4.26E-01	1.36E-01	2.61E-02		1.83E-01
2,3,7,8,-TCDF	6.69E-03	1.84E-02	1.68E-02	1.90E-02	1.10E-02	4.06E-02	9.08E-03	1.08E-02		2.19E-02
PeCDFs (total)	1.65E-02	4.95E-02	4.72E-02	1.34E-01	5.77E-02	1.46E-01	3.21E-02	3.55E-02		1.58E-01
1,2,3,7,8,-PeCDF	1.13E-02	1.30E-02	3.96E-02	2.11E-02	1.31E-02	2.99E-02	1.05E-02	9.89E-03		1.78E-02
2,3,4,7,8-PeCDF	9.15E-03	1.08E-02	3.47E-02	2.68E-02	1.99E-02	5.19E-02	1.08E-02	1.35E-02		3.36E-02
HxCDFs (total)	1.83E-02	4.95E-02	5.96E-02	9.50E-02	5.25E-02	3.06E-01	3.84E-02	4.94E-02		1.68E-01
1,2,3,4,7,8-HxCDF	1.34E-02	3.37E-02	3.25E-02	3.87E-02	3.20E-02	8.65E-02	3.21E-02	3.01E-02		6.10E-02
1,2,3,6,7,8-HxCDF	8.45E-03	2.02E-02	4.39E-02	2.04E-02	1.94E-02	5.52E-02	1.78E-02	1.53E-02		3.36E-02
2,3,4,6,7,8-HxCDF	1.48E-02	2.47E-02	5.10E-02	3.06E-02	2.36E-02	7.32E-02	2.13E-02	2.34E-02		4.32E-02
1,2,3,7,8,9-HxCDF	1.16E-02	5.85E-03	2.17E-02	8.10E-03	1.52E-02	3.13E-02	1.36E-02	1.26E-02		2.44E-02
HpCDFs (total)	5.28E-02	7.64E-02	8.68E-02	6.69E-02	8.40E-02	2.00E-01	7.33E-02	8.54E-02		2.03E-01
1,2,3,4,6,7,8-HpCDF	5.28E-02	7.64E-02	8.68E-02	6.69E-02	8.40E-02	2.00E-01	7.33E-02	8.54E-02		1.37E-01
1,2,3,4,7,8,9-HpCDF	3.03E-02	7.19E-03	3.09E-02	1.23E-02	1.47E-02	2.80E-02	4.54E-02	1.44E-02		2.59E-02
OCDF	5.99E-02	8.99E-02	1.08E-01	5.98E-02	7.35E-02	2.80E-01	7.33E-02	8.99E-02		1.53E-01

Appendix 3. Observed TEQ Concentrations (pg-TEQ/m^3).

Run		1						2			
INLET\OUTLET		INLET				OUTLET		INLET			OUTLET
SAMPLE PLACEMENT	TEQ Factor	W. VENT	B3	B4	E. VENT	B3	B4	W. VENT	B4	E. VENT	B4
2,3,7,8-TCDD	1	6.00E-03	8.04E-03	1.24E-02	2.67E-03	1.48E-02	5.60E-03	5.73E-03	7.57E-03	5.69E-03	1.20E-02
1,2,3,7,8,-PeCDD	0.5	4.91E-03	4.02E-03	1.01E-02	2.17E-03	4.79E-03	1.49E-02	2.76E-03	4.46E-03	2.01E-03	8.02E-03
1,2,3,4,7,8-HxCDD	0.1	9.99E-04	1.09E-03	1.18E-03	6.35E-04	1.44E-03	1.79E-03	6.96E-04	1.16E-03	4.52E-04	1.33E-03
1,2,3,6,7,8-HxCDD	0.1	1.60E-03	1.64E-03	2.61E-03	8.36E-04	1.91E-03	2.08E-03	8.18E-04	2.00E-03	8.87E-04	2.39E-03
1,2,3,7,8,9-HxCDD	0.1	2.66E-03	2.57E-03	4.97E-03	1.32E-03	2.87E-03	2.68E-03	1.37E-03	3.79E-03	1.34E-03	4.08E-03
1,2,3,4,6,7,8-HpCDD	0.01	1.15E-03	1.22E-03	2.08E-03	9.19E-04	1.40E-03	1.79E-03	9.82E-04	2.22E-03	8.87E-04	1.63E-03
OCDD	0.001	3.50E-04	5.14E-04	7.14E-04	4.85E-04	5.58E-04	8.33E-04	3.89E-04	7.03E-04	3.35E-04	4.35E-04
2,3,7,8,-TCDF	0.1	9.83E-04	2.22E-03	2.23E-03	7.52E-04	1.64E-03	2.02E-03	1.17E-03	1.24E-03	1.10E-03	1.14E-03
1,2,3,7,8,-PeCDF	0.05	3.33E-04	1.08E-03	9.62E-04	3.18E-04	9.18E-04	2.11E-03	4.50E-04	6.90E-04	4.27E-04	5.71E-04
2,3,4,7,8-PeCDF	0.5	5.16E-03	1.50E-02	1.54E-02	6.10E-03	1.50E-02	2.05E-02	5.63E-03	9.46E-03	8.04E-03	1.09E-02
1,2,3,4,7,8-HxCDF	0.1	2.33E-03	5.47E-03	4.97E-03	2.84E-03	5.58E-03	5.12E-03	2.45E-03	4.60E-03	4.35E-03	4.35E-03
1,2,3,6,7,8-HxCDF	0.1	1.30E-03	2.83E-03	2.73E-03	1.65E-03	3.03E-03	1.79E-03	1.31E-03	2.27E-03	2.01E-03	1.99E-03
2,3,4,6,7,8-HxCDF	0.1	2.33E-03	4.50E-03	4.66E-03	3.34E-03	5.98E-03	4.29E-03	2.66E-03	4.06E-03	4.85E-03	4.08E-03
1,2,3,7,8,9-HxCDF	0.1	6.66E-04	1.22E-03	1.40E-03	9.19E-04	8.38E-04	1.31E-03	1.25E-03	6.49E-04	1.32E-03	1.39E-03
1,2,3,4,6,7,8-HpCDF	0.01	7.49E-04	1.19E-03	1.24E-03	1.14E-03	1.64E-03	1.67E-03	7.57E-04	1.30E-03	1.42E-03	1.20E-03
1,2,3,4,7,8,9-HpCDF	0.01	1.10E-04	1.64E-04	1.74E-04	1.84E-04	2.67E-04	2.08E-04	1.31E-04	2.57E-04	2.51E-04	1.71E-04
OCDF	0.001	8.83E-05	1.29E-04	1.43E-04	1.60E-04	2.03E-04	1.96E-04	1.17E-04	1.62E-04	1.52E-04	1.44E-04
Total TEQ		3.17E-02	5.28E-02	6.79E-02	2.64E-02	6.28E-02	6.89E-02	2.87E-02	4.66E-02	3.55E-02	5.58E-02

Appendix 3 (cont.). Observed TEQ Concentrations (pg-TEQ/m^3).

Note: Run 4 Bore 4 Outlet not valid due to changes in analytical procedure, see text.

RUN	3						4			
INLET\OUTLET	INLET				OUTLET		INLET			OUTLET
SAMPLE PLACEMENT	W. VENT	B3	B4	E. VENT	B3	B4	W. VENT	B4	E. VENT	B4
2,3,7,8-TCDD	5.87E-03	7.60E-03	8.97E-03	4.13E-03	2.94E-03	3.31E-02	2.79E-03	2.40E-03	3.82E-03	6.84E-03
1,2,3,7,8,-PeCDD	2.33E-03	4.66E-03	7.12E-03	3.64E-03	2.82E-03	1.02E-02	2.35E-03	2.20E-03	1.76E-03	3.04E-03
1,2,3,4,7,8-HxCDD	7.08E-04	6.38E-04	1.33E-03	1.51E-03	5.89E-04	2.25E-03	6.28E-04	7.99E-04	4.59E-04	7.60E-04
1,2,3,6,7,8-HxCDD	8.50E-04	1.52E-03	2.23E-03	1.75E-03	6.87E-04	3.10E-03	1.39E-03	1.74E-03	9.32E-04	1.97E-03
1,2,3,7,8,9-HxCDD	1.48E-03	2.33E-03	3.71E-03	3.73E-03	1.64E-03	5.63E-03	1.92E-03	2.07E-03	1.31E-03	2.20E-03
1,2,3,4,6,7,8-HpCDD	8.09E-04	9.81E-04	1.52E-03	3.17E-03	8.34E-04	3.17E-03	1.29E-03	1.57E-03	8.71E-04	1.75E-03
OCDD	3.44E-04	3.43E-04	6.81E-04	1.18E-03	3.44E-04	2.04E-03	4.88E-04	6.34E-04	3.21E-04	7.98E-04
2,3,7,8,-TCDF	1.17E-03	8.34E-04	1.61E-03	7.28E-04	1.10E-03	5.28E-03	8.72E-04	1.07E-03	8.87E-04	1.41E-03
1,2,3,7,8,-PeCDF	4.86E-04	4.91E-04	7.12E-04	3.08E-04	4.66E-04	1.62E-03	4.71E-04	6.75E-04	3.52E-04	5.89E-04
2,3,4,7,8-PeCDF	6.07E-03	6.38E-03	9.75E-03	4.48E-03	7.48E-03	2.39E-02	6.10E-03	7.03E-03	6.04E-03	7.03E-03
1,2,3,4,7,8-HxCDF	2.43E-03	2.31E-03	3.09E-03	1.66E-03	2.28E-03	8.44E-03	2.79E-03	3.31E-03	2.29E-03	2.66E-03
1,2,3,6,7,8-HxCDF	1.52E-03	1.50E-03	1.67E-03	8.21E-04	1.23E-03	4.57E-03	1.26E-03	1.52E-03	1.05E-03	1.22E-03
2,3,4,6,7,8-HxCDF	2.23E-03	2.09E-03	2.69E-03	1.44E-03	2.01E-03	5.77E-03	2.27E-03	3.03E-03	2.14E-03	1.97E-03
1,2,3,7,8,9-HxCDF	9.31E-04	6.62E-04	1.08E-03	3.36E-04	7.12E-04	1.55E-03	8.20E-04	1.02E-03	3.21E-04	4.18E-04
1,2,3,4,6,7,8-HpCDF	5.87E-04	4.66E-04	6.81E-04	3.73E-04	4.91E-04	1.76E-03	6.80E-04	8.82E-04	6.42E-04	6.84E-04
1,2,3,4,7,8,9-HpCDF	1.09E-04	1.01E-04	1.33E-04	7.47E-05	9.57E-05	3.59E-04	1.13E-04	1.10E-04	9.78E-05	1.37E-04
OCDF	5.26E-05	5.40E-05	8.05E-05	4.85E-05	5.15E-05	1.69E-04	7.50E-05	9.10E-05	6.27E-05	9.12E-05
Total TEQ	2.80E-02	3.30E-02	4.71E-02	2.94E-02	2.58E-02	1.13E-01	2.63E-02	3.01E-02	2.34E-02	3.36E-02

Appendix 3 (cont.). Observed TEQ Concentrations (pg-TEQ/m^3).

RUN	5						6			
INLET\OUTLET	INLET				OUTLET		INLET			OUTLET
SAMPLE PLACEMENT	W. VENT	B3	B4	E. VENT	B3	B4	W. VENT	B4	E. VENT	B4
2,3,7,8-TCDD	6.39E-03	5.89E-03	1.56E-02	5.01E-03	1.01E-02	1.07E-02	8.79E-03	3.81E-03	5.04E-03	8.48E-03
1,2,3,7,8,-PeCDD	6.39E-03	2.12E-03	4.30E-03	3.85E-03	7.11E-03	6.81E-03	6.36E-03	2.48E-03	2.97E-03	3.22E-03
1,2,3,4,7,8-HxCDD	6.01E-04	4.71E-04	5.30E-04	7.71E-04	1.56E-03	2.23E-03	2.43E-03	3.47E-04	1.44E-03	8.14E-04
1,2,3,6,7,8-HxCDD	7.52E-04	7.07E-04	1.23E-03	1.46E-03	2.25E-03	3.47E-03	2.24E-03	1.17E-03	2.52E-03	1.70E-03
1,2,3,7,8,9-HxCDD	8.46E-04	1.27E-03	1.72E-03	2.70E-03	2.75E-03	4.96E-03	2.24E-03	1.26E-03	5.22E-03	2.65E-03
1,2,3,4,6,7,8-HpCDD	5.45E-04	7.30E-04	9.60E-04	1.54E-03	1.74E-03	3.59E-03	8.98E-04	7.78E-04	5.22E-03	1.39E-03
OCDD	2.25E-04	3.06E-04	5.63E-04	4.24E-04	7.34E-04	1.73E-03	3.55E-04	2.81E-04	1.75E-03	6.44E-04
2,3,7,8,-TCDF	1.71E-03	1.30E-03	1.85E-03	1.46E-03	2.61E-03	4.13E-03	9.91E-04	9.27E-04	8.82E-04	4.07E-03
1,2,3,7,8,-PeCDF	6.95E-04	5.18E-04	8.11E-04	7.61E-04	1.19E-03	2.06E-03	8.32E-04	3.47E-04	2.34E-04	5.94E-04
2,3,4,7,8-PeCDF	6.58E-03	7.30E-03	1.47E-02	1.93E-02	2.29E-02	3.72E-02	7.30E-03	4.72E-03	2.79E-03	9.16E-03
1,2,3,4,7,8-HxCDF	1.82E-03	2.83E-03	4.64E-03	5.01E-03	9.17E-03	1.16E-02	1.01E-03	1.65E-03	1.17E-03	3.32E-03
1,2,3,6,7,8-HxCDF	8.08E-04	1.11E-03	2.19E-03	1.58E-03	4.36E-03	4.54E-03	1.38E-03	7.28E-04	4.68E-04	1.76E-03
2,3,4,6,7,8-HxCDF	1.75E-03	2.59E-03	3.97E-03	4.82E-03	7.79E-03	9.08E-03	1.59E-03	1.29E-03	9.00E-04	2.31E-03
1,2,3,7,8,9-HxCDF	3.01E-04	1.11E-03	1.36E-03	3.66E-04	2.93E-03	3.88E-03	1.87E-03	4.30E-04	5.94E-04	5.09E-04
1,2,3,4,6,7,8-HpCDF	4.70E-04	5.89E-04	8.94E-04	1.00E-03	1.97E-03	2.44E-03	3.37E-04	3.14E-04	3.60E-04	6.11E-04
1,2,3,4,7,8,9-HpCDF	4.32E-05	1.27E-04	1.56E-04	1.31E-04	3.62E-04	3.55E-04	1.03E-04	4.47E-05	8.10E-05	1.15E-04
OCDF	3.95E-05	6.83E-05	8.28E-05	6.94E-05	2.02E-04	2.19E-04	3.93E-05	3.47E-05	6.48E-05	7.12E-05
Total TEQ	3.00E-02	2.90E-02	5.56E-02	5.02E-02	7.97E-02	1.09E-01	3.88E-02	2.06E-02	3.17E-02	4.14E-02

Appendix 3 (cont.). Observed TEQ Concentrations (pg-TEQ/m^3).

RUN	7						8			
INLET\OUTLET	INLET				OUTLET		INLET			OUTLET
SAMPLE PLACEMENT	W. VENT	B3	B4	E. VENT	B3	B4	W. VENT	B4	E. VENT	B4
2,3,7,8-TCDD	1.43E-02	9.69E-03	9.03E-03	5.98E-03	7.07E-03	1.01E-02	7.46E-03	5.40E-03	5.21E-03	1.32E-02
1,2,3,7,8,-PeCDD	7.87E-03	8.80E-03	1.07E-02	2.44E-03	2.78E-03	4.81E-03	1.77E-03	2.05E-03	9.78E-04	5.89E-03
1,2,3,4,7,8-HxCDD	1.59E-03	2.40E-03	3.01E-03	3.44E-04	6.06E-04	1.15E-03	2.42E-04	4.32E-04	3.26E-04	1.77E-03
1,2,3,6,7,8-HxCDD	3.31E-03	2.27E-03	2.86E-03	6.16E-04	1.11E-03	2.64E-03	5.97E-04	8.63E-04	4.24E-04	4.05E-03
1,2,3,7,8,9-HxCDD	5.38E-03	2.24E-03	2.83E-03	8.15E-04	9.85E-04	3.03E-03	8.02E-04	1.04E-03	6.19E-04	6.99E-03
1,2,3,4,6,7,8-HpCDD	4.76E-03	6.89E-04	8.73E-04	4.35E-04	6.06E-04	3.27E-03	5.22E-04	6.69E-04	4.07E-04	5.89E-03
OCDD	2.90E-03	3.32E-04	5.12E-04	2.17E-04	3.03E-04	2.07E-03	2.24E-04	3.24E-04	1.58E-04	2.39E-03
2,3,7,8,-TCDF	2.03E-03	1.48E-03	1.29E-03	1.27E-03	1.79E-03	5.77E-03	6.16E-04	7.55E-04	5.70E-04	4.05E-03
1,2,3,7,8,-PeCDF	8.59E-04	1.26E-03	1.04E-03	5.61E-04	5.30E-04	1.11E-03	4.01E-04	3.02E-04	1.63E-04	8.46E-04
2,3,4,7,8-PeCDF	1.24E-02	1.11E-02	4.82E-03	4.62E-03	6.44E-03	1.47E-02	2.52E-03	3.99E-03	2.04E-03	1.25E-02
1,2,3,4,7,8-HxCDF	5.17E-03	1.02E-03	2.02E-03	9.05E-04	1.14E-03	3.65E-03	8.21E-04	1.64E-03	1.17E-03	4.05E-03
1,2,3,6,7,8-HxCDF	3.93E-03	1.38E-03	1.63E-03	5.07E-04	1.29E-03	2.21E-03	4.10E-04	8.63E-04	4.40E-04	2.02E-03
2,3,4,6,7,8-HxCDF	4.35E-03	1.61E-03	1.90E-03	7.24E-04	4.54E-04	2.45E-03	6.90E-04	1.19E-03	9.61E-04	3.02E-03
1,2,3,7,8,9-HxCDF	4.14E-03	1.94E-03	2.29E-03	2.35E-04	3.03E-04	1.49E-03	8.58E-04	5.40E-04	5.05E-04	9.57E-04
1,2,3,4,6,7,8-HpCDF	1.66E-03	4.34E-04	5.12E-04	2.17E-04	4.04E-04	1.01E-03	2.42E-04	3.67E-04	3.42E-04	9.94E-04
1,2,3,4,7,8,9-HpCDF	2.07E-04	8.93E-05	8.13E-05	3.62E-05	3.79E-05	1.30E-04	4.29E-05	1.29E-04	5.38E-05	1.55E-04
OCDF	2.07E-04	3.32E-05	5.12E-05	3.08E-05	4.29E-05	1.20E-04	3.73E-05	5.40E-05	4.07E-05	1.36E-04
Total TEQ	7.51E-02	4.68E-02	4.54E-02	1.99E-02	2.59E-02	5.97E-02	1.83E-02	2.06E-02	1.44E-02	6.90E-02

Appendix 3 (cont.). Observed TEQ Concentrations (pg-TEQ/m^3).

RUN	9						10			
INLET\OUTLET	INLET				OUTLET		INLET			OUTLET
SAMPLE PLACEMENT	W. VENT	B3	B4	E. VENT	B3	B4	W. VENT	B4	E. VENT	B4
2,3,7,8-TCDD	1.02E-02	1.30E-02	2.33E-02	6.34E-03	1.42E-02	3.33E-02	1.08E-02	1.44E-02		2.34E-02
1,2,3,7,8,-PeCDD	3.70E-03	4.27E-03	2.03E-02	4.22E-03	6.03E-03	1.40E-02	5.24E-03	3.59E-03		1.20E-02
1,2,3,4,7,8-HxCDD	7.75E-04	1.71E-03	6.51E-03	9.50E-04	1.10E-03	3.06E-03	9.78E-04	1.26E-03		3.56E-03
1,2,3,6,7,8-HxCDD	1.34E-03	3.24E-03	5.96E-03	1.51E-03	1.99E-03	7.32E-03	1.40E-03	2.20E-03		5.60E-03
1,2,3,7,8,9-HxCDD	1.48E-03	2.83E-03	5.96E-03	2.46E-03	3.46E-03	9.32E-03	2.65E-03	3.10E-03		1.02E-02
1,2,3,4,6,7,8-HpCDD	1.55E-03	1.98E-03	2.60E-03	1.27E-03	1.84E-03	5.59E-03	1.75E-03	2.20E-03		6.10E-03
OCDD	6.69E-04	1.03E-03	1.30E-03	4.93E-04	7.35E-04	3.13E-03	6.63E-04	9.44E-04		2.34E-03
2,3,7,8,-TCDF	6.69E-04	1.84E-03	1.68E-03	1.90E-03	1.10E-03	4.06E-03	9.08E-04	1.08E-03		2.19E-03
1,2,3,7,8,-PeCDF	5.63E-04	6.52E-04	1.98E-03	1.06E-03	6.56E-04	1.50E-03	5.24E-04	4.94E-04		8.90E-04
2,3,4,7,8-PeCDF	4.58E-03	5.40E-03	1.74E-02	1.34E-02	9.97E-03	2.60E-02	5.41E-03	6.74E-03		1.68E-02
1,2,3,4,7,8-HxCDF	1.34E-03	3.37E-03	3.25E-03	3.87E-03	3.20E-03	8.65E-03	3.21E-03	3.01E-03		6.10E-03
1,2,3,6,7,8-HxCDF	8.45E-04	2.02E-03	4.39E-03	2.04E-03	1.94E-03	5.52E-03	1.78E-03	1.53E-03		3.36E-03
2,3,4,6,7,8-HxCDF	1.48E-03	2.47E-03	5.10E-03	3.06E-03	2.36E-03	7.32E-03	2.13E-03	2.34E-03		4.32E-03
1,2,3,7,8,9-HxCDF	1.16E-03	5.85E-04	2.17E-03	8.10E-04	1.52E-03	3.13E-03	1.36E-03	1.26E-03		2.44E-03
1,2,3,4,6,7,8-HpCDF	5.28E-04	7.64E-04	8.68E-04	6.69E-04	8.40E-04	2.00E-03	7.33E-04	8.54E-04		1.37E-03
1,2,3,4,7,8,9-HpCDF	3.03E-04	7.19E-05	3.09E-04	1.23E-04	1.47E-04	2.80E-04	4.54E-04	1.44E-04		2.59E-04
OCDF	5.99E-05	8.99E-05	1.08E-04	5.98E-05	7.35E-05	2.80E-04	7.33E-05	8.99E-05		1.53E-04
Total TEQ	3.12E-02	4.54E-02	1.03E-01	4.42E-02	5.11E-02	1.34E-01	4.01E-02	4.52E-02		1.01E-01

Appendix 4. Volumetric Flows for the Fort McHenry Tunnel. All flows are cubic meters.

Run	W. Vent	E. Vent	Inlet Bore 3	Inlet Bore 4	Outlet Bore 3	Outlet Bore 4
1	5.93E+06	5.96E+06	2.33E+07	2.36E+07	2.76E+07	2.99E+07
2	5.76E+06	5.85E+06		1.44E+07		2.14E+07
3	5.93E+06	5.87E+06	1.77E+07	2.47E+07	2.12E+07	3.24E+07
4	5.82E+06	6.02E+06		1.53E+07		2.47E+07
5	5.93E+06	5.40E+06	1.49E+07	2.86E+07	1.85E+07	3.89E+07
6	5.93E+06	5.85E+06		1.87E+07		2.82E+07
7	5.93E+06	5.85E+06	2.02E+07	3.07E+07	2.38E+07	2.82E+07
8	5.93E+06	5.85E+06		2.19E+07		3.12E+07
9	2.96E+06	2.93E+06	1.00E+07	1.52E+07	1.15E+07	1.96E+07
10	2.96E+06	2.93E+06		1.11E+07		1.55E+07

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