Modelling Traffic Influences on Particulate Concentration

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EXECUTIVE SUMMARY

The Ambassador Bridge in Windsor is one of the busiest international crossing points in North America. Since security has been heightened at the Canada - United States border, long queues of trucks, sometimes several kilometres long, form periodically along Huron Church Road leading to the bridge. This has lead to concerns about an increase in air pollution and prompted the Ministry of Environment to investigate air quality in the area.

Between November 2002 and July 2003, the Ministry of the Environment carried out a series of measurements of particulate levels near Huron Church Road in Windsor. The object of these measurements was to determine the influence of traffic on the local particulate concentrations. Measurements were made on nine different days and the results were reported in 2004.

Operational constraints (staff and equipment availability, secure monitoring locations, variable traffic patterns, security, etc) meant that it would not be possible to monitor under all the conditions needed to fully understand the impacts of the truck traffic.

Ministry staff decided to address these monitoring constraints through modelling the traffic emissions with current air-dispersion models. It was felt that if the model was successful in replicating the results from the monitoring program, it could be applied to other situations where monitoring was not available.

A model was compiled based upon the latest information available for traffic patterns in Windsor and fleet statistics. However no data were available for emissions from trucks in stop-and-go traffic, so a series of trials was made to determine a reasonable fit.

Traffic was then modelled based upon meteorological conditions for seven of the monitoring days and the output compared to the monitoring results.

In general the model was found to give a reasonable representation of the traffic effects. In most cases, predictions were slightly higher than monitoring results, though usually within 5 $\mu g/m^3$. Given the nature of the generalizations that must be made for such a broad based model, this was considered a good result.

To put this in perspective, over any given hour our particulate monitors may typically have variations of 2-3 $\mu g/m^3$ which are not related to longer term trends. So, modelled concentration differences of this order and lower are not thought of as significant.

A series of maps were created which show modelled particulate concentrations in the area around the monitoring locations. These maps illustrate the area is influenced emissions from the trucks on Huron Church Road. In one or two cases, the model predicts increases for more than a kilometre but on most of the monitored days, the influence is considerably less. However, most of the influence is confined to an area 200 m - 400 m downwind of the road.

The model was also run for a series of idealized weather patterns which were based upon Windsor meteorology. Three wind directions were chosen for modelling: winds blowing across the road, winds blowing nearly parallel to the road and winds typical of the dominant flow in the Windsor area. For each of these situations, a number of cases were distinguished reflecting different meteorological stabilities: convective, neutral and very stable.

Maps for these model runs were produced and are included at the end of this document. These runs indicate that, in general the most pronounced influences of the traffic are felt when the atmosphere is stable and hence dispersion occurs only slowly. In these conditions, the influence can be seen for over a kilometre downwind of Huron Church Road. However, as in the comparison runs, the heaviest influence is confined to a much smaller area.

BACKGROUND

The Ambassador Bridge in Windsor is one of the busiest international crossing points in North America. Since security has been heightened at the Canada - United States border, long queues of trucks, sometimes several kilometres long, form periodically along Huron Church Road approaching the bridge. This has lead to concerns about an increase in air pollution and prompted the Ministry of Environment to investigate air quality in the area. During a period in 2002-2003, the Ministry of the Environment conducted a monitoring campaign to assess the impact of traffic emissions on air quality near Huron Church Road. The results have been summarized in another document, *Preliminary Air Quality Assessment Related to Traffic Congestion at Windsor's Ambassador Bridge* (2004), which is available from the Ministry of Environment Web Site[1]. A summary of its results are presented below to put this work in context.

- During normal traffic movement (no delays), the average increase in particulate matter adjacent to the road was minimal.

- During events when truck traffic was backed up, the increase in particulate matter could increase fine particulate concentrations ($PM_{2.5}$) by over 10 $\mu g/m^3$ over background concentrations.

- Increases in particulate concentrations above ambient conditions were observed distances from a few metres (m) to 300 m from the roadway.

- The increase was dependent upon traffic volume, length of delays and meteorological conditions (wind direction and speed).

- Volatile Organic Compound (VOC) sampling results adjacent to the road indicated no significant concentration increases from Huron Church Road traffic within the limits of the instruments available.

[1] http://www.ene.gov.on.ca/envision/techdocs/index.htm#airgeneral

RATIONALE FOR MODELLING

Real time monitoring of the traffic impacts on Huron Church Road, as described in the first report, was subject to a number of operational constraints.

- The samplers could not be left unattended and there were competing demands for staff time and equipment. This limited sampling time.
- Sampling sites were limited by the need to have access to electricity.
- As monitoring had to be scheduled in advance, traffic and weather were often less than ideal for the study's purposes (e.g. no truck queues, rain, and wind conditions that did not meet the study's needs.)
- In order to understand the impacts of traffic, it is preferable to monitor in an area away from other sources. This was not completely possible in an urban area but was used as a guiding principle in site selection.
- Sampling could only be conducted where unobstructed upwind and downwind areas were available. These two conditions restricted sampling locations as both are limited in an urban setting.
- It is not usually practical to determine the extent of the influence of a source by monitoring.
- Establishing permanent stations was not within the scope of this study.
- The accuracy of any measuring instruments is inherently limited. The ones used in this study are taken to be better than ± 10%. However during periods when background levels are elevated, as on smog days, and sources are small, as with free-running traffic, these small inaccuracies can lead to the appearance that downwind levels are higher than those upwind. Hence it would appear that the traffic is cleaning the air.

To address some of these issues, Ministry staff developed a model of the traffic's particulate emissions using the conditions during the field study. This model could then be compared with study's monitoring results to determine the model's accuracy and refine it as necessary. This model could then provide a broader-based tool enabling the Ministry to predict impacts at other locations where monitoring was not available.

The model could be applied to other traffic emissions (NOx, CO, etc) if proper input information were available.

Ministry staff chose AERMOD PRIME to model the traffic. It is a flexible model which allows a greater control of its inputs than other numerical models that were available. While not specifically designed for traffic modelling, it is a state of the art model that allowed more flexibility. This permitted easier adjustment to match monitoring results.

COMPUTER SIMULATION OF AIR POLLUTANT DISPERSAL

Introduction

Over the last few decades, the improvement in computers has enabled atmospheric scientists to develop increasingly detailed and accurate models. These models make use of the latest developments in atmospheric dynamics and chemistry, as well as state of the art programming to simulate processes in the atmosphere.

A wide suite of models are now available as different scientific agencies continue work to develop or improve the science on which they are based. These models are designed for a number of different purposes including predicting weather, estimating the effects of worldwide pollution on climate, and determinating the impact of particular pollution sources.

Details

Computer modelling is the computerized implementation of a set of analytical and numerical algorithms[2] that describe the physical and chemical aspects of a problem. Air pollution studies make use of computer modelling to estimate the concentrations and movement of material released into the atmosphere. This report considers the application of a class of deterministic models[3].

A deterministic model uses a series of mathematical representations of the pollutant source and equations governing the movement of the pollutant material. Descriptions of the source, pollutants, method of release, and the atmospheric conditions into which the material is released are represented in a computer program. Models differ in their scope and applicability, depending on the level of detail[4] they represent.

Wind speed and thermal currents caused by sunlight are key factors which determine the atmosphere's ability to cause vertical and horizontal diffusion of material. Turbulence is generated which causes mixing and dilution of the contaminants as they

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[2] **ALGORITHM**: A fixed step-by-step procedure used to accomplish a given result. The New Webster's Library of Practical Information, 1990, Charles J. Sippl, ISBN 0-7172-4579-9

[3] **Air Pollution Modelling. Theories, Computational Methods and Available Software.** Paolo Zannetti, Van Nostrand Reinhold, New York, 1990, ISBN 0-442-308051, Section 2.1, p. 27

[4] Ibid, appendix on available models: Section 14.1.1

are carried through the air. Older models such as SCREEN and the Industrial Source Complex (ISC) characterized the stability (or turbulence) of the atmosphere using the Pasquill-Gifford stability designation[5]. This classifies the atmosphere as "A" through "G", with "A" being the most turbulent and "G" the most stable. The ISC system uses only A through E for urban simulations. More current models such as AERMOD PRIME characterize the turbulence of the atmosphere in a more thorough manner, but are more computationally intensive. Advances in computer processor capability have made the more advanced treatments more practical. AERMOD PRIME was ultimately used in this report, with a variety of more simplistic models used for preliminary investigation to develop and refine an understanding of the situation.

The presence of structures, trees, barriers, etc. can be important factors which affect low-level turbulence. The conditions of the ground, the amount of sunlight and the energy it carries also affect dispersion. Each parameter that is included in a model carries with it a measurement uncertainty which affects the result. There is a trade-off between including every possible physical effect, the measurement of the effect, the calculation of it's impact on the final result, and the ability of computers to execute the required calculations in a reasonable time.

The description of the release conditions regarding roadway traffic is complex and requires substantial approximations. Large trucks have a wide variety of engine systems, operator differences, and emissions profiles that vary in short time frames. Passenger vehicles have a similar range of properties that are relevant to their emission of pollutants. These factors must be represented as peak and average emission factors for consideration in a model. A variety of techniques were considered for this process, including analysis of US EPA models designed for motor vehicle pollution assessment.

Consider a simulation in the same context as a map which describes a territory. Care must be exercised to ensure that the user does not confuse the map with the territory it describes. The real world contains features and details that cannot be completely represented by equations and calculations. There is a tendency to take computer-generated results as absolute truth instead of scientific guidance that experts can consider in their analysis of a situation. A balanced approach makes use of measurements to increase confidence in simulation results wherever possible.

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[5] Ibid, Tables 7-1, 7-2, 7-3 pp. 148-149

MODEL SETUP

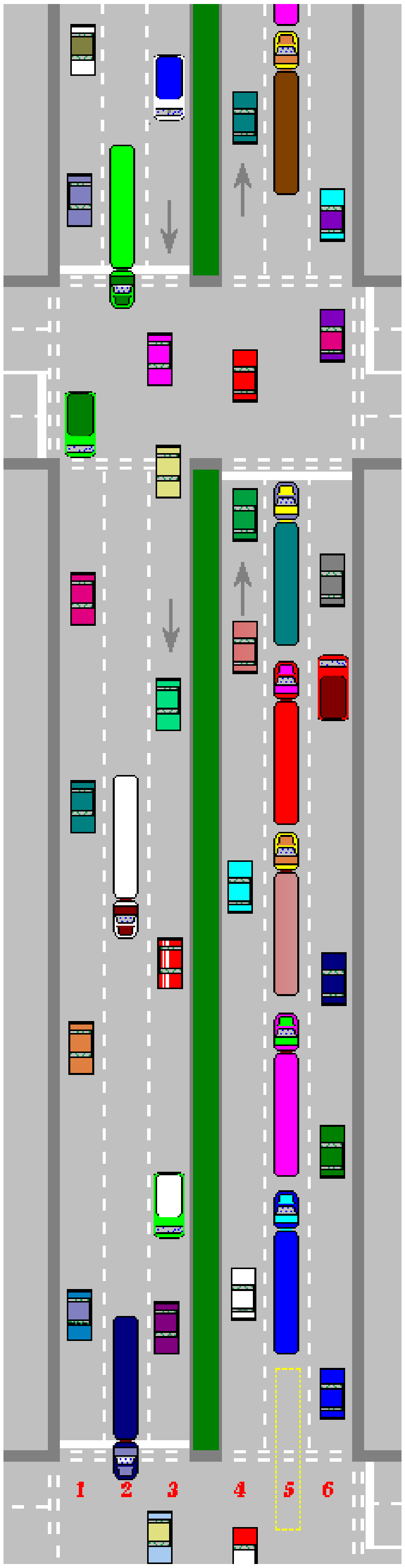

Figure 1: Traffic On HuronChurch

Application of models to most physical situations requires the use of simplifications. For example, in theory one could measure the emission of every car on Huron Church Road and make calculations for each car. These could then be added at each spot downwind to give a result. However the computer time needed for this calculation would not be practical.

The adjacent figure illustrates traffic on Huron Church Road during periods when truck queues have formed. The lanes on the right represent those heading toward the bridge (approximately north). For purposes of the model, truck queues are confined to the middle lane on the right (lane # 5) although there are trucks in the far right lane (#6) as they merge from side streets.

In order to understand the limitations of the model, it is helpful to know how various inputs were treated. The main ones are briefly described below.

1. Traffic volume for free flowing vehicles was based upon traffic survey data. Data were only available for a few intersections in this area. Traffic volumes for blocks without their own measurements were interpolated from data for the closest intersections. A block was defined as the mid point of one intersection to the midpoint of the next one.

2. Each city block was treated as a separate source.

3. The modelled traffic volume was the average of the three busiest hours in the survey. Since traffic volume varies during the day, using the heaviest hours will tend to over-predict pollutant concentration during lighter traffic periods. While it might be possible to refine the model to include different traffic densities, this was beyond the scope

of the current project. The method chosen, however will present a worst-case situation which should be a more conservative approach for assessing impacts of changes in traffic.

4. Traffic volume for queued trucks was based upon average truck length and observed truck spacing (distance between stopped trucks) in the queues. For instance Figure 1 shows that while the block is longer than five trucks, only five would be there as a sixth would project into the intersection (yellow box). Thus a truck space consisting of an average length and spacing was used. This was then divided into the length of the block and rounded down to the nearest whole number to give the number of trucks in the queue for that block.

5. Each lane in each block was treated as a single *line source*. That is, instead of modelling several small moving sources in each lane, the average emission for the lane was calculated based upon the number of vehicles and their average emission, and this was "spread out" along the lane as though the emissions were originating from all along this line. Since the cars were moving for the majority of the time and this caused the emission points to move, and since the cars movement would mix air in the lane, this is a reasonable approach. It is often used for modelling traffic.

6. Traffic on each side of the road was treated as though the trucks were confined to one lane and the cars to the remaining one or two depending upon whether the road was four lanes or six lanes wide at that point.

7. Emissions for the free flowing vehicles (no delays) were based upon published emission factors[6]. This required some knowledge of the average vehicle age of the traffic. Since no accurate determination of this was possible, this was also based upon published values from the United States. These values expressed as percentages had to be "translated" from the latest available data. Since newer cars form the bulk of the vehicles on the road, it was expected that small differences in the age distribution would not make a significant difference. Tests of this on the model confirmed that small distribution differences were well within the range of other uncertainties in the calculations. However, emission rates were not available for the newest cars so the model may slightly over-predict in this area.

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[6] An emission factor is a relationship between the amount of emissions that are released and the activity of the producer. http://www.epa.gov/air/oaqps/emissns.html

8. *Cars* in this model also includes *light trucks*. All references to trucks in this model refer only to heavy diesel trucks.

9. Emissions for the truck queue were based upon published emission factors for idling trucks. However, truck emissions are much higher when a stopped truck accelerates so an arbitrary multiplier was used to "correct" these values. Several emission estimates were tested to determine a reasonable fit to the monitored data.

10. No attempt was made to include emissions from traffic on cross streets or other parallel roads. The study was confined to determining if the model could adequately replicate the difference between situations where a queue existed and traffic was free flowing.

11. Meteorological information for the modelling period was based upon ground level wind measurements taken at the monitoring site and upper wind determinations from the White Lake site in Michigan.

MODEL EVALUATION

Average hourly concentrations were modelled for each $PM_{2.5}$ monitor deployed by the Ministry for each sampling day. The same emission rates were used for all days except July 3rd & 4th when there were no truck queues. Emission rates used for this lane were more than a factor of 10 lower on those days. These were compared with the monitoring results.

Since the model calculates only the contribution from traffic on Huron Church Road while the monitors measure total ambient particulate, the two values are not directly comparable. An upwind monitor was used to compensate for this. The model results are compared to the difference between the downwind and upwind monitors - the difference between the average particulate concentration before and after the air crosses the road.

Other approaches are possible. The monitored background could have added to the modelled traffic contribution and compared that to the monitored downwind results. The two different approaches are illustrated below.

The graphs show the following. Time of day is given along the bottom of the graph in Eastern Standard Time (regardless of the month) - this is a standard practice for environmental monitoring. The particulate concentration is given on the side axis in micrograms per cubic metre, ($\mu g/m^3$). In this report, we have modelled $PM_{2.5}$.[7] (A microgram is a millionth of a gram). The blue line represents the hourly average of the monitored level of $PM_{2.5}$ [8]. The red line represents the modelled average for that hour.

These are the same results. However, Figure 2 permits a more useful comparison as the differences between the monitored and modelled values can be small when compared to the background levels. In addition, background levels of particulate can vary considerably depending on such things as humidity, wind direction, recent precipitation, industrial activity. Including the variations that these factors cause could make the graphs more difficult to examine.

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[7] $PM_{2.5}$ is a short form for airborne particles smaller than 2.5 microns (millionths of a metre) in diameter. They are considered important as particles of this size can reach the deepest parts of the lungs.

[8] The Canadian Council of Ministers of the Environment have established a Canada Wide Standard for $PM_{2.5}$ of 30 $\mu g/m^3$ based upon a 24-hour averaging time to be adopted by all provinces by the year 2010. Achievement to be based on the 98th percentile ambient measurement annually, averaged over 3 consecutive years.

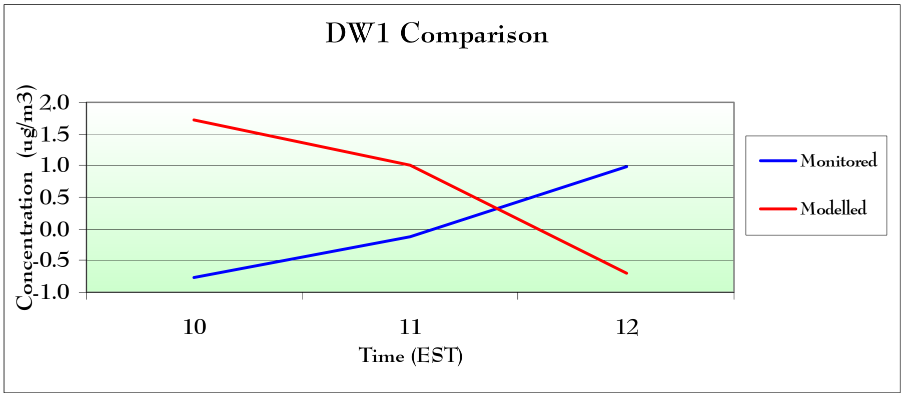

Figure 2: Comparison with Background Concentration Subtracted

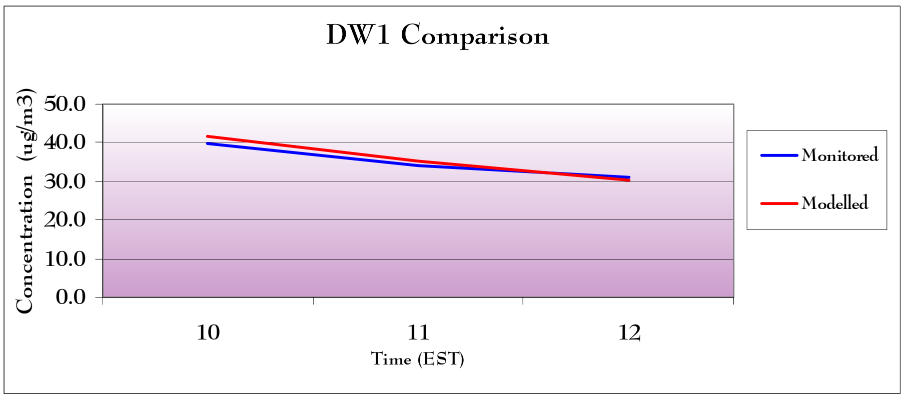

Figure 3: Comparison with Background Concentration Included

There is always some uncertainty in any measurement. A newly calibrated GRIMM monitor, should have a reliability of ±5% over its useful range (≤1500 μg/m^3). However, it was not always possible to calibrate the monitors immediately before a monitoring day. In order to reflect this uncertainty, the original measurements were assumed to be within ±10% of the "true" environmental value. This permitted calculation[9] of an estimate of the uncertainty in the measured results and these are included on the graph as dashed lines ("upper" and "lower") on either side of the reported values.

To keep the model results in perspective , it is useful to have a benchmark such as the values normally seen in the environment. The Ministry of Environment maintains two Air Quality Index stations in Windsor. One station (12016) is located near College St and South St. – about 1 ½ km from the study site. The other station (12008) is

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[9] Methods for calculation of uncertainties in measured quantities follows well developed methods laid out in a large number of references. cf. *Data Reduction and Error Analysis in the Physical Sciences* by Philip R Bevington; 1969, McGraw Hill Book Company.

downtown on University Avenue. In 2002, these stations reported the following for respirable particulate concentration [10].

One Hour Statistics for $PM_{2.5}$				
Station	Average (μg/m^3)	Maximum (μg/m^3)	Median[11] (μg/m^3)	90th Percentile[12] (μg/m^3)
12016	12.2	74	9	26
12008	11.8	88	9	26

There is also some error in location. Most GPS units have an accuracy of not better that ± 5 m under ideal conditions. While this should not present a serious challenge in most cases, it should be remembered that the monitor nearest the road will often be closer than 5 metres and hence the uncertainty is of the same order as its distance from the source. This implies that there is a greater relative uncertainty in the model predictions for positions close to the road.

Modelling results can also vary depending on a number of factors including uncertainties and variability in emission and meteorological input fields. Uncertainties in emission rates from idling then accelerating trucks as well as day to day variability would affect model/monitoring inter-comparisons. Local monitoring of winds at the GRIMM sites showed variations in wind speeds and directions on some days. Modelling results would be affected by the site chosen for wind data. Variability in winds were largest on days with lighter wind speeds.

Data are presented on a day-by-day basis. However not all days were suitable for comparison. The first monitoring was done without a nearby "upwind" monitor. Since the comparisons are based upon the difference between upwind and downwind measurements, the data for these days are not useable. Measurements at the AQI station, about a kilometre away, may not accurately reflect upwind conditions near the road. It is also a different type of instrument and so may not react in an identical way to certain types of particulate or under certain environmental conditions.

[10] *Air Quality in Ontario 2002 - Appendix*, http://www.ene.gov.on.ca/envision/techdocs/index.htm#AIR, Table 6, pg 13

[11] Half of all values are higher than the *median*, half are lower.

[12] 90% of all results are below this value

Measurements that may have included another source are presented but require some caution in interpretation. In this study, we were limited in our choice of locations and monitored in a field near a shopping mall. It is possible that southerly wind directions would lead to the monitors, especially those farther from the road, being influenced by sources at this mall. There may have also been some small contribution from the open field during drier days as dust was picked up by the wind.

The model computes one-hour averages for each hour of the day starting on the hour. The monitors reported ten minute averages which began when they were switched on. Comparing these two required some monitoring data to be interpolated and meant that not all of the monitoring data could be used in this exercise.

Monitoring took place in an open field between a school and a small plaza. This allowed for a clear line of site between the monitors and relatively little obstruction to the wind for most of the sampling days. The upwind (or background) monitor was placed on the other side of Huron Church Road usually at the Windsor Visitors' Centre. Modelling and some of the results indicate that it may have sometimes been too close to the road for best results but operationally it was the only location available.

These monitoring limitations mentioned earlier limit the amount of data and conditions available for comparison.

In most cases, the model predicts a small upwind value, on the order of 0.5 $\mu g/m^3$. The modelled downwind results were not "corrected" for this however. There can be cases with "upwind" impacts from roadway emissions. These can occur for hours with light winds and for cases when the wind direction is close to parallel to the roadway. Two occasions when wind directions were nearly parallel were December 12th and May 20th.

MODELLING RESULTS AND COMPARISON WITH MONITORING

July 4, 2003

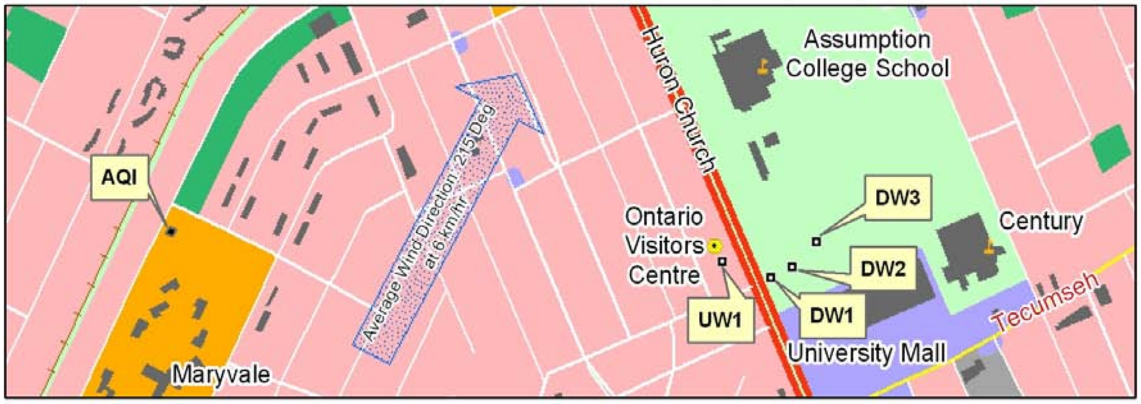

Figure 4: Monitoring Locations and Wind Direction, July 4, 2003

Traffic was somewhat lighter than usual on July 4th – a holiday in the United States – though it picked up somewhat as the day progressed. An air quality alert had been issued the previous day and was still in effect. The average wind direction is displayed in Figure 4. Winds were light to moderate and background levels (upwind of the road) were quite high, ranging from 40 $\mu g/m^3$ early on down to 30 $\mu g/m^3$ later in the day. This may have lead to the apparent negative values downwind of the road. There were also significant variations in wind speeds and directions from site to site which would affect model results

Comparison of the model and monitoring is displayed in Figures 5 - 7. The agreement of the model and the monitoring is good; most of the model predictions fall wit hin the uncertainty expected from the monitoring equipment. The largest difference was seen farthest from the road. Since this monitor's location makes it the most susceptible to influence from the mall, this is not a surprising result. It may have been made more noticeable by the lower contribution from the road since any contribution from the mall would form a larger percentage of the (non-background) particulate levels.

Comparison for the third hour is not based upon a full hour of monitoring. All but the closest monitor to the road, DW1, stopped before the end of the hour.

The increase seen in the monitoring over the day is probably due to the increase in traffic levels. Since the model assumes constant traffic throughout the day it cannot replicate this effect.

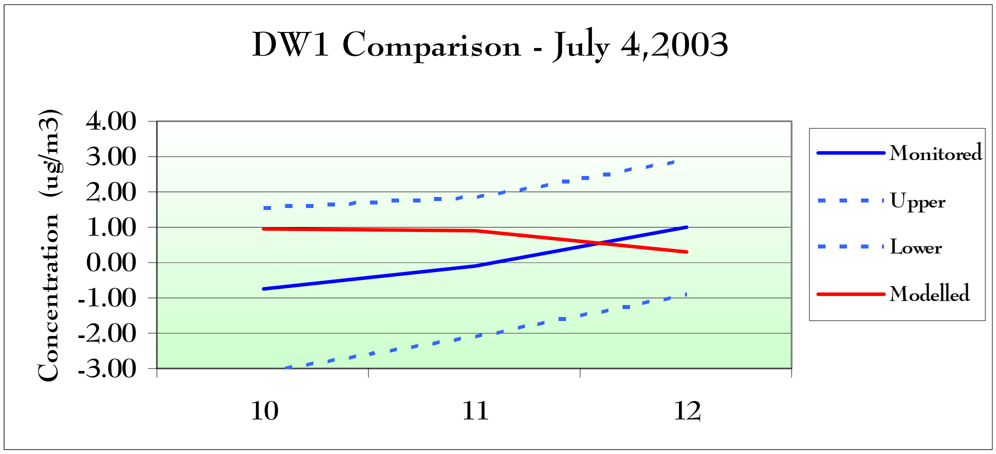

Figure 5

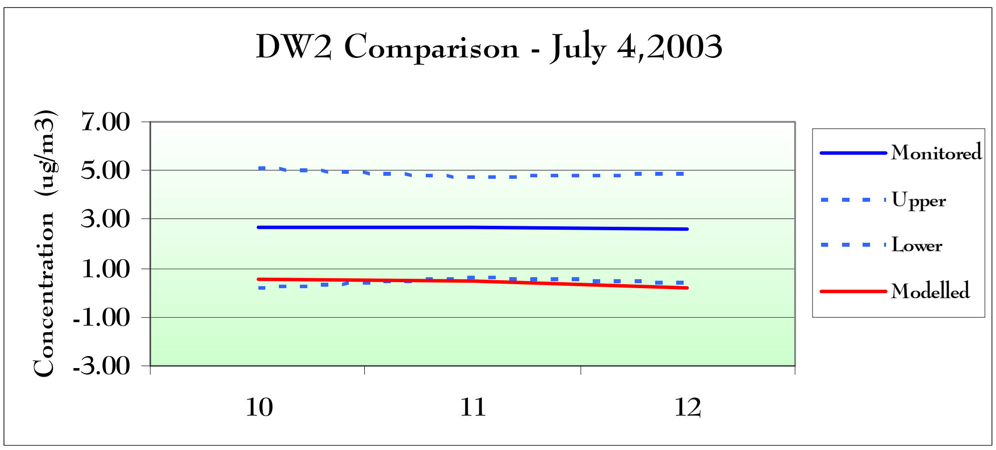

Figure 6

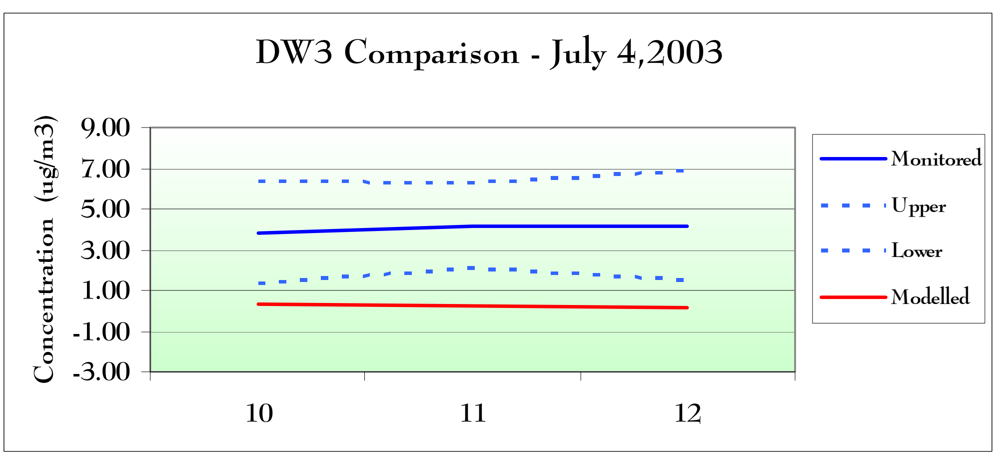

Figure 7

July 3, 2003

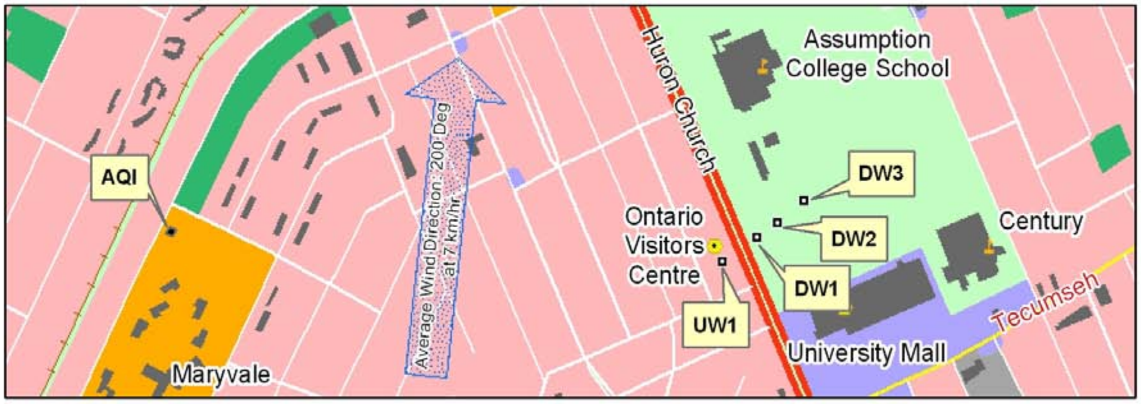

Figure 8: Monitoring Locations and Wind Direction, July 3, 2003

Background levels ranged from approximately 14 μg/m^3 to 20 μg/m^3 during monitoring. An air quality alert had been issued for the area, so background levels of particulate were high. The winds were light to moderate and blowing in a direction nearly parallel to the road as illustrated in Figure 8. This meant that the downwind monitors would be influenced by any sources at the mall. There were no truck queues during monitoring.

Near the road (Figure 9), the model agrees quite well with the monitoring data, falling within the expected range of instrument variability. Farther away (Figures 10-11) it seems to diverge. However, as can be seen from the map the wind may well be carrying particulate from the mall which would preferentially influence the farther downwind sites. Nonetheless the disagreements are not substantial. Influence from the road appears to have been relatively light.

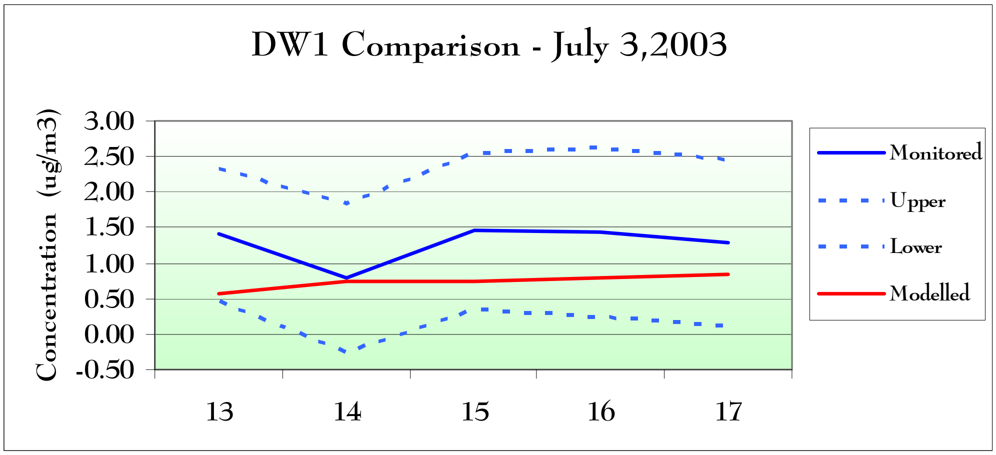

Figure 9

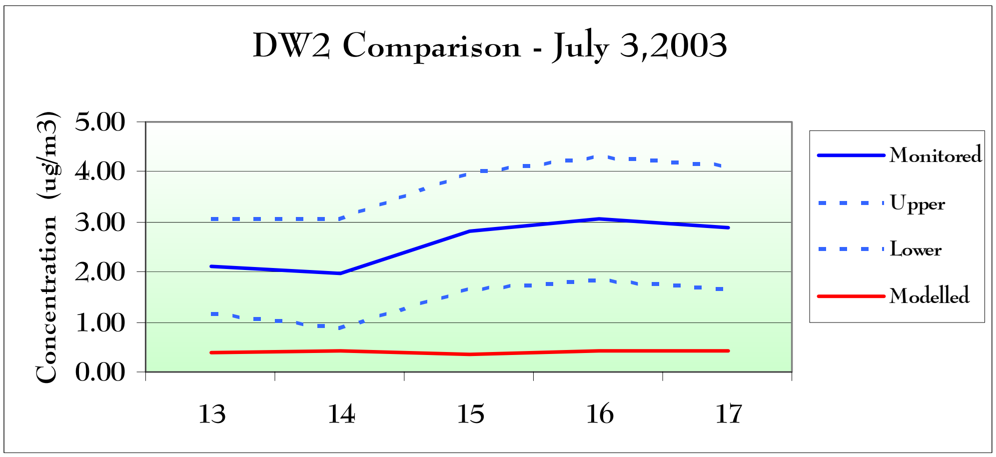

Figure 10

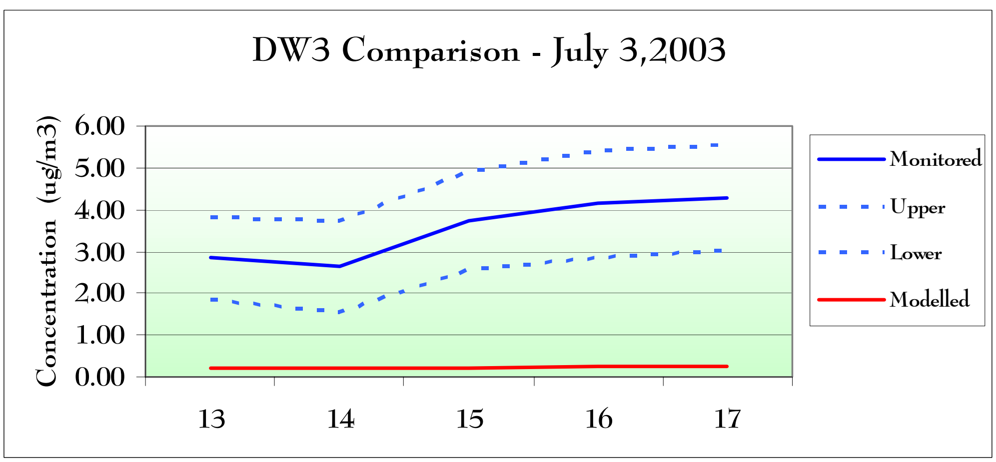

Figure 11

December 12, 2002

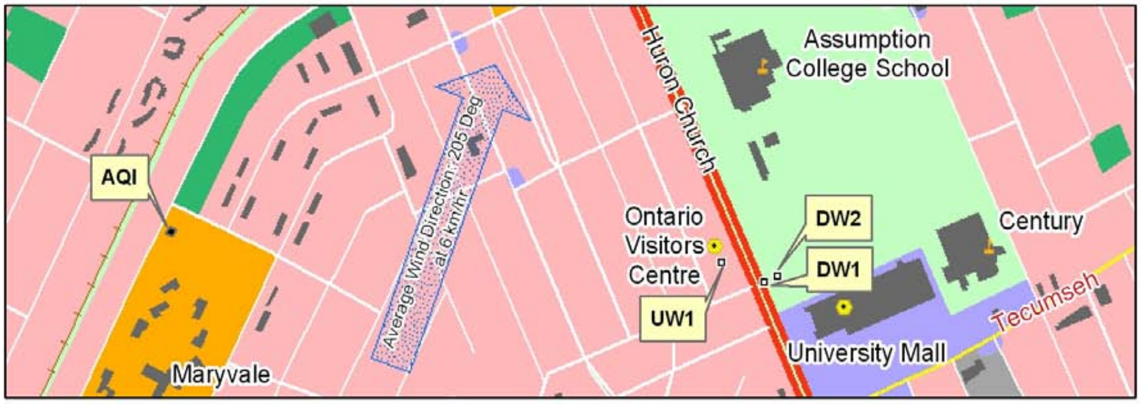

Figure 12: Monitoring Locations and Wind Direction, Dec 12, 2002

Winds were moderate during the sampling period and blew from the south to southwest (Figure 12). Since meteorological data at the GRIMM sites were not available on this day, data from the College St and South St station located about 1 ½ km away was used. Traffic volumes were normal but truck traffic was delayed with queues extending past the samplers during the entire sampling period.

Agreement on December 12th was very good for the roadside monitor and reasonable for the farther one (Figures 13-14). The background level was about 25 $\mu g/m^3$.

The model behaviour was different for the two stations on this day. While the more distant levels (Figure 14) rose slightly over the day, levels for the nearer monitor (Figure 13) rose by about 6 $\mu g/m^3$ and then fell slightly. As can be seen from the map the DW1 monitor was very close to the road. The wind directions in the model simulations were more parallel to the roadway on the second and third hours. The monitor closest to the road is impacted by these more parallel wind directions resulting in higher predicted concentrations than in the first hour. Differences in wind directions between the monitor locations and the College St and South St station could affect the model results.

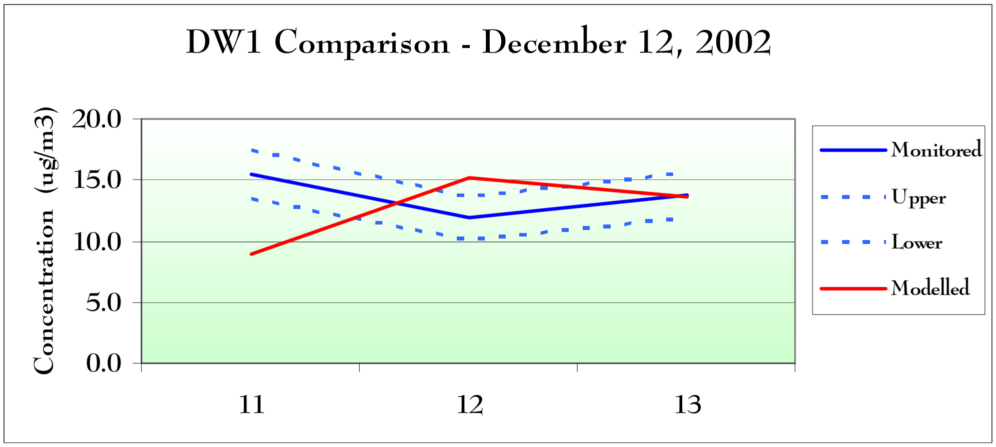

Figure 13

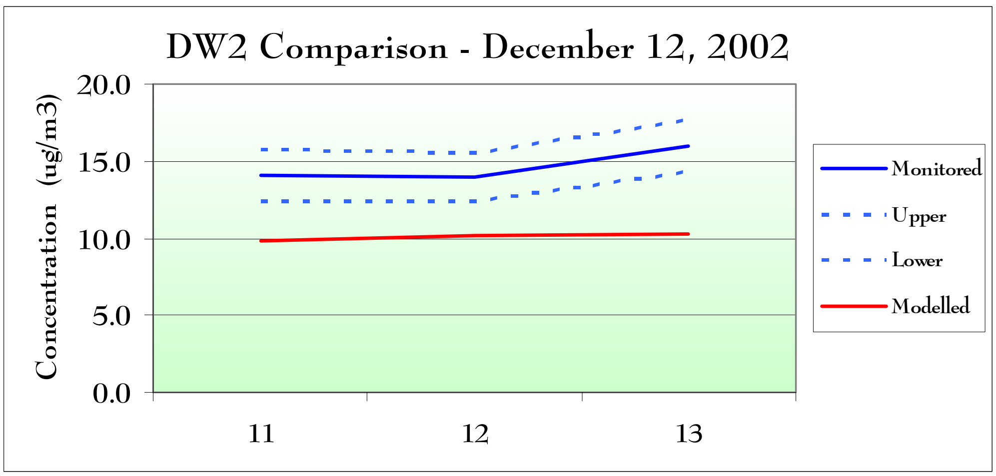

Figure 14

May 22, 2003

Figure 15: Monitoring Locations and Wind Direction, May 22, 2003

Winds were reasonably strong and blowing to the west on this day (Figure 15). As a result, downwind monitors were placed on the west side of the road. The residential character of the west side of Huron Church Road limited the number of available monitoring locations. Unlike the east side which is an open field, there were bushes, fences, houses and other obstructions.

Background $PM_{2.5}$ levels were about 11 $\mu g/m^3$ through most of the monitoring period Only two downwind samplers were deployed

The results (Figures 16-17) indicate that the model slightly over-predicted the influence of traffic but the range and general behaviour agree for both samplers. It is possible that the vegetation on the west side of the street may have also scavenged particulate. There seems to be little influence from the mall though the higher wind will tend to disperse particulate more, and since monitoring occurred in the morning, traffic at the mall may have been lighter than it would be later in the day.

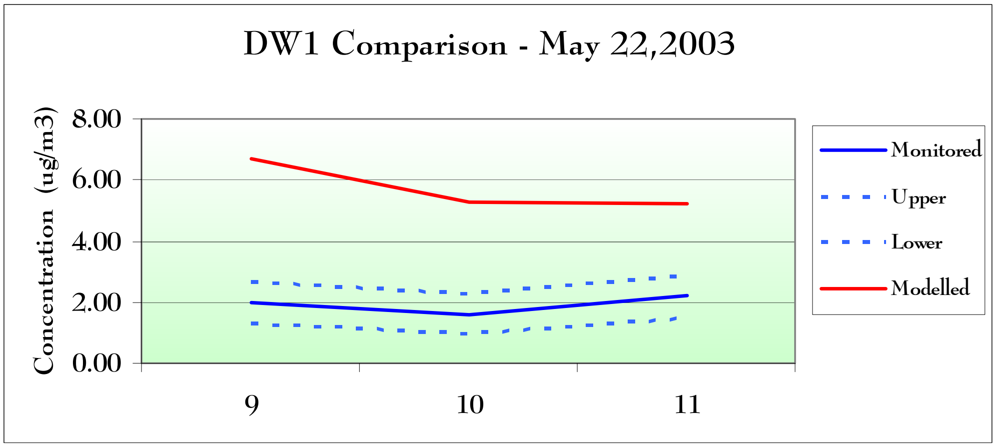

Figure 16

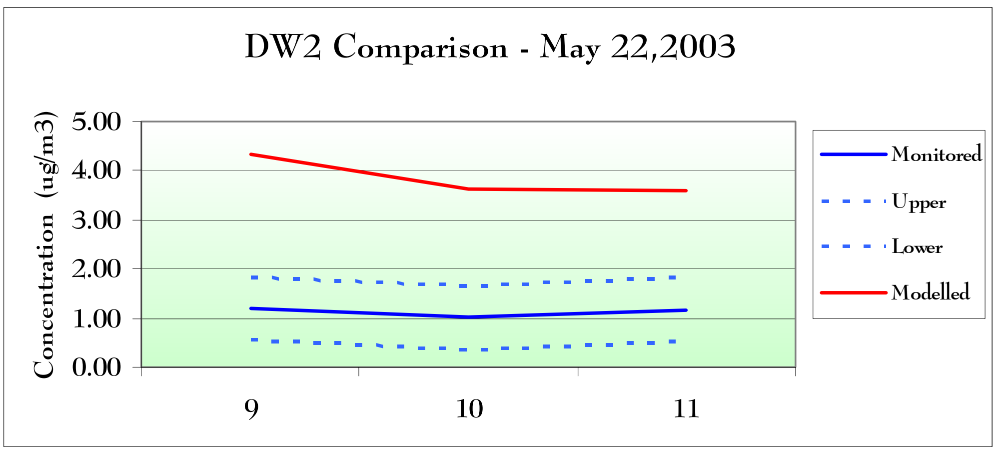

Figure 17

May 21, 2003

Figure 18: Monitoring Locations and Wind Direction, May 21, 2003

The wind was strong, blowing from the northeast during sampling (Figure 18). This resulted in the downwind samplers being placed on the west side of Huron Church Road. The topography was less open (bushes, trees, parked cars) and this may have suppressed the particulate levels somewhat.

Traffic volumes were normal but truck traffic was delayed with queues extending past the samplers during the entire sampling period. Background levels on May 21st were quite low ranging from about 5 $\mu g/m^3$ to 7 $\mu g/m^3$

DW2 (Figure 20) shows an upturn near the end of the monitoring run that was not seen by the other two monitors, suggesting that they may have been more sheltered. If this effect is due to an increase in (non truck) traffic, the model cannot replicate it as it uses a constant traffic volume.

It is also possible that the upwind monitor may have experienced a minor influence from fugitive dust from the field.

Overall, the model predicts concentrations which are of the same order as that monitored though slightly higher (Figures 19-21).

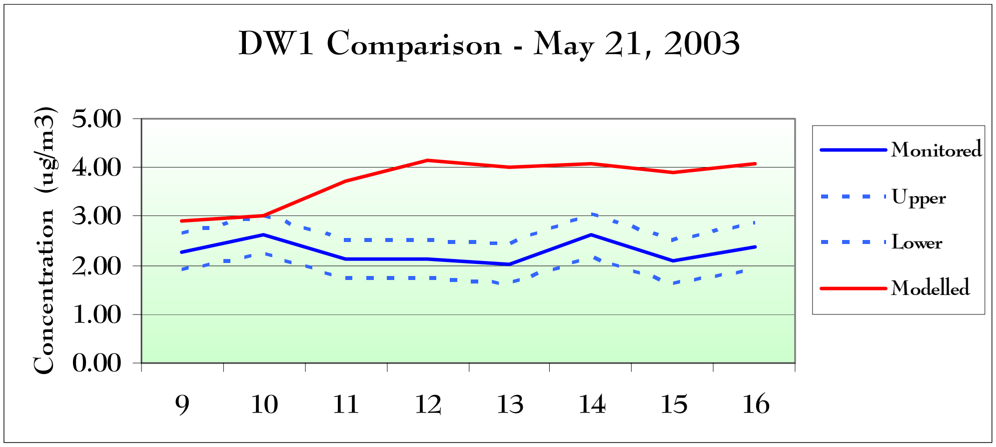

Figure 19

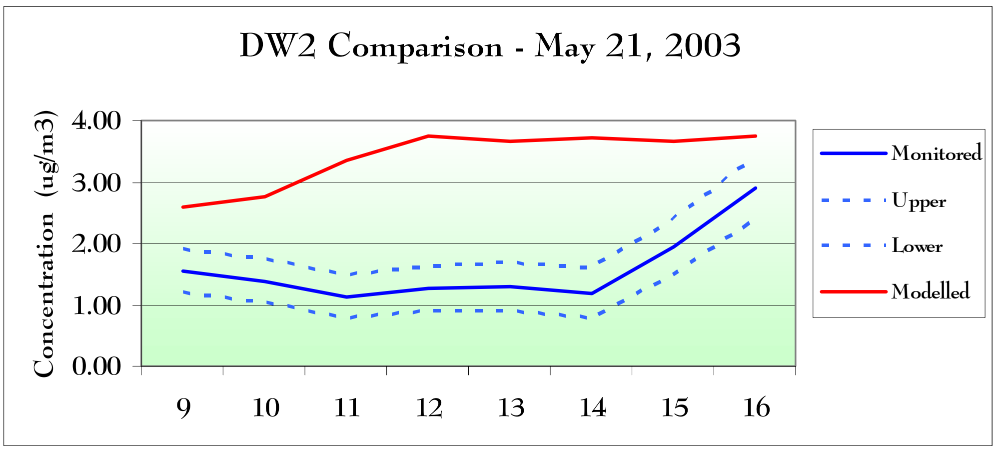

Figure 20

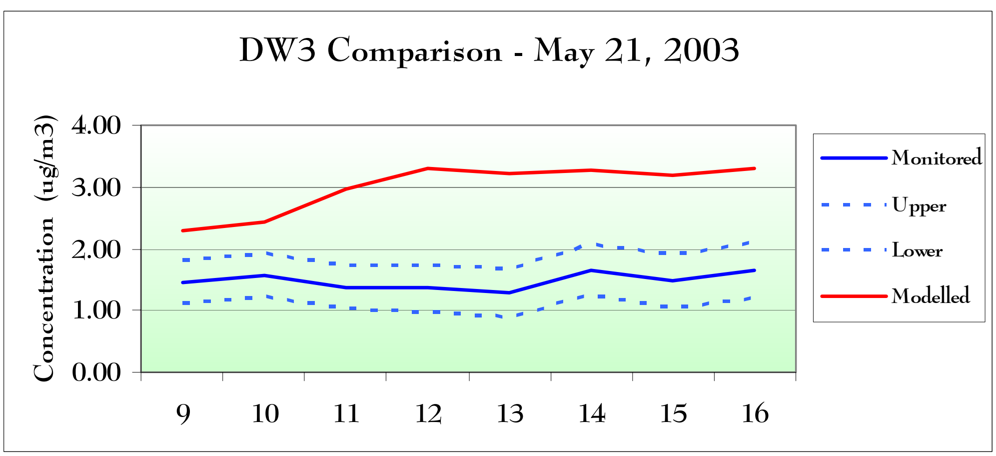

Figure 21

May 20, 2003 - Early

Figure 22: Monitoring Locations and Wind Direction, May 20, 2003 - Morning

When sampling began on May 20, winds were blowing from the southwest (Figure 22) but as the day progressed, they came around to the northwest and strengthened. This change in wind direction prompted the relocation of the downwind monitors. The results have been separated into two sessions to reflect the change in wind direction.

Background levels during the first period were of the order of 20 $\mu g/m^3$. A truck queue had formed by the time sampling began and persisted throughout the sampling period. DW1 was not modelled as it was felt that the monitor was too close to the road to properly reflect the emissions from the trucks.

Agreement for the morning session was of the same order, although the results had a different trend (Figures 23-24). Influence from the nearby mall may account for some of this trend difference. The wind direction for the first model hour was nearly parallel to the roadway. Concentrations near the roadway can vary significantly with small variations in wind directions when they are nearly parallel to the roadway

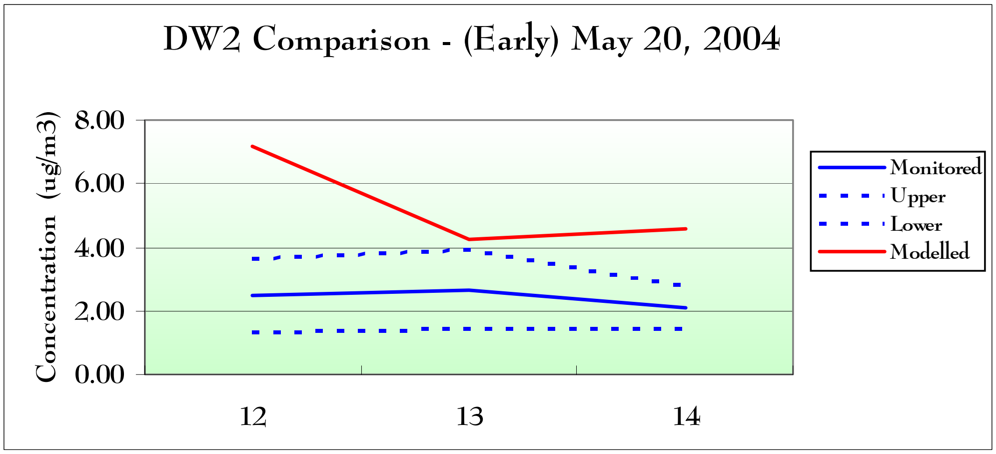

Figure 23

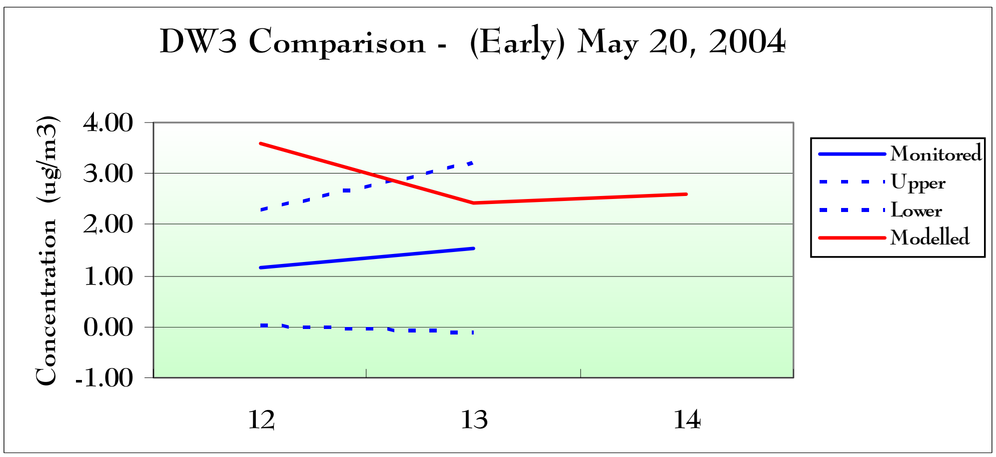

Figure 24

May 20, 2003 - Afternoon

Figure 25: Monitoring Locations and Wind Direction, May 20, 2003 - Afternoon

By the afternoon, the wind direction nearly reversed and its speed increased (Figure 25). Traffic volumes were normal but truck traffic continued to be delayed with queues extending past the samplers during the entire sampling period. Background levels fell to about 11 μg/m^3 in the afternoon

The comparisons are not quite as good as some others though the negative numbers for the monitored values suggests that the background site was being influenced either by traffic or another source. If this is the case, it might also explain the opposite trend in the monitored results when compared to the modelled one. Nonetheless the model while predicting higher levels is still within 7 μg/m^3 of the monitored difference at its worst (Figure 26). While this is not as good the previous cases, the uncertainties are more pronounced near the road as mentioned earlier.

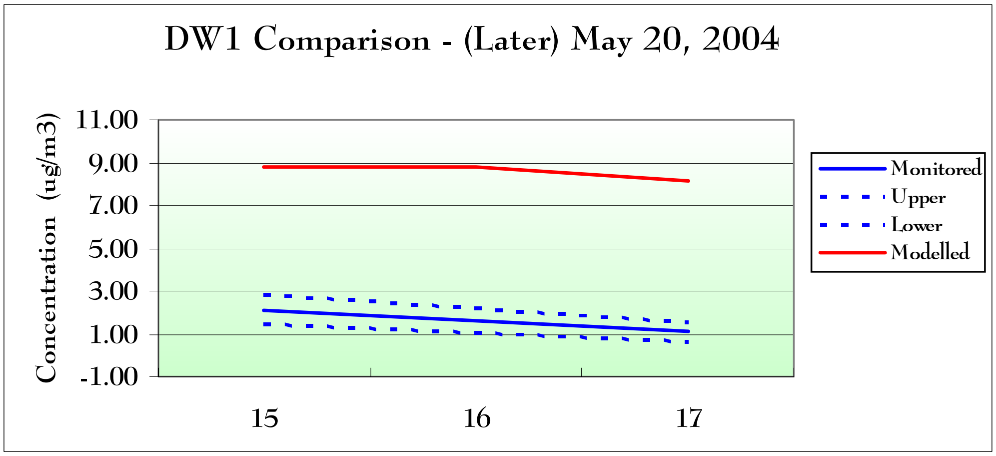

Figure 26

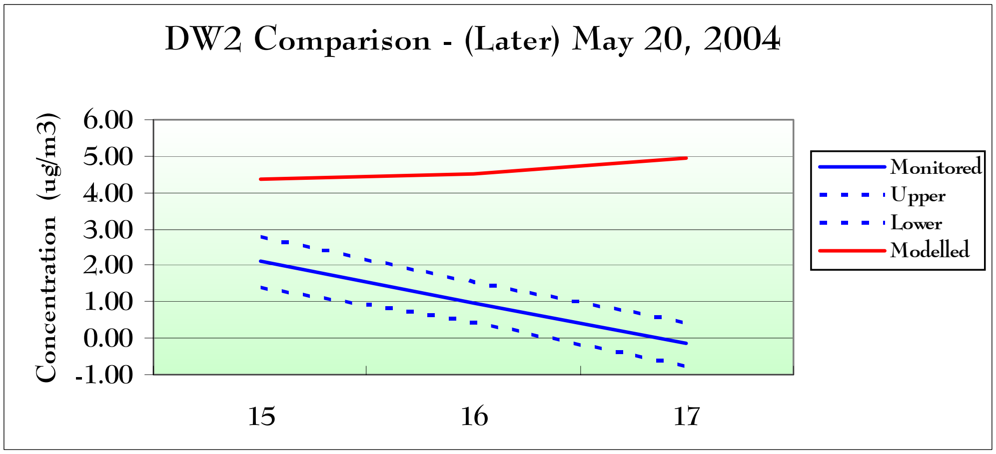

Figure 27

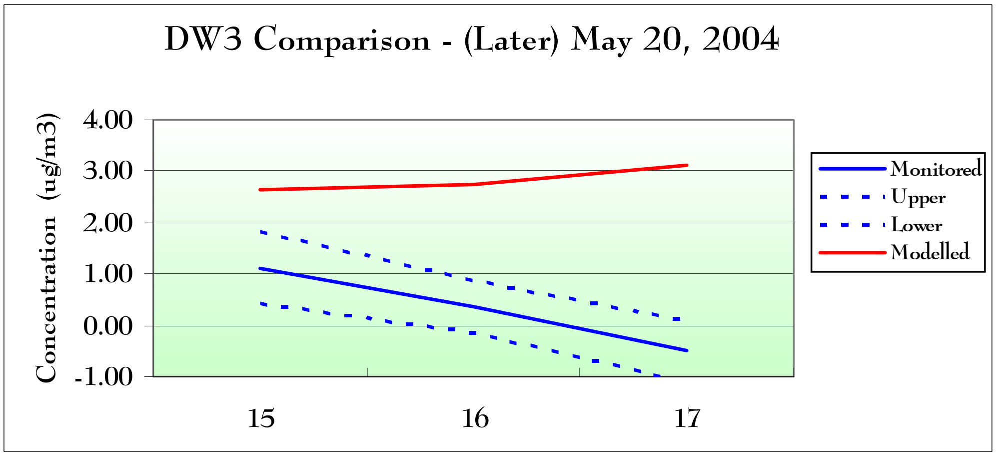

Figure 28

December 11, 2002

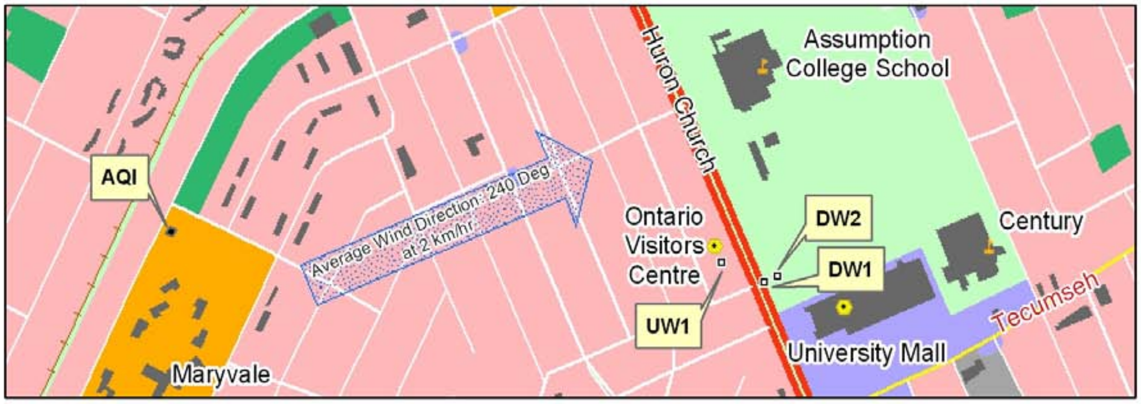

Figure 29: Monitoring Locations and Wind Direction, Dec 11, 2002

Winds during the sampling period were, very light and highly variable - in fact they blew from nearly opposite directions at different times. About a quarter of the winds fell into the "calm" category. Directional information is not reliable when winds are this light as there is not sufficient energy in the wind to "push" the wind vane well. As a result, the average direction (Figure 29) is at best a general indication. Since the models were based upon winds measured at the site, this introduces a higher degree of uncertainty into the result.

Traffic volumes were normal but truck traffic was delayed with queues extending past the samplers during the entire sampling period.

The results (Figures 30-31), while of the same order as the monitored values show a higher degree of variability than seen in the other results. Since this is true for both downwind monitors, and since the upwind monitor also showed high concentrations, it is probable that it is related to the winds.

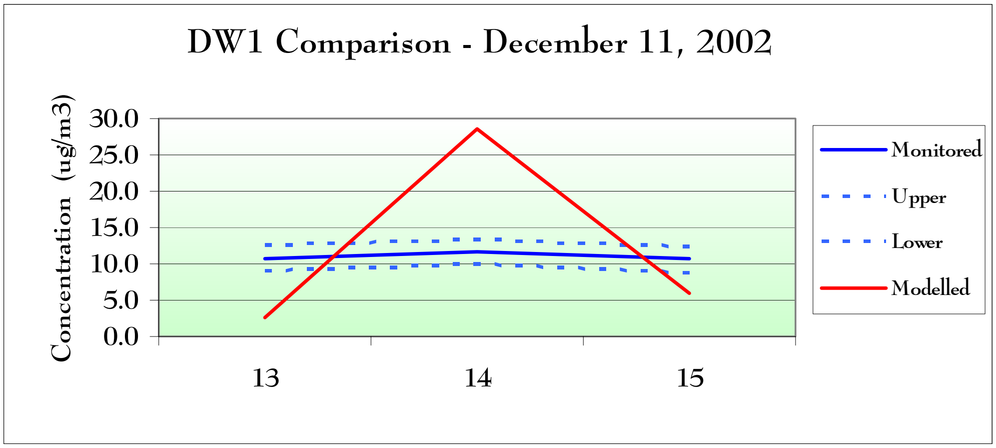

Figure 30

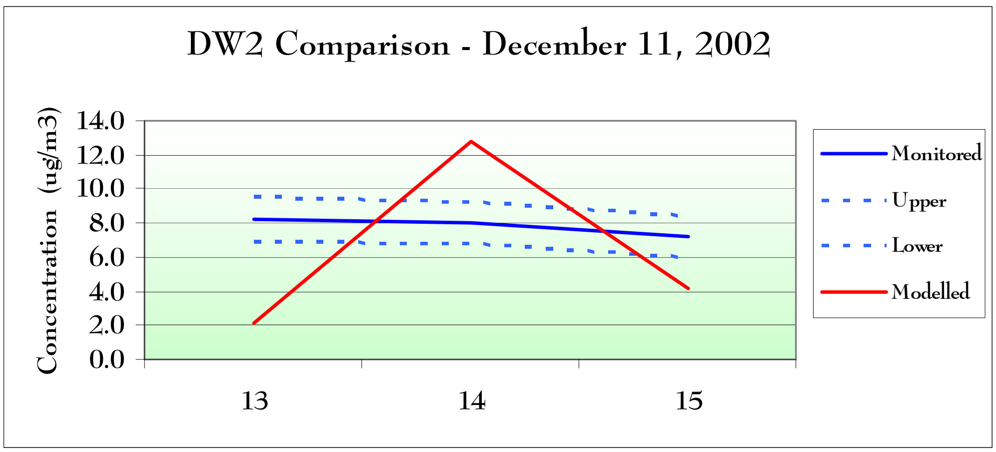

Figure 31

Discussion

Overall the model seems to give results that agree reasonably well with the monitored values with some occasions where the results were higher than observed values.. While not precise, the model gives useful estimations of particulate loading and hence could be used as a tool in a variety of applications.

Most estimates other than those beside the road were within 5 $\mu g/m^3$ of the monitored results. As well, the model tended to provide a slight overestimate of the effect of traffic. Since the model input was designed to present a worst-case approximation, this is not unexpected. This suggests that the model will provide a conservative forecast when used to assess the impact of traffic on nearby areas.

As well, further refinement would be possible for specific locations through the use of input parameters that match local conditions more closely, e.g. traffic volumes for the modelling period, current fleet distributions, etc.

MAP OUTPUT FOR AIR MODELS

The comparisons presented above were limited to two or three points where monitoring had been performed. This was necessary to evaluate the model. However the purpose of the model is to predict concentrations when monitoring is not available and in places where it would not normally be conducted.

To this end, the model was used to predict concentrations for the entire area around Huron Church Road. A maximum concentration map was prepared for each modelling period. The results are presented, in the same order, on the following pages as concentration maps.

The model computes average concentrations for each hour during the sampling periods for each of a number of specified points called *receptors*. In this case, slightly over two thousand receptors were employed. The choice of points and the number used depends upon the nature of the source and the amount of computing time available. They may be varied as necessary by the modeller to improve the usefulness of the output.

Each value is stored in a table and at the end of the model run, the worst (highest concentration) value for each location is found and placed in a plot file. The graphing software then attempts to draw closed lines, called *isopleths*, through points that have the same value and then shades the areas inside these curves, starting with the highest concentration areas and working out. Thus the middle area will have concentrations equal to or greater than the value for that colour given in the scale on the right hand side of the diagram. The concentrations chosen for these isopleths are selected to give a reasonable overview of the results without unduly crowding the output.

The model was then used to estimate the effect of traffic for a number of idealized three-hour periods which reflect common or significant local weather patterns in Windsor. These have been included at the end of this report. These results may be used to estimate the worst-case influence of the traffic.

All the results are presented using the same scale to permit easier interpretation. However for some days all the results fall below the minimum display value, leaving the map blank or nearly so. On these days the results are also plotted on a second map with an expanded scale (showing lower values). The secondary scales are plotted with separate colour schemes to reduce any confusion concerning the scales represented.

The colours themselves have no intrinsic meaning but are chosen merely to show the variation of concentration with distance.

It should be noted that the process which generates the isopleths can lead to patchy diagrams. This occurs for two reasons.

- The program represents each line of traffic as a series of points rather than a single line. Where the different blocks meet, the points may not be the same distance apart as elsewhere. This causes the model to believe there are "hot spots". This shows up on the graph as areas of higher concentration.

- The graphing program *estimates* where isopleths should go between the calculated points. While sophisticated algorithms are used for this, they are subject to certain assumptions. A different choice of assumptions or slightly different placement of receptors might change their appearance in small ways. However, in situations where it is important to know values at a particular point, additional receptors may be added to ensure the graphing software reflects the model's most accurate attempt for that particular point.

As a result, the fine details of the map should not be taken as exact. Rather the model output indicates how far from Huron Church Road that a given level of effect might reasonably be expected in a worst case.

Like all such influences, the particulate contribution from the traffic will gradually diminish and merge into the general background. Deciding upon how far the influence actually extends is somewhat arbitrary and will depend upon the purpose of the analysis and the person making it. The graphs shown here represent the worst hour for each calculated point and the average over a longer period will may not be so high.

Furthermore, while the model treats the winds as "average", the reality is quite different. Gusting of wind will cause moment-to-moment and spot-to-spot changes in concentration that will never be captured in any average whether modelled or monitored.

These plots include the UTM (Universal Transverse Mercator - NAD 83) coordinates for the area, along the side of the diagram. They are given in metres so the scale of the diagram may be readily ascertained.

Houses and most buildings are given in grey. Educational institutions have a green square superimposed upon them.

Two sets of maps follow. The first set are for days where measurements were taken. These are referred to as “program days”. The second set are for different idealized weather conditions. Most of these maps assume the presence of a queue of trucks. However, in cases where the model calculates a substantial downwind concentration, an additional map showing the same situation with free flowing traffic is also included.

MAPS FOR PROGRAM DAYS

July 4, 2003

There was only a small effect from the traffic as there was no truck queue and traffic was lighter than usual due to the US holiday.

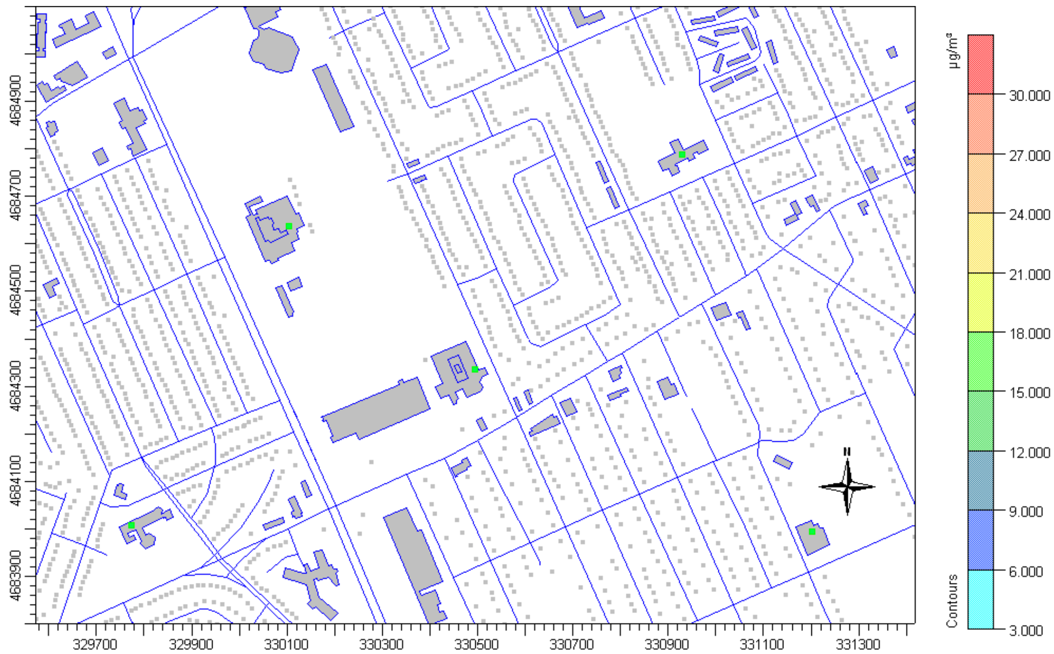

Figure 32: Modelled Concentrations for July 4, 2003 - Standard Scale

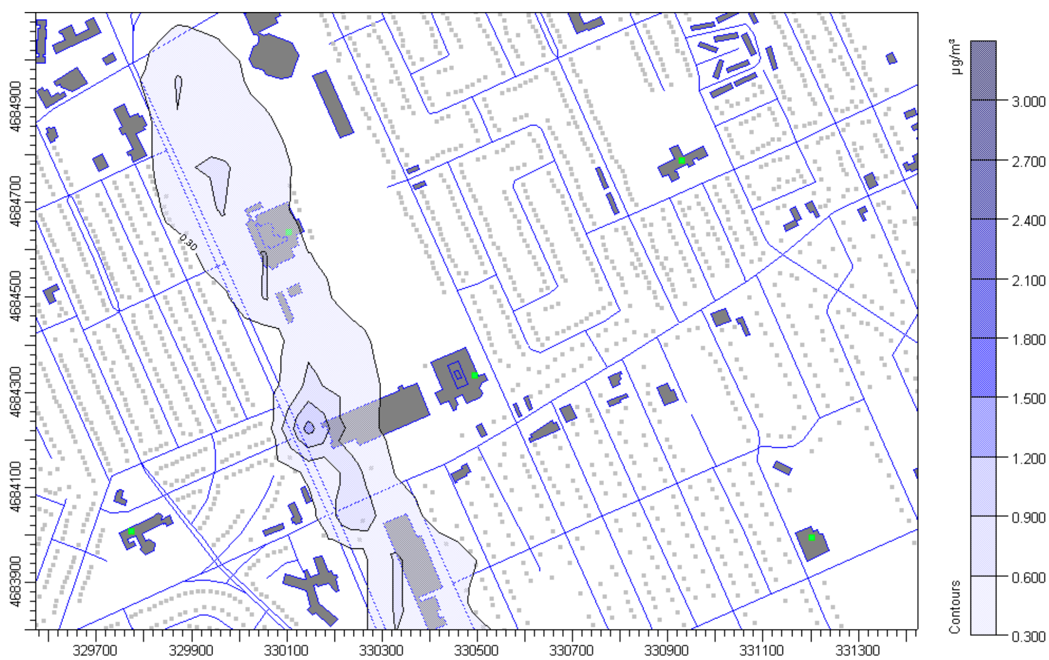

Figure 33: Modelled Concentrations for July 4, 2003 - Expanded Scale

July 3, 2003

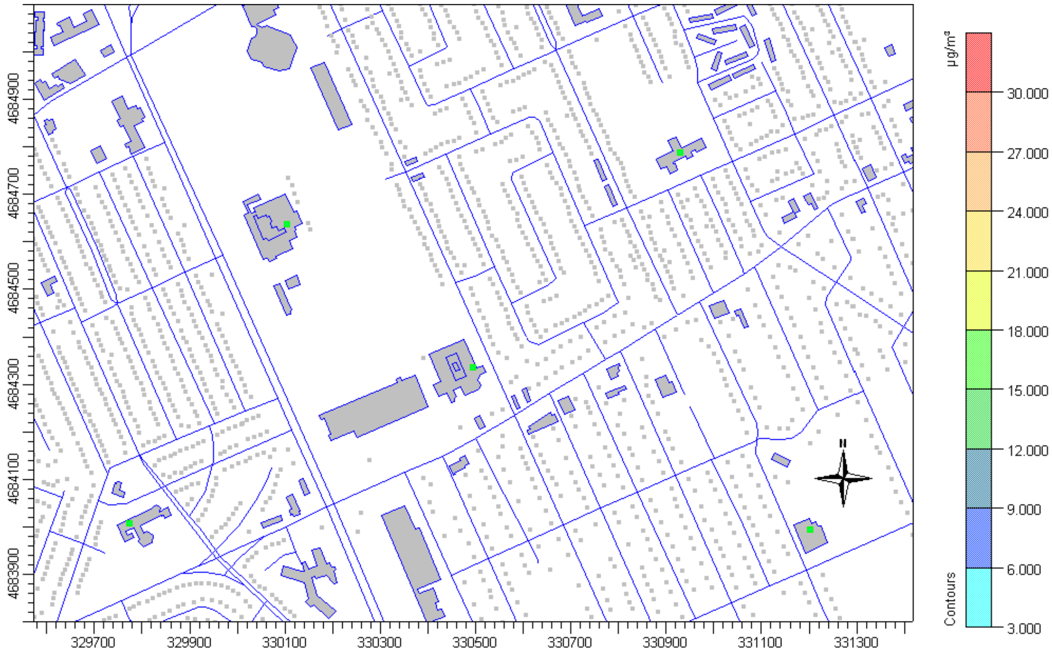

Figure 34: Modelled Concentrations for July 3, 2003 - Standard Scale

The lack of a truck queue and meteorological conditions combine to give a very small influence to the neighbouring area.

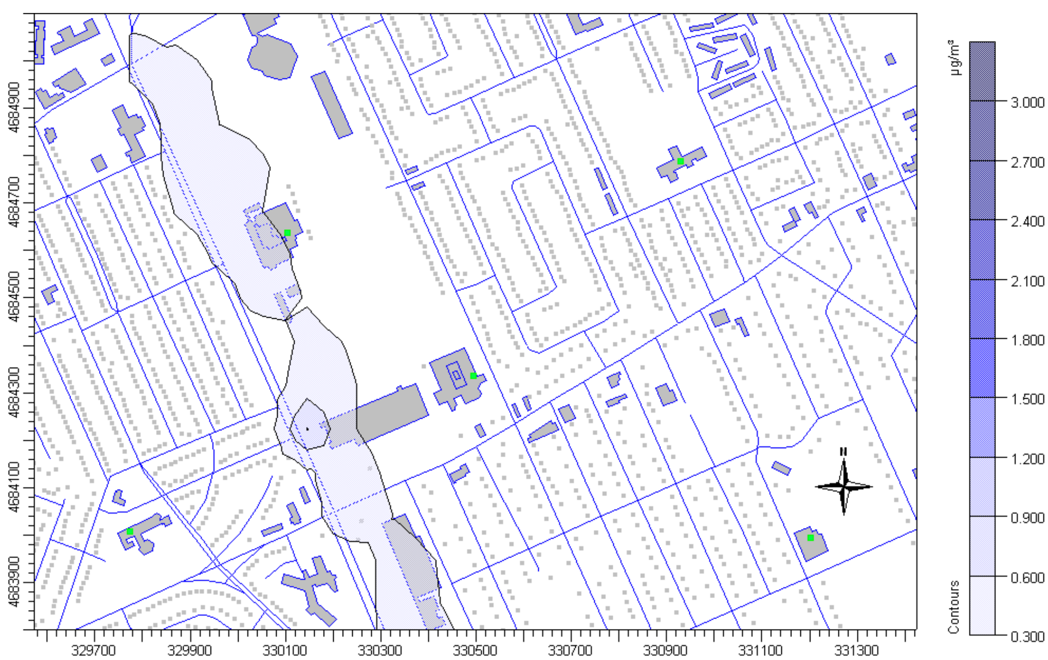

Figure 35: Modelled Concentrations for July 3, 2003 - Expanded Scale

December 12, 2002

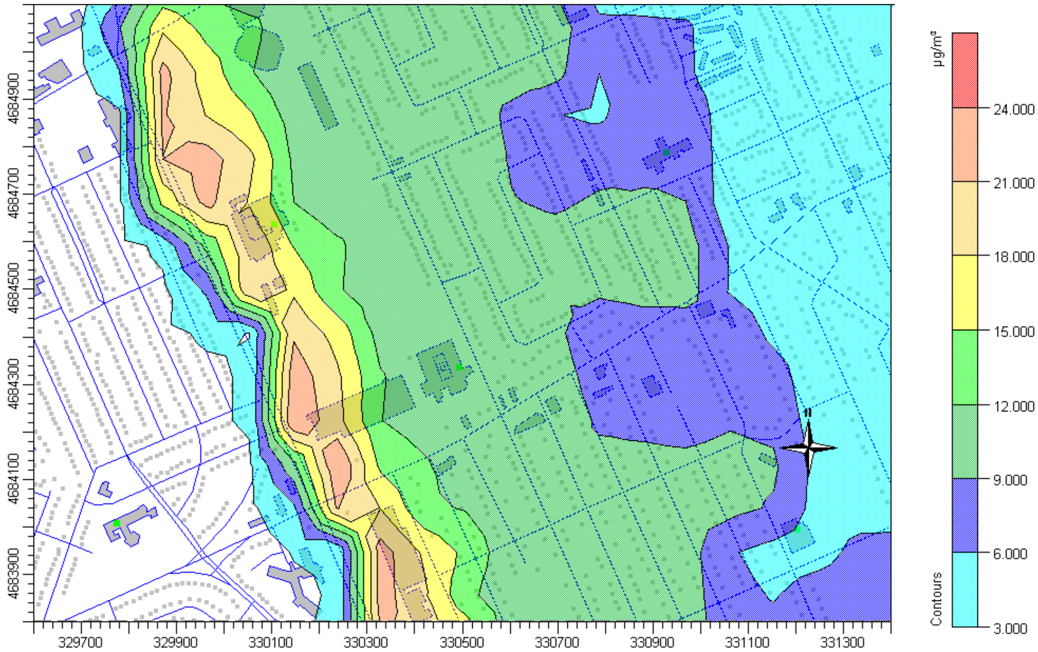

Figure 36: Modelled Concentrations for Dec 12, 2002 - Standard Scale

While a significant increase can be seen near the road, the contribution to particulate level drops to below 12 $\mu g/m^3$ within 200 m of the road. However the meteorological conditions do not favour a complete dispersion of the particulate and a noticeable influence is present for at least a kilometre downwind.

May 22, 2003

Figure 38: Modelled Concentrations for May 22, 2003 - Standard Scale

Little influence is seen past 150 m or so from the road. As explained earlier, the patchiness, in part, is due to numerical effects in the model. However, there are varying traffic levels over the length of Huron Church Road and this will contribute to some of the modelled change in particulate concentration.

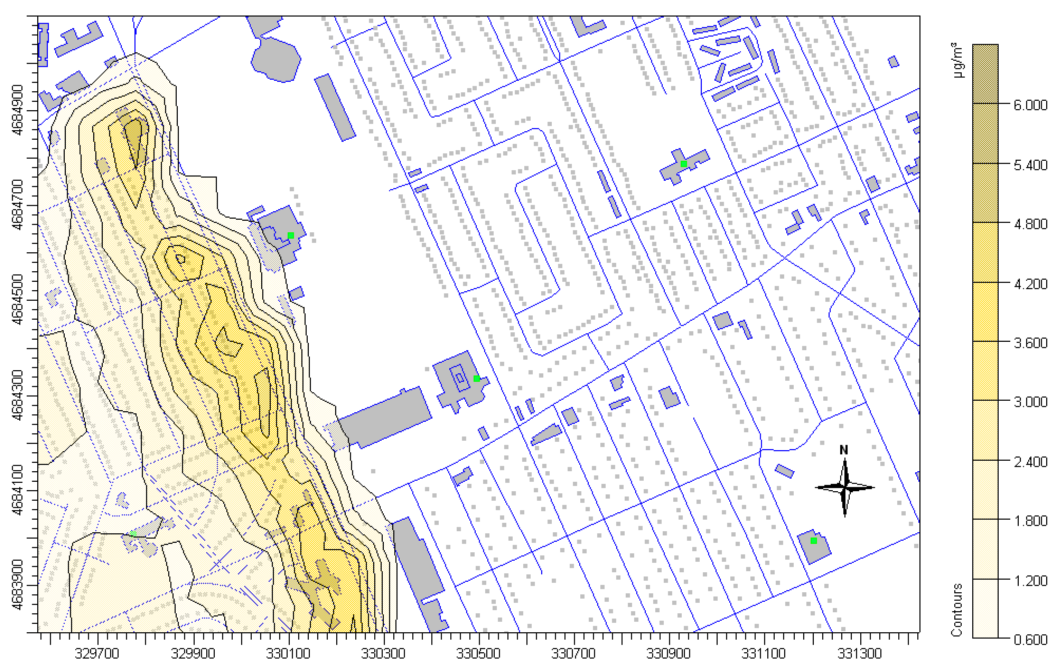

Figure 37: Modelled Concentrations for May 22, 2003 - Expanded Scale

May 21, 2003

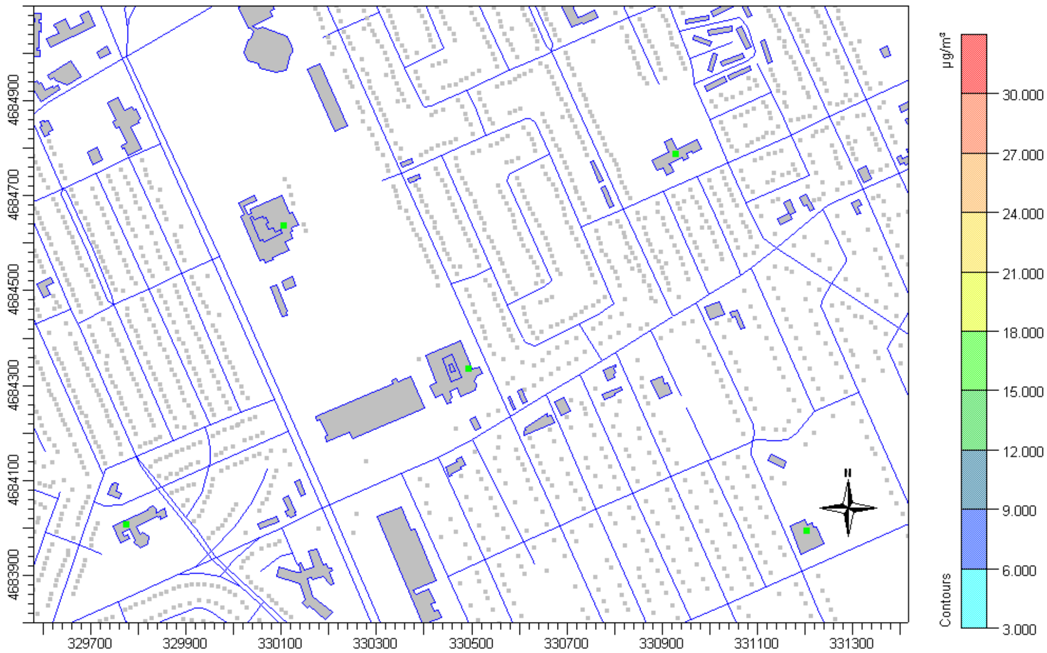

Figure 39: Modelled Concentrations for May 21, 2003 - Standard Scale

No influence is seen in this diagram in spite of the presence of a truck queue. This is encouraging as it implies that on certain days, meteorological conditions will be conducive to the quick dispersal of the truck emissions.

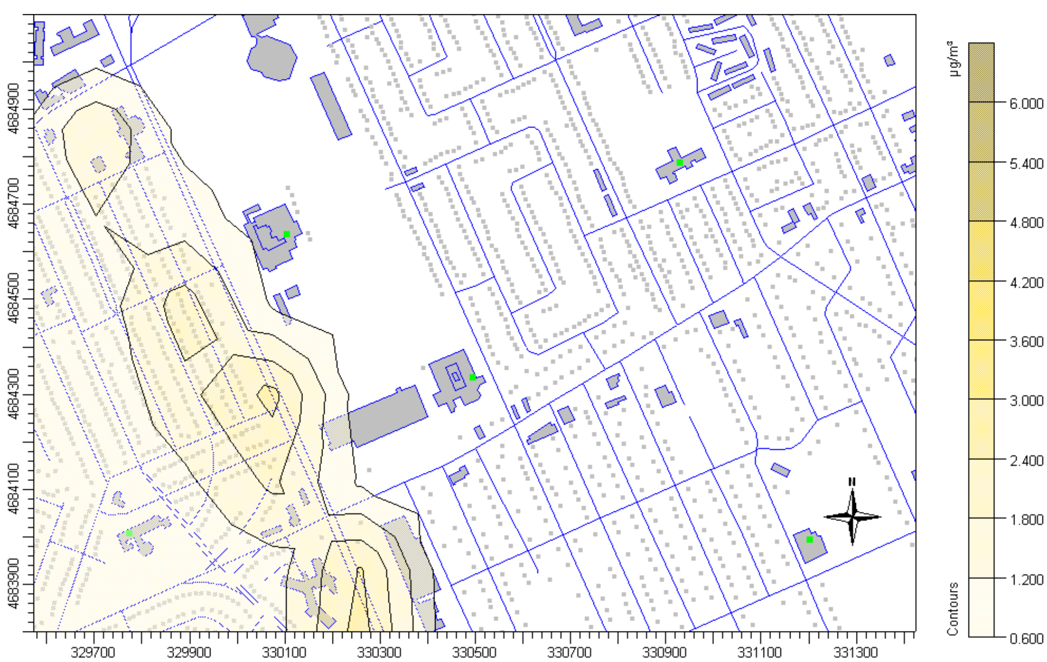

Figure 40: Modelled Concentrations for May 21, 2003 - Expanded Scale

May 20, 2003 - Early

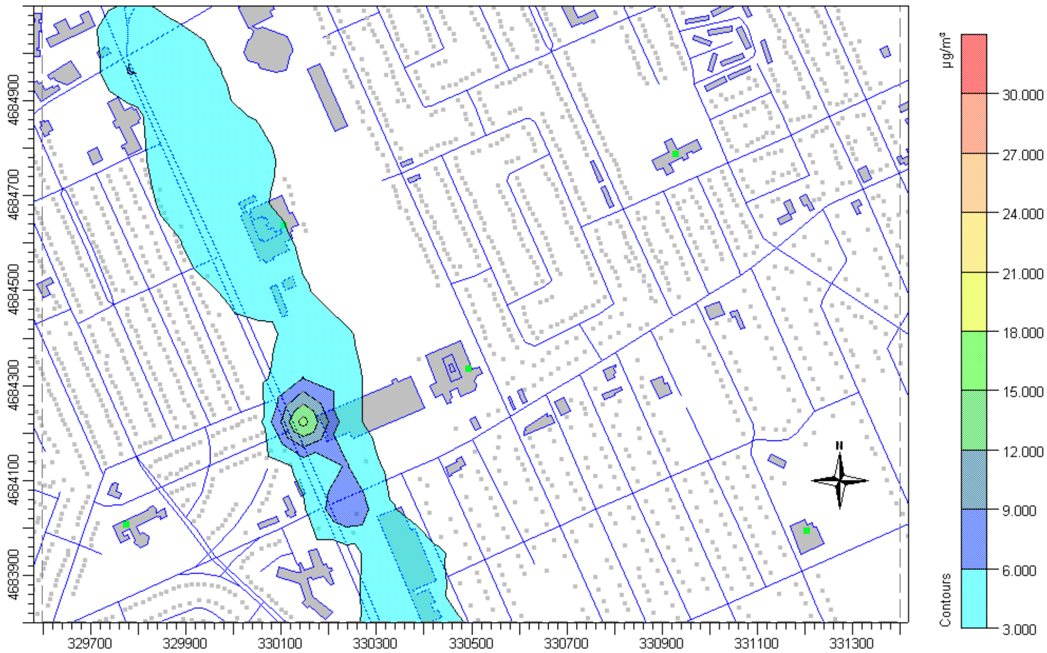

Figure 41: Modelled Concentrations for May 20, 2003, Early - Standard Scale

A measurable influence was noted for some 100 m - 200 m downwind. The somewhat higher hotspot suggests that near the road slightly higher values may be seen from time to time. However they will still be quite low.

May 20, 2003 - Afternoon

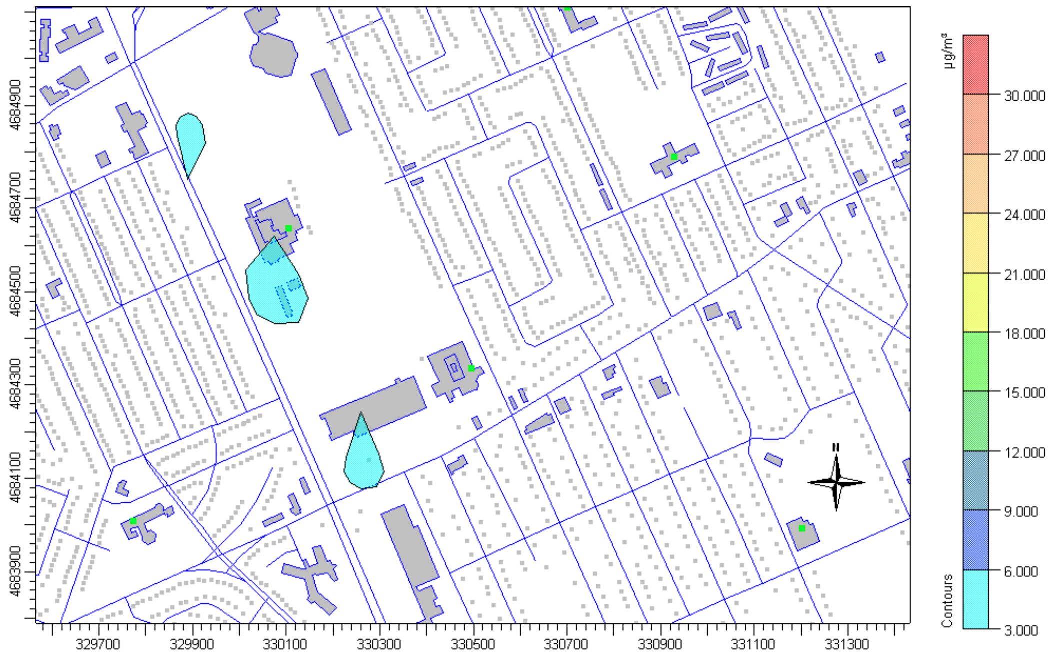

Figure 42: Modelled Concentrations for May 21, 2003, Afternoon - Standard Scale

The change in the wind caused increased dispersion that lead to lower concentrations. This diagram is a good illustration of the distance needed for the particulate from the truck to reach lower levels. Thus the highest concentrations are seen not at the road but 50 m or so back from it.

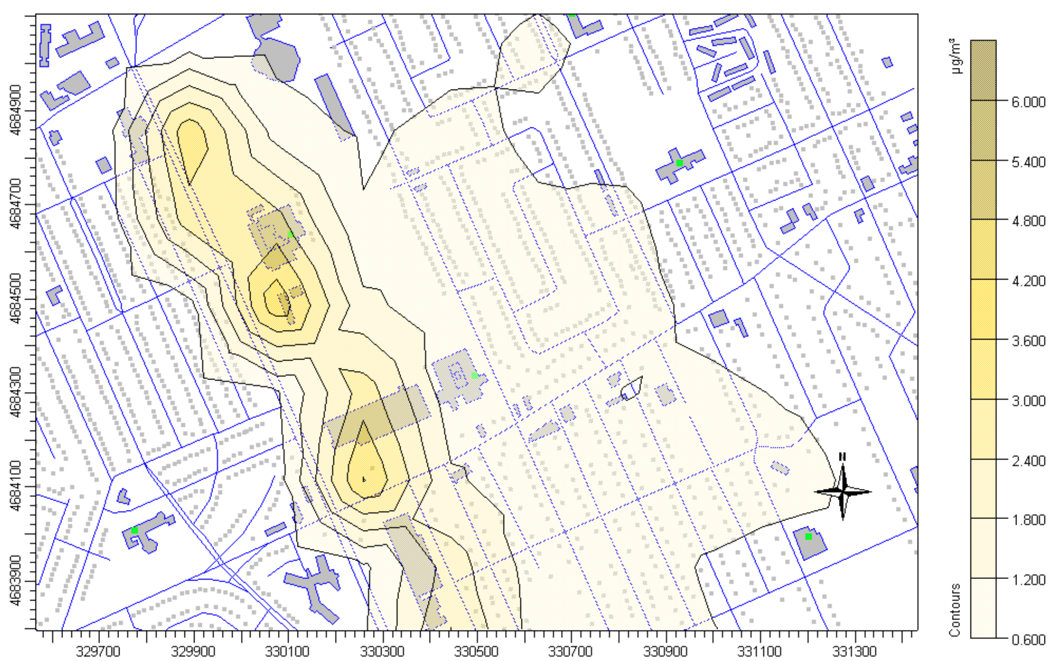

Figure 43: Modelled Concentrations for May 21, 2003, Afternoon - Expanded Scale

December 11, 2002

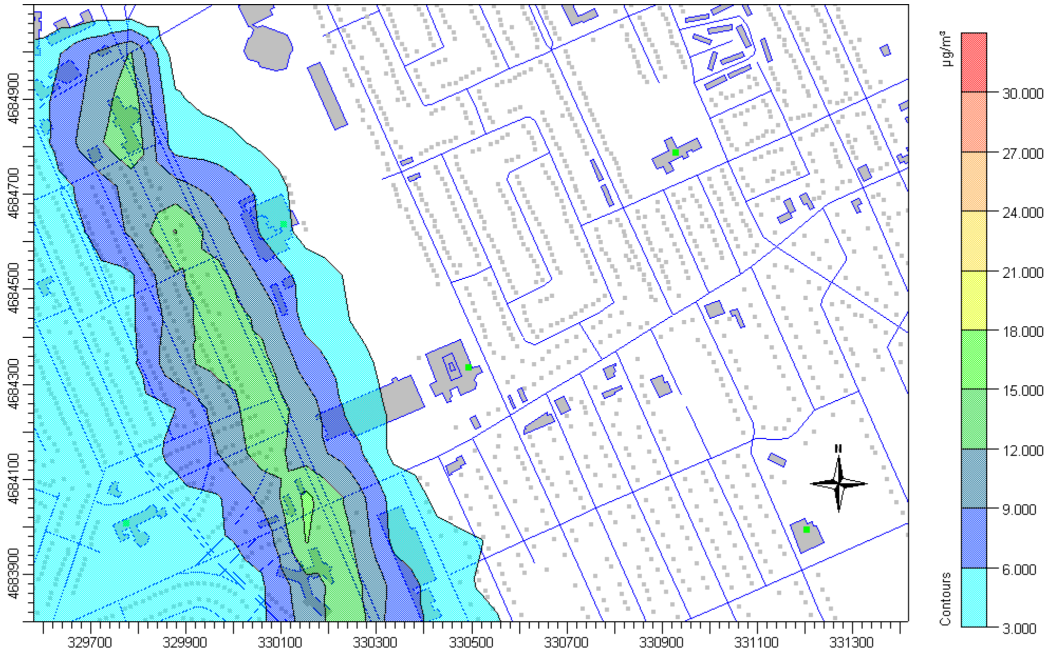

Figure 44: Modelled Concentrations for Dec 11, 2002 - Standard Scale

December 11 had light variable winds. This would work against quick dispersion of fine particulate. However, since meteorological information for very light winds is not highly dependable from portable equipment, the details may not be as reliable. Nonetheless it is clear that conditions on December 11 could contribute to high fine particulate loading for some distance from the road.

Discussion

The area of highest impact may not be directly on the road, but a few metres downwind as the plume from the (elevated) truck exhaust must diffuse downward. This will take longer on days with little wind. Maximum concentrations appear to occur within 50 m to 100 m of the road.

In general particulate concentration diminishes quickly with distance from the road. The exceptions seem to be for moderate to low winds when a truck queue is present. Otherwise little influence is seen beyond 200m - 400m from the road.

MAPS FOR IDEALIZED CONDITIONS

There are twelve maps below. They represent three different wind directions and different meteorological conditions for these directions. All are based on three-hour simulations. Truck queues are assumed to be present during each of these days.

The first set represent winds that are approximately perpendicular to the road - blowing from 60 ° (between E and NE).

The second set represent winds that are approximately parallel to the road - blowing from 170 ° (between S and SE).

The third set represent typical winds in the Windsor area - blowing from 230 ° (between SW and W). There are two sets fo these, one for low winds and one for higher winds.

Within each set, there are three different cases based upon different atmospheric stabilities. Stability is a measure of the strength of the forces that cause turbulence in the atmosphere.

The first is a "very stable" condition. This occurs when there is little no heating to cause convection. There is also little or no wind, as mechanical turbulence will still tend to mix the air especially near the ground. Anything released into the atmosphere will tend remain near the release point, dispersing only slowly.

In neutral conditions, the atmospheric conditions neither favour convection nor oppose it. Mixing will occur primarily due to wind turbulence. Pollution will disperse more quickly in these conditions than in stable conditions.

In convective conditions, the atmosphere is heated from below and so vertical mixing will occur much like that seen in boiling water. This occurs in addition to any effects due to wind forces. These conditions tend to disperse pollution much more quickly.

Winds Parallel to Road

Figure 45: Winds for Parallel Conditions

Figures 46, 48, and 49 show modelled concentrations for a three hour period with light winds from the typical wind direction for Windsor. Significant concentrations are seen downwind only in the case of very stable conditions.

Figure 47 shows the same conditions as figure 46 but with the traffic queue replaced by free-flowing truck traffic. The model suggests that near the road the difference in particulate concentration approaches 20 $\mu g/m^3$.

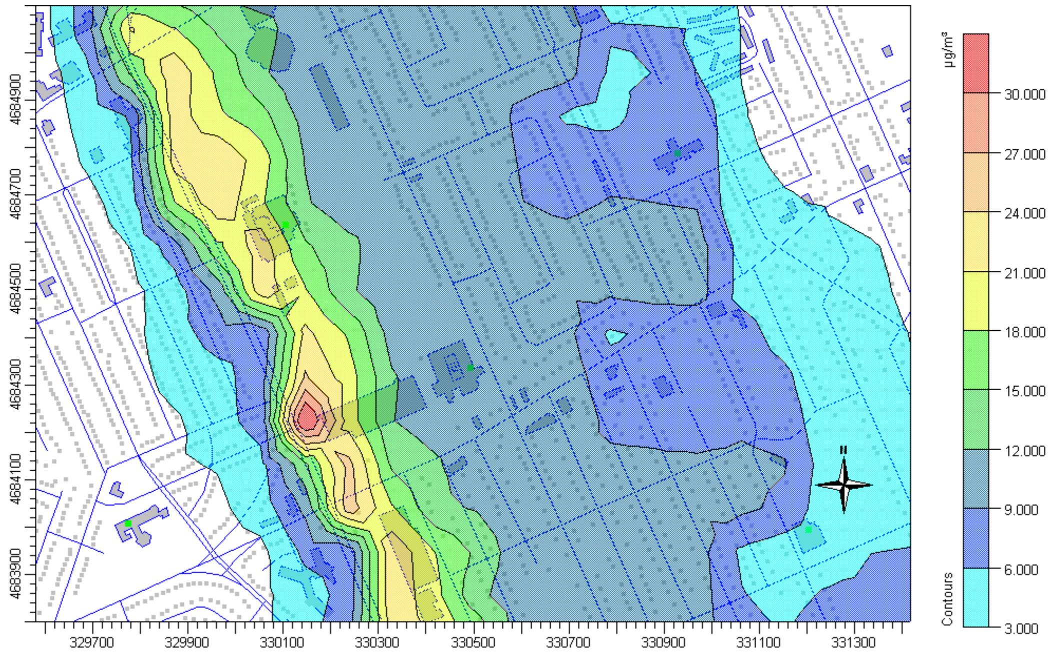

Figure 46: Modelled Concentrations for Very Stable Conditions - Standard Scale

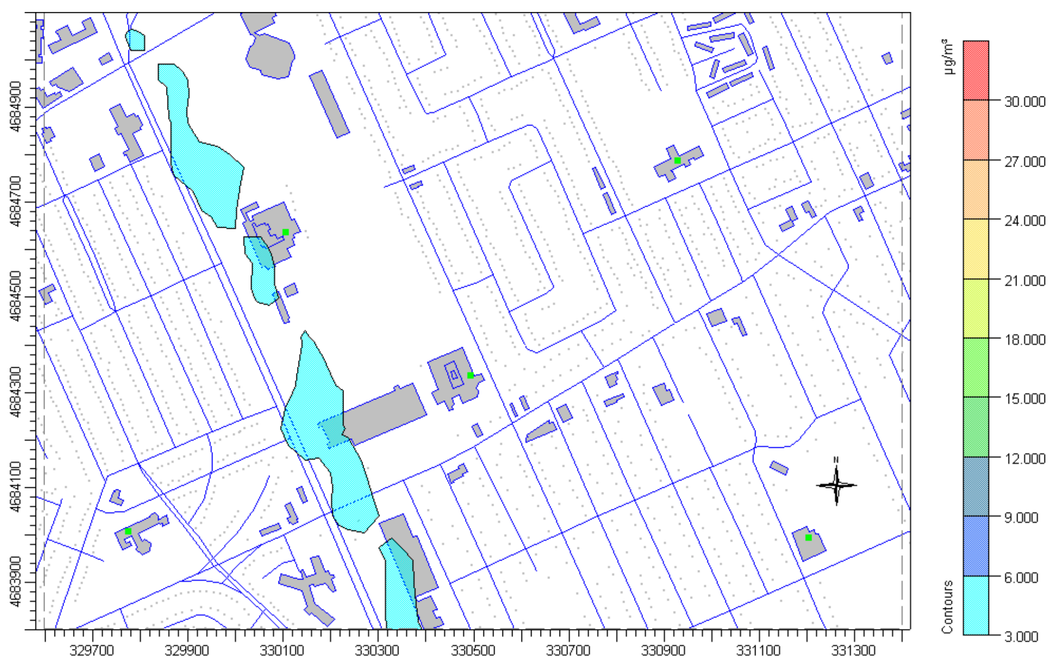

Figure 47: Modelled Concentration for Very Stable Conditions without Truck Queue

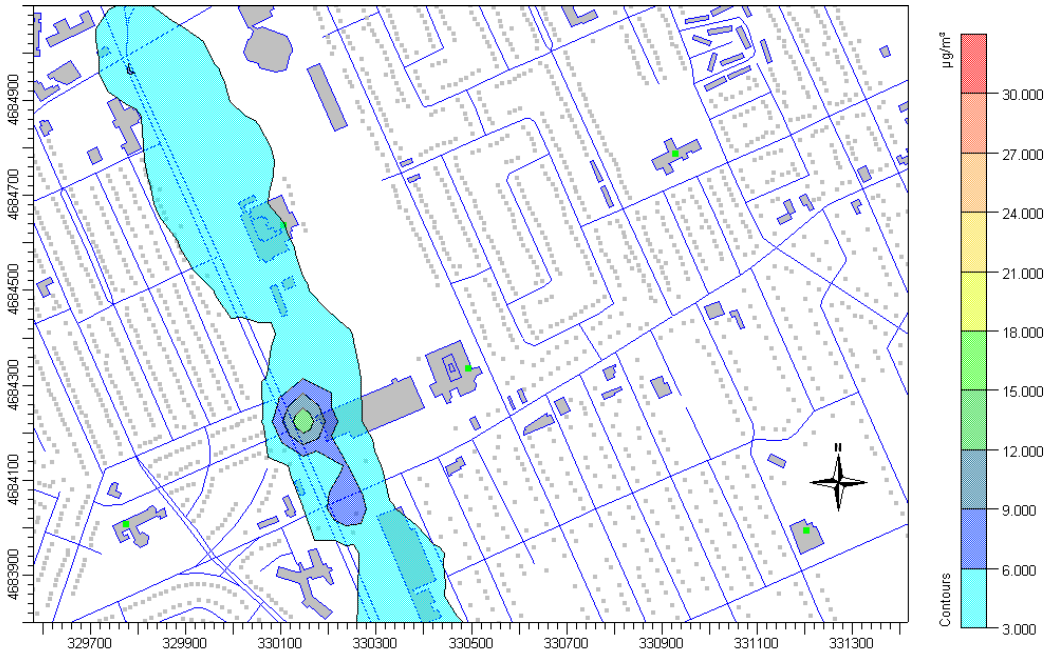

Figure 48: Modelled Concentrations for Neutral Conditions - Standard Scale

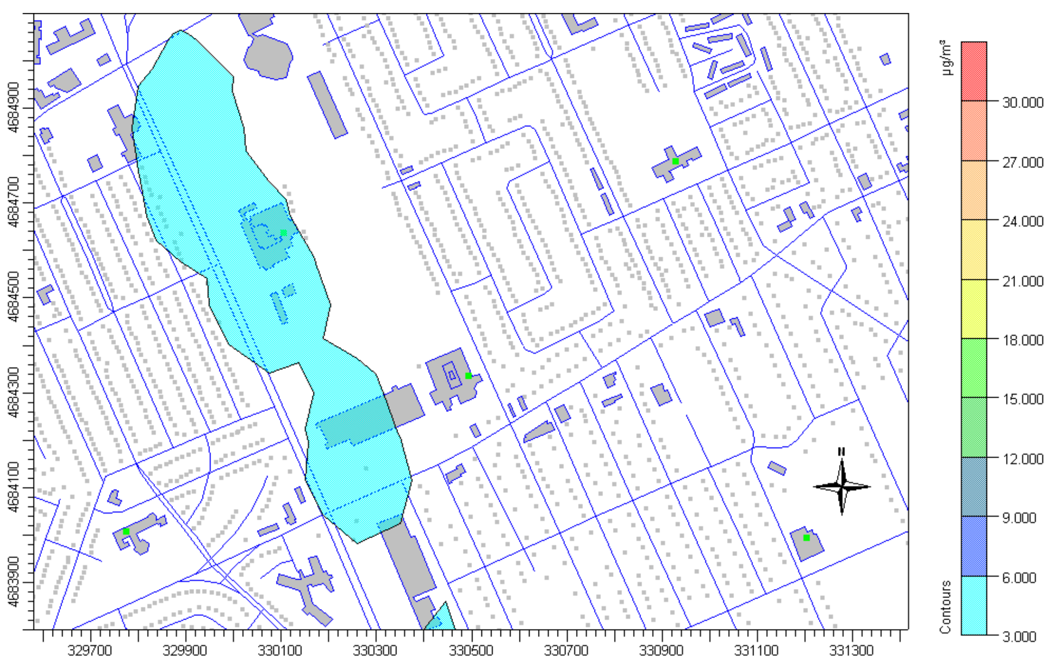

Figure 49: Modelled Concentrations for Convective Conditions - Standard Conditions

Very Stable - Little mixing **Neutral** - Some mixing **Convective** - Strong mixing

Winds Perpendicular to Road

Figure 50: Winds for Perpendicular Conditions

Figures 51, 53, and 54 show modelled concentrations for a three hour period with light winds from the typical wind direction for Windsor. Significant concentrations are seen downwind only in the case of very stable conditions.

Figure 52 shows the same conditions as figure 51 but with the traffic queue replaced by free-flowing truck traffic. The model suggests that near the road the difference in particulate concentration approaches 15 $\mu g/m^3$.

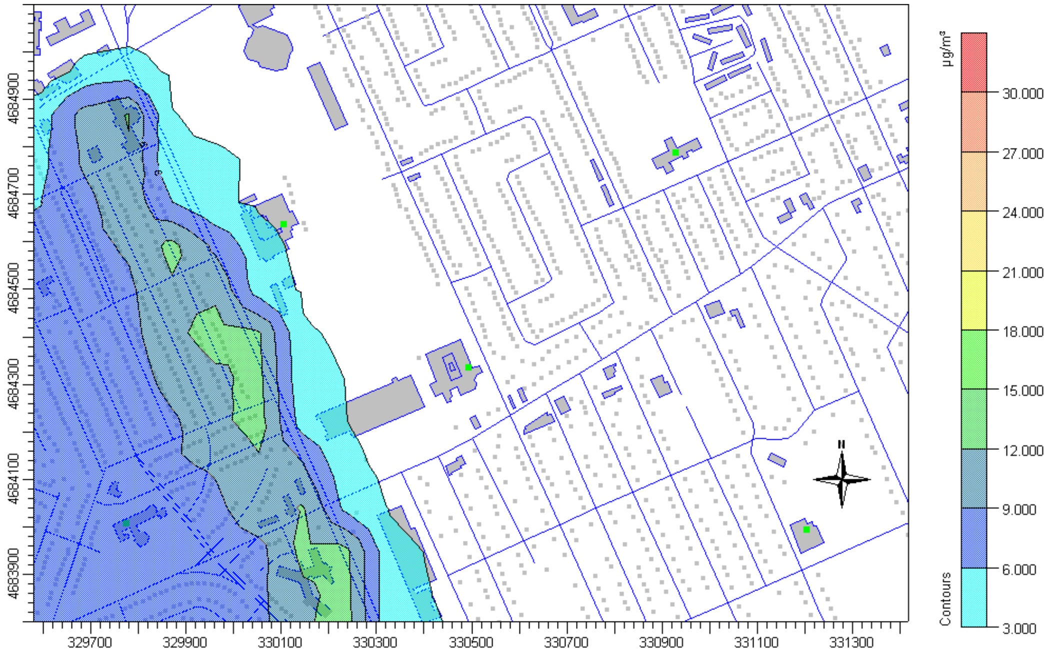

Figure 51: Modelled Concentrations for Very Stable Conditions - Standard Scale

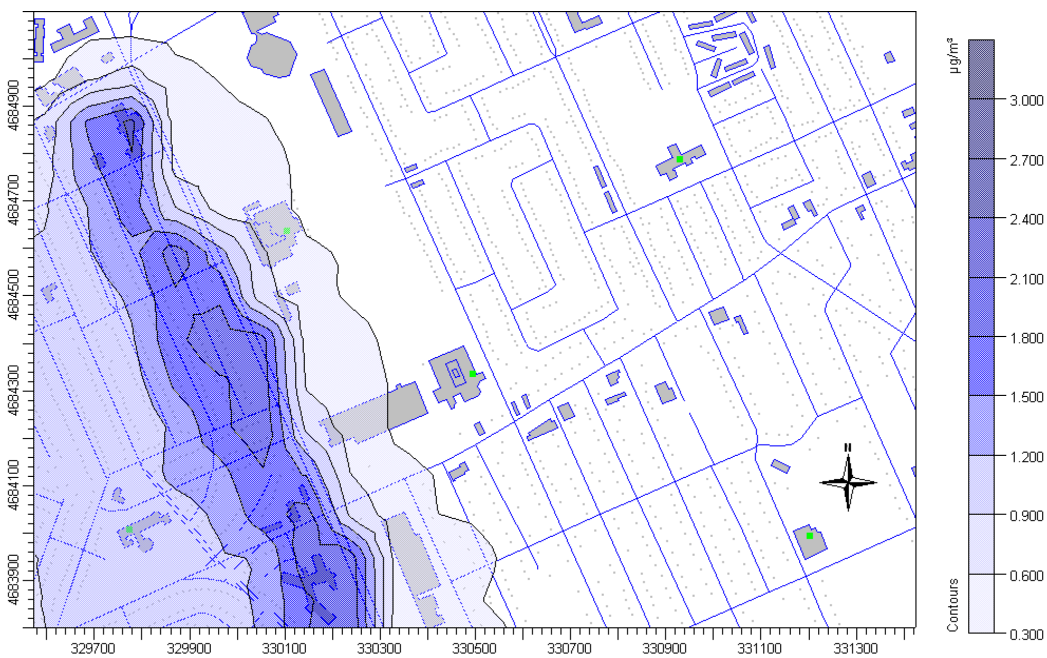

Figure 52: Modelled Concentrations for Very Stable Conditions without Truck Queue

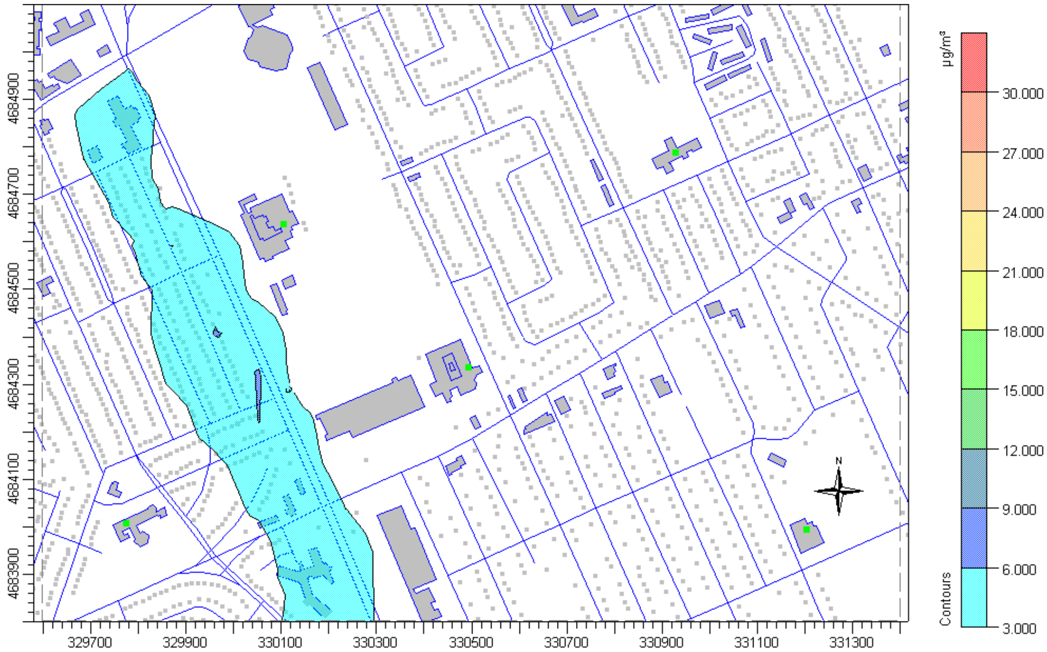

Figure 53: Modelled Concentrations for Neutral Conditions - Standard Scale

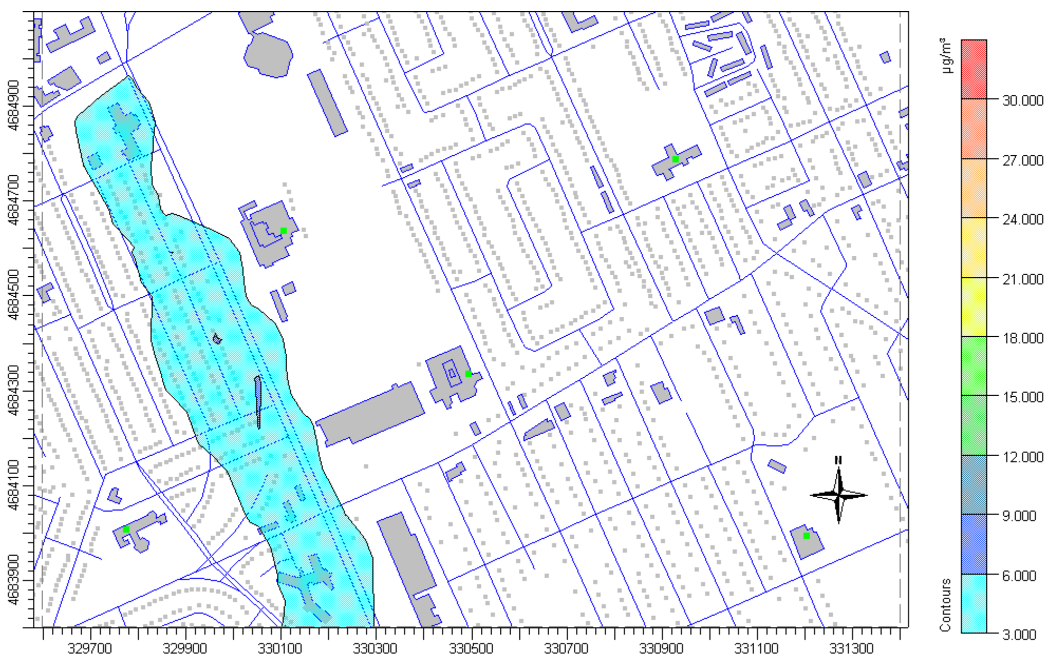

Figure 54: Modelled Concentrations for Convective Conditions - Standard Scale

Very Stable - Little mixing **Neutral** - Some mixing **Convective** - Strong mixing

Typical Windsor Wind Directions - Low Velocity

Figure 55: Typical Windsor Wind Direction

Figures 56, 58, and 59 show modelled concentrations for a three hour period with light winds from the typical wind direction for Windsor. Significant concentrations are seen downwind only in the case of very stable conditions.

Figure 57 shows the same conditions as figure 56 but with the traffic queue replaced by free-flowing truck traffic. The model suggests that near the road the difference in particulate concentration approaches 15 $\mu g/m^3$.

Very Stable - Little mixing **Neutral** - Some mixing **Convective** - Strong mixing

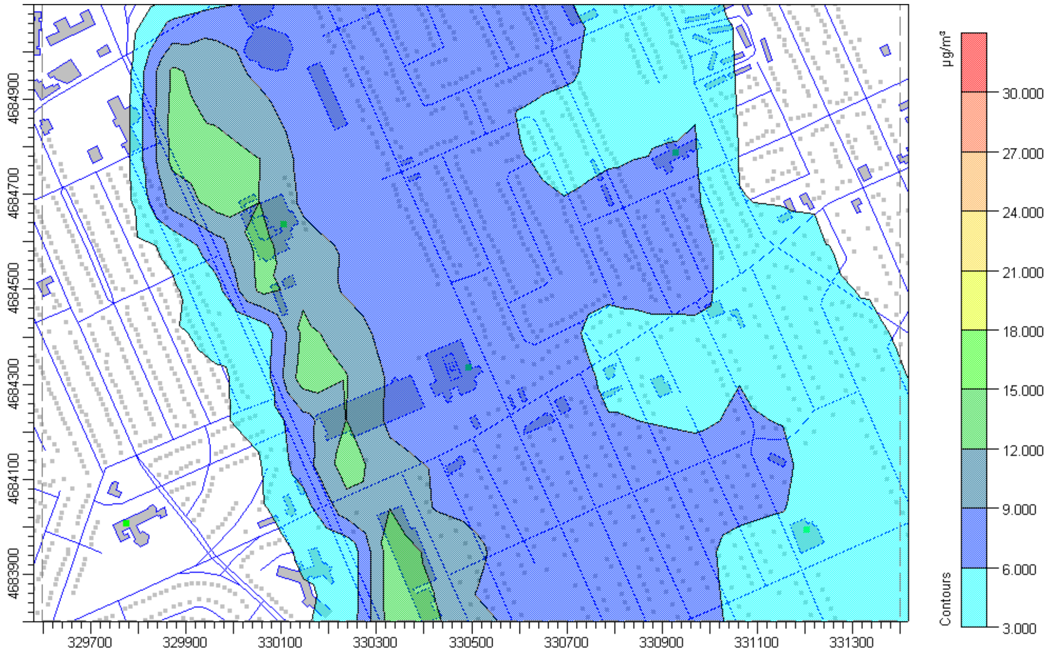

Figure 56: Modelled Concentrations for Very Stable Conditions - Standard Scale

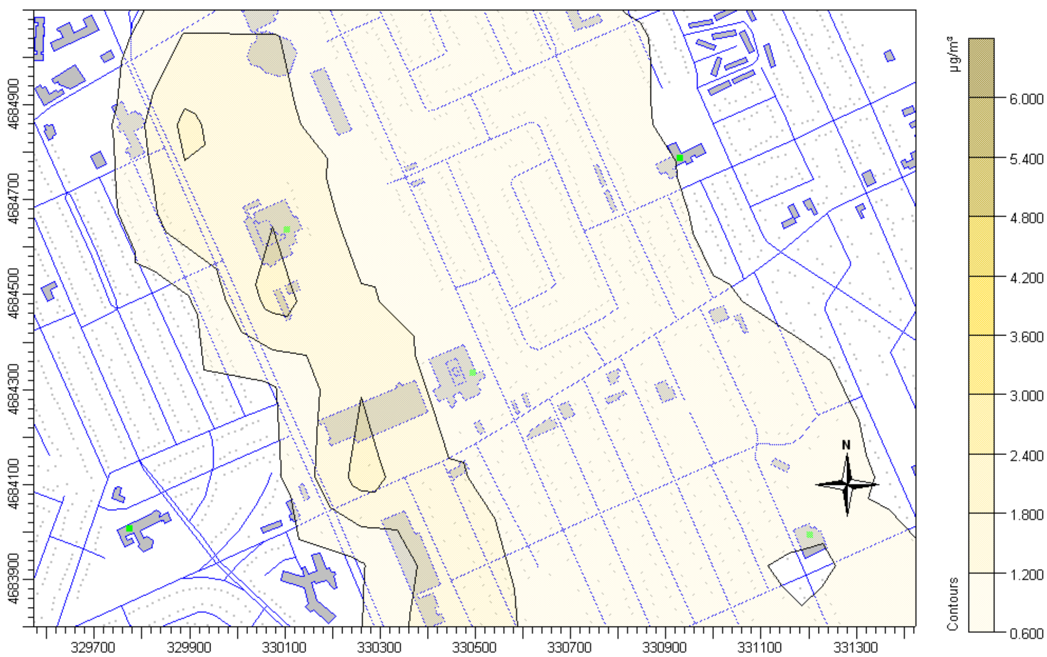

Figure 57: Concentrations for Very Stable Conditions without Truck Queue

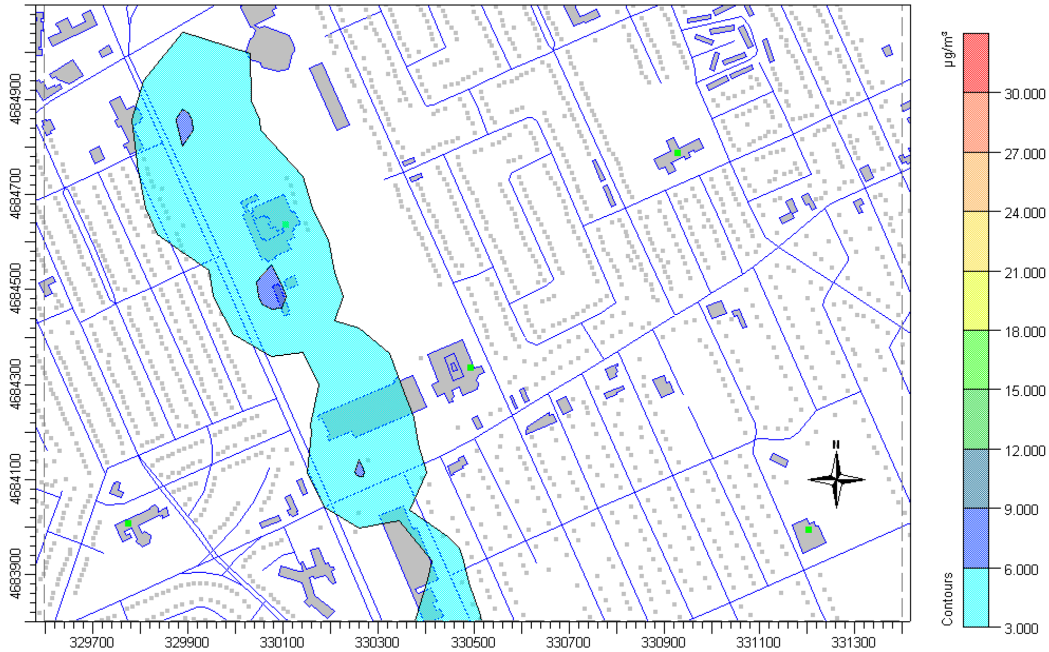

Figure 58: Modelled Concentrations for Neutral Conditions - Standard Scale

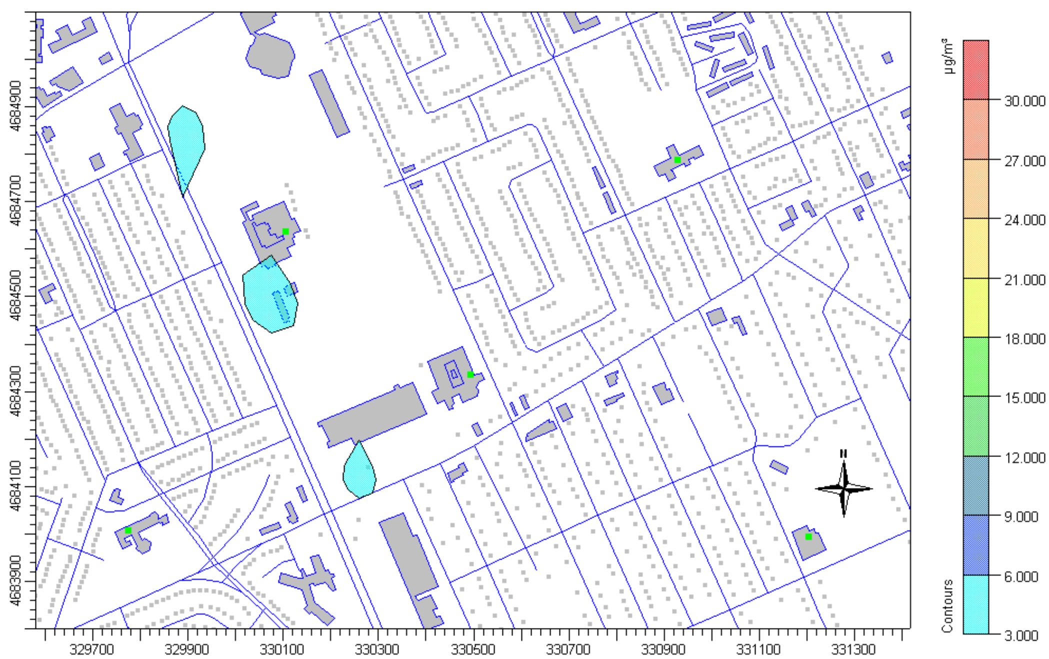

Figure 59: Modelled Conditions for Convective Conditions - Standard Scale

Very Stable - Little mixing **Neutral** - Some mixing **Convective** - Strong mixing

Typical Windsor Wind Directions - Higher Velocity

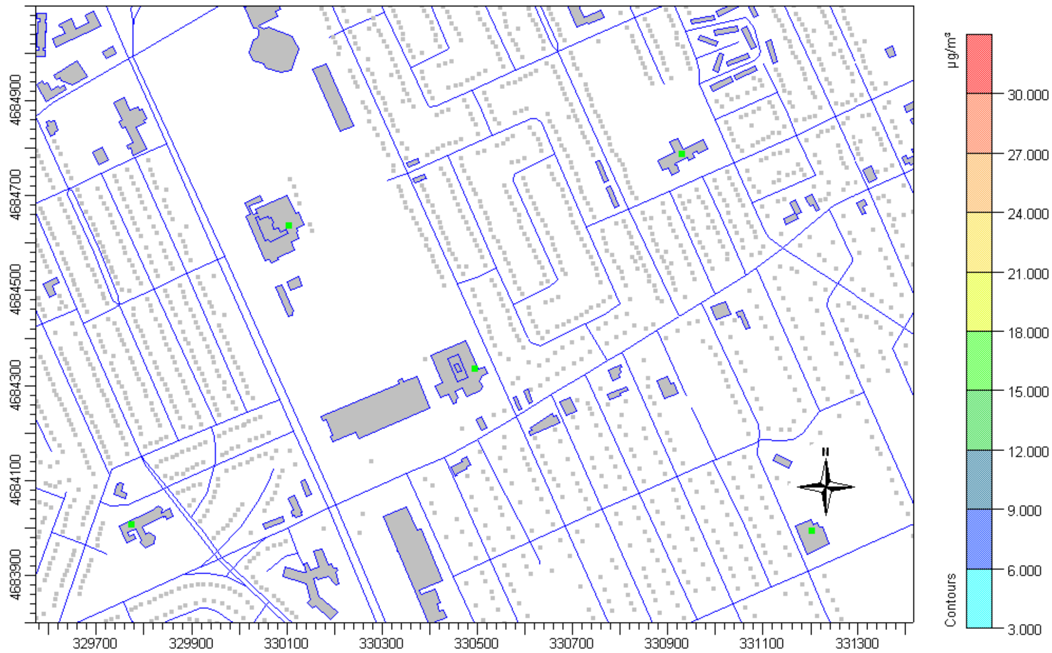

Figure 60: Modelled Concentrations for Very Stable Conditions - Standard Scale

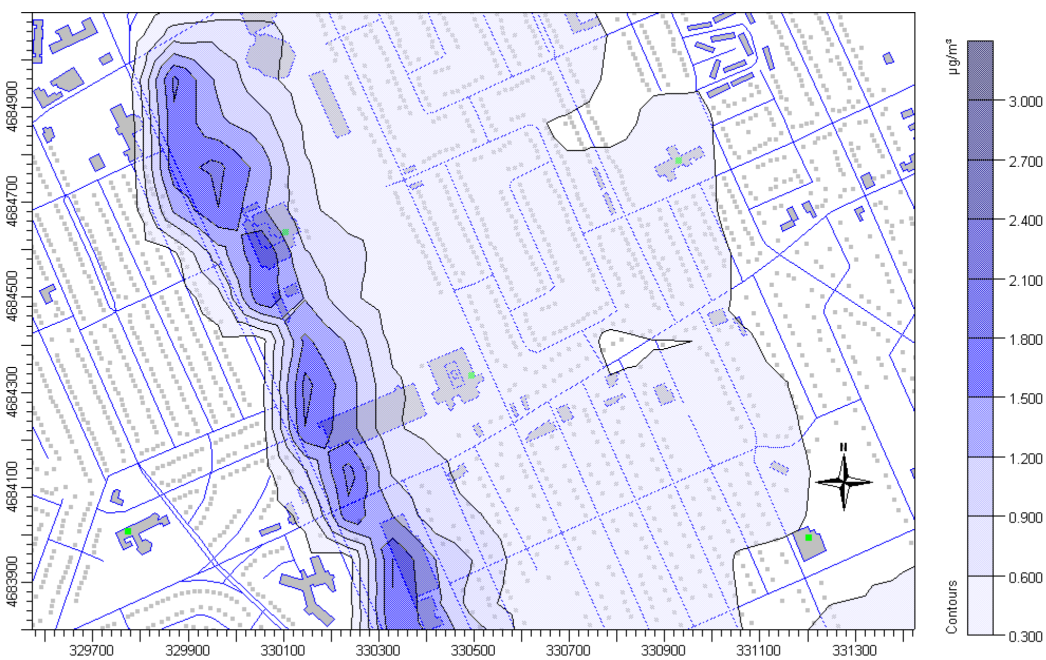

Figure 61: Modelled Concentrations for Very Stable Conditions - Expanded Scale

Very Stable - Little mixing **Neutral** - Some mixing **Convective** - Strong mixing

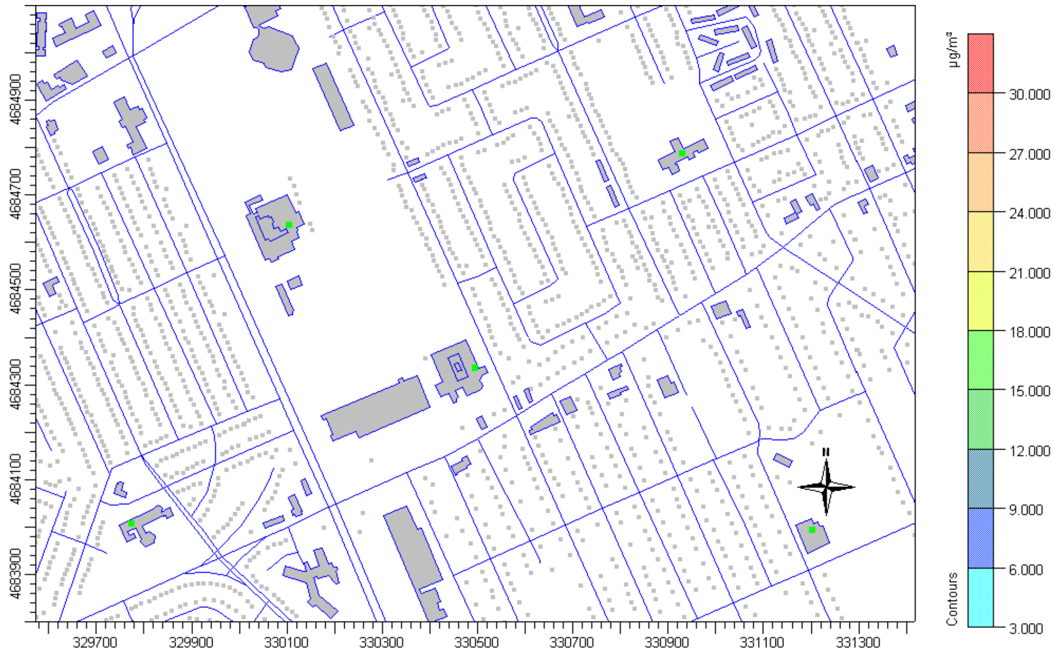

Figure 62: Modelled Concentrations for Neutral Conditions - Standard Scale

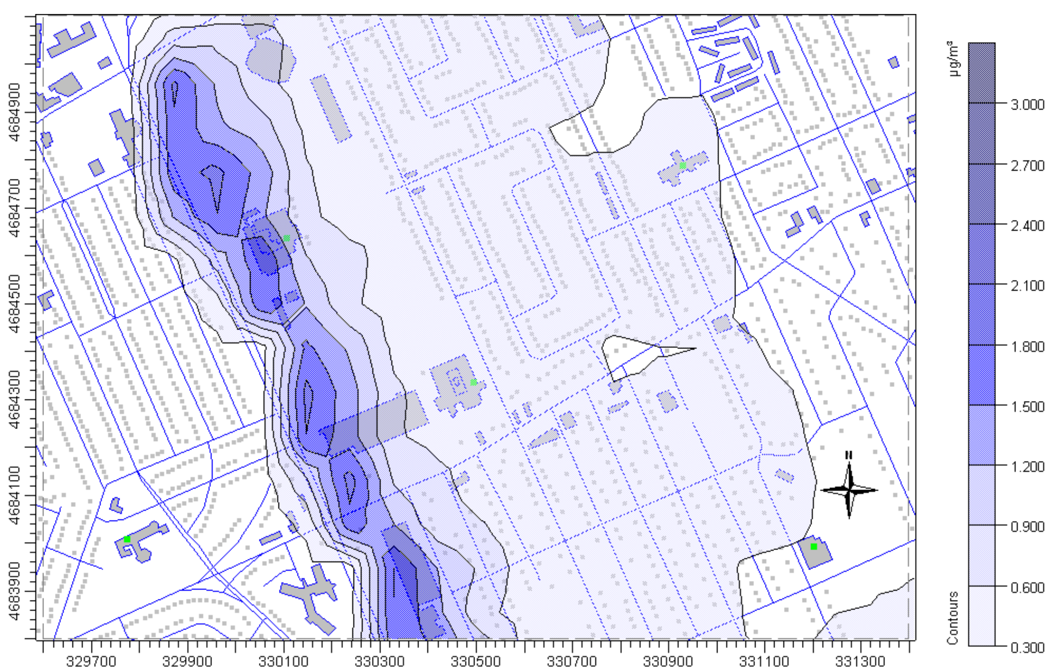

Figure 63: Modelled Concentrations for Neutral Conditions - Standard Scale

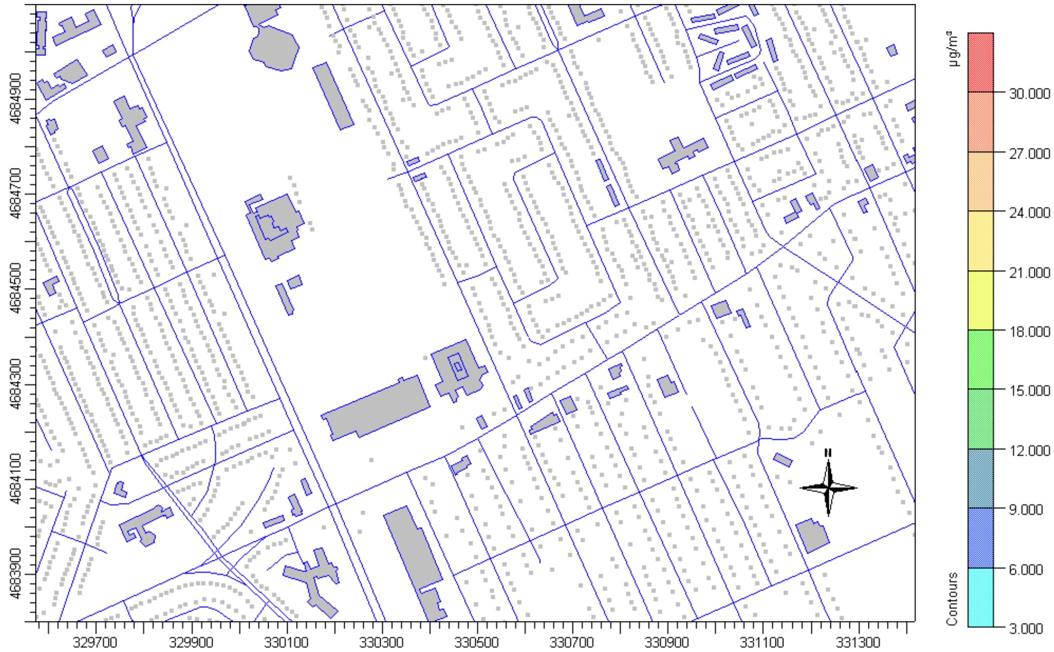

Figure 64: Modelled Concentrations for Convective Conditions - Standard Scale

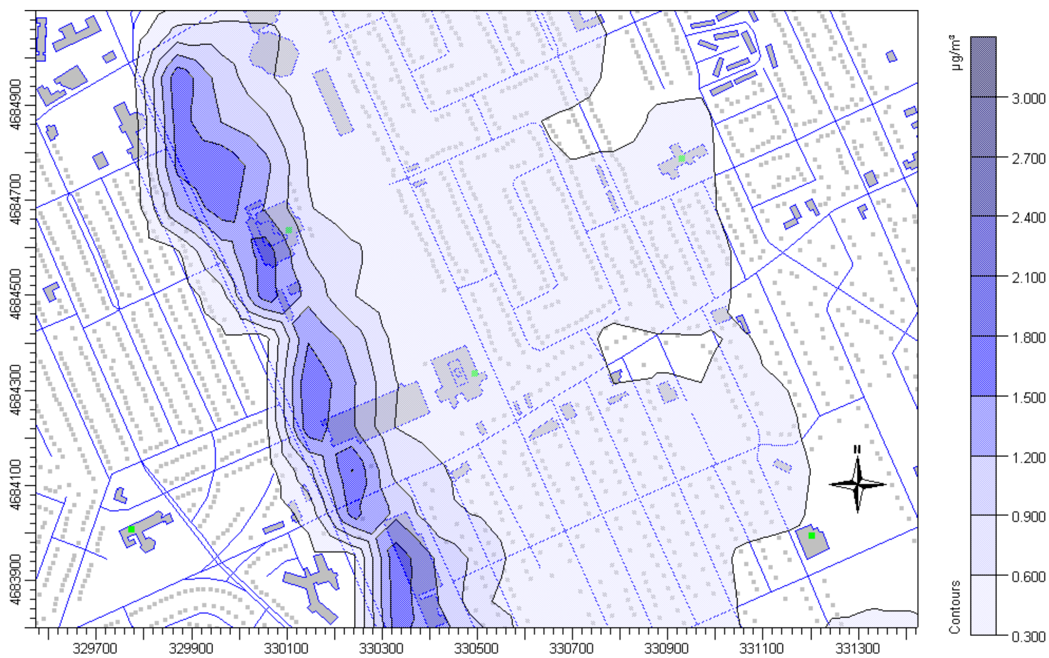

Figure 65: Modelled Concentrations for Convective Conditions - Expanded Scale

Very Stable - Little mixing **Neutral** - Some mixing **Convective** - Strong mixing

Discussion

The model predicts that the highest concentrations will occur with the least amount of mixing - stable conditions and low winds.

If stability decreases or the winds are higher, then mixing rapidly dilutes the effect of traffic emissions. The effect of wind appears to be strong enough to completely overwhelm the difference in stability. This is seen in more than one case where different model outputs are basically identical.

Stable or Very Stable conditions can occur up to 35% of the time during the summer though usually during the night and never between 7 in the morning and 8 in the evening. Fall frequencies are about the same, though stable conditions can occur later in the day. During spring and summer, stable conditions occur about 25% of the time and occur as late as 10 in the morning and as early as 5 in the afternoon. Since truck queues occur primarily during the day, the relative frequency of high impact situations may be fairly low.

Under certain conditions, the effect of traffic emissions may carry a considerable distance downwind – at least on the order of a kilometre. As might be expected this occurs under stable conditions and lighter winds. Lighter winds do not tend to be as turbulent thus the mechanical mixing is slower. Stable conditions mean that vertical mixing is low and so the particulate will not be diluted as quickly.