

Patterns of Atmospheric Nitrogen Dioxide in Kelowna, British Columbia

Abstract

Prior to 1994, atmospheric monitoring in the central Okanagan Valley region of British Columbia (BC) was restricted to ozone analysis and sporadic determinations of total suspended particulates, and dust. In May 1994, a BC Government air monitoring station measuring $PM_{2.5}$, CO, NO_x , O_3 and SO_2 was installed in the city of Kelowna. To complement the data obtained at this fixed location this study measured the spatial distribution of nitrogen dioxide gas at various locations throughout Kelowna. Twelve sites were chosen for a twelve month monitoring program (June 1994 to May 1995). Sampling, over 7 to 10 day periods, was carried out using Palmes passive diffusion tubes; analysis of the trapped NO_2 was determined spectrophotometrically. Estimates of mean accuracy ($\pm 4\%$), and precision (standard deviation $\pm 8\%$), were determined by comparing diffusion tube data with that obtained by the monitoring station. Average daily NO_2 concentrations varied from 8 to $79 \mu g/m^3$. High concentrations of NO_2 were measured in late July 1994 coincident with a nearby large forest fire. The highest overall values were obtained adjacent to Highway 97, the main traffic route, during a period of stagnant air conditions in late November and early December 1994. Average annual mean values ranged from $21 \mu g/m^3$ to $50 \mu g/m^3$, well within the Canadian and US (NAAQS) air quality objectives. The data obtained in this study provides a suitable base from which future comparisons of NO_2 levels, and air quality trends, may be assessed.

Introduction

The largest regional population in the interior of British Columbia (BC) is found in the Okanagan Valley of south central BC. The main city of the region, Kelowna (Figure 1), has experienced a particularly rapid population growth over the past 20-30 years, increasing from about 20,000 in 1970 to in excess of 95,000 today (de Scally and Turchak 1996). There is concern that the air quality in the region is deteriorating due to this population increase. For this reason, the BC Provincial Ministry of Environment, Lands and Parks in 1994 installed a comprehensive atmospheric monitoring station at the KLO Road campus of Okanagan University College (OUC) in Kelowna. This station continuously monitors atmospheric concentrations of inhalable particulate matter (PM_{10}), ozone (O_3), nitrogen oxides (NO_x), carbon monoxide (CO) and sulfur dioxide (SO_2), producing hourly average concentrations of these target pollutants (Josefowich and Reid 1995). Prior to the opening of this station, air quality monitoring for O_3 and total suspended particulates had been carried out on a less regular basis (Richardson and Jensen 1991).

Two aspects of air quality of immediate concern in Kelowna and the Okanagan Valley are: (i) high concentrations of PM_{10} , which may lead to respiratory impairment (Vedal 1993; Vedal 1995), and (ii) the potential for summertime

production of high concentrations of ground level O_3 (Reid 1995).

As well as being a strong oxidant, ground level O_3 combined with NO_x , atmospheric hydrocarbons (from automobiles or trees/plants), intense sunlight, high temperatures and static air can lead to the formation of photochemical smog. This smog may be deleterious to health (particularly of the young and elderly), can adversely affect crop production, can attack materials (plastic and rubber) and is unsightly (a yellow/brown haze). Thus the onset of photochemical smog episodes could have serious repercussions to the public health and economy of the Kelowna area. Tourism and agriculture are major industries of this region.

Tropospheric O_3 is produced by a series of reactions which start with nitric oxide, NO (Jeffries 1995; Finlayson-Pitts and Pitts 1997). Natural sources of NO include microbial activity in soils and the interaction of lightning with atmospheric nitrogen and oxygen. However, the major source of NO is high temperature fossil fuel combustion as generated by the transportation sector, Equation (1). NO, in the presence of O_3 , is readily oxidized to NO_2 , Equation (2). NO_2 is decomposed by UV-A sunlight, Equation (3), releasing an oxygen atom capable of combining with O_2 to produce O_3 , Equation (4). As indicated by Finlayson-Pitts and Pitts (1997), these latter two

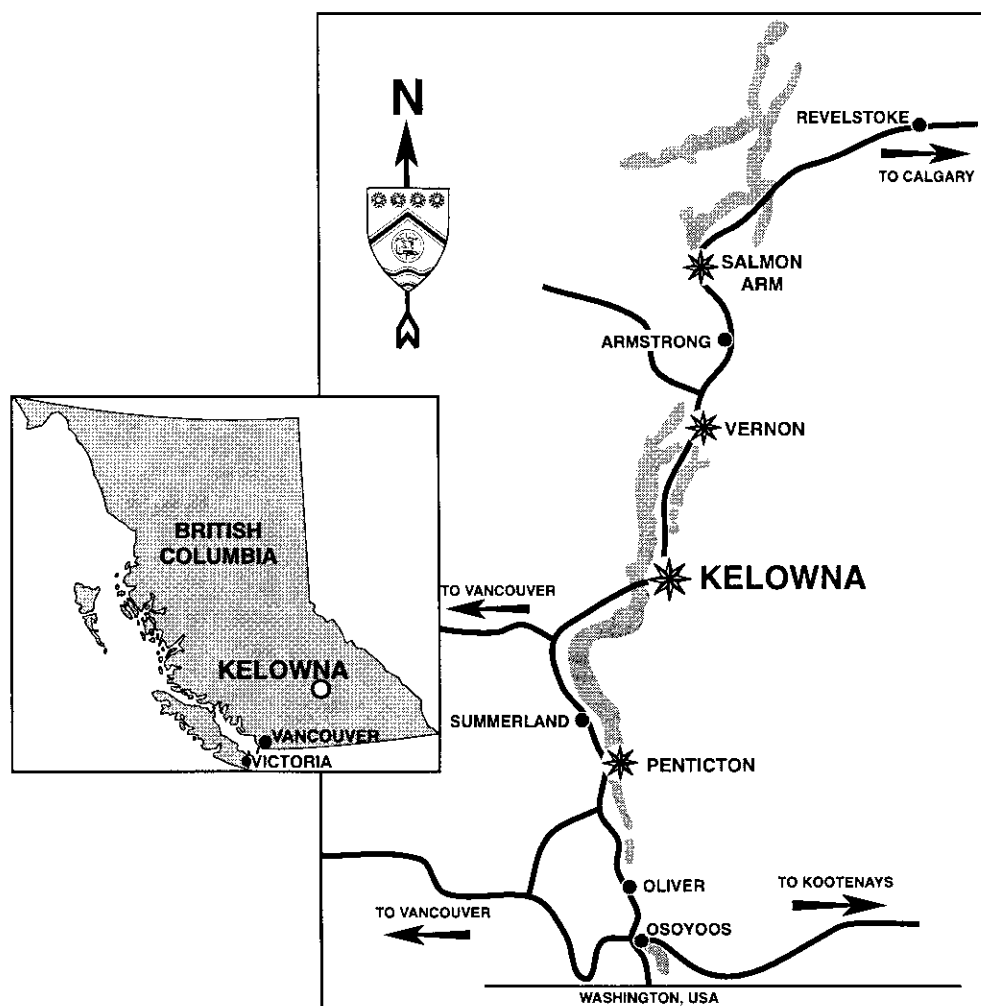
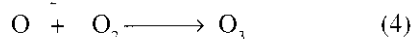
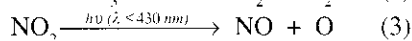
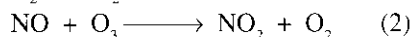
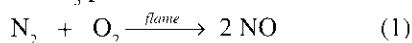
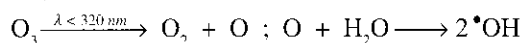


Figure 1. Location of the city of Kelowna, Okanagan Valley, British Columbia, Canada.

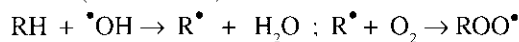
reactions are the only known methods of tropospheric O_3 production.



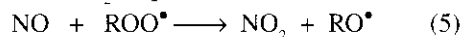
From these equations, it appears that there is no net gain of O_3 ; one molecule of O_3 is used up and one is produced, resulting in a null cycle. However, O_3 can react photochemically and, in the presence of water, produces the hydroxyl radical, $\cdot OH$.



In an atmosphere containing volatile organic compounds (VOC), such as hydrocarbons (RH) the very reactive $\cdot OH$ species can abstract a proton. Further reaction with O_2 gives a peroxy radical, $ROO\cdot$ (Bunce 1994).

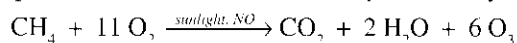


These peroxy radicals are also capable of oxidizing NO to NO_2 , Equation (5).



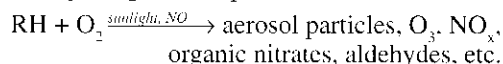
As a single hydrocarbon molecule is capable of producing several peroxy radicals (Baird 1995), enhanced production of NO_2 by reactions equivalent to Equation (5) can occur. This NO_2 can further react to produce more O_3 , via Equations (3)

and (4). So, under appropriate climatic conditions, rather than having a null cycle, a build up of O_3 is obtained in an atmosphere polluted with NO_x and VOC. For example, the complete atmospheric oxidation of methane is represented by:



This is an oversimplification because there may also be other products.

Peroxy radicals are not the only species produced by the photochemical oxidation of hydrocarbons. In an atmosphere containing high concentrations of NO and RH , irradiation with sunlight may, through a series of complex photochemical reactions, produce photochemical smog, as indicated by the general equation:



To estimate a region's potential for smog generation, data are required on spatial and temporal distributions of NO_x , O_3 and RH , as well as meteorological parameters such as sunlight intensity, temperature and wind motion. Obtaining information on spatial and temporal distributions of NO_x , O_3 and RH requires several monitors to be placed at locations within the sampling region. The high cost of monitoring instruments generally prohibits this approach.

As well as being a fundamental chemical involved in O_3 and photochemical smog production, NO_2 is also recognized as a toxic pollutant, acting as a respiratory irritant and plant growth suppressant (Hilborn and Still 1990). The spatial distribution of NO_2 can readily be measured using inexpensive passive diffusion tubes (Palmer 1976, Campbell 1988, Shooter 1993, Campbell et al. 1994), consequently this gas has been selected as the target analyte for this study. NO_2 was measured at various locations within the city of Kelowna throughout a twelve month sampling period.

Methods

Passive diffusion tubes, as described by Shooter (1993), are 7 cm x 1 cm acrylic cylinders with one end open to the atmosphere. The closed end houses a stainless steel mesh impregnated with an aqueous solution of triethanolamine. The tubes are mounted on poles, walls, trees etc. using a specially designed bracket. Atmospheric NO_2 enters the diffusion tubes by molecular diffusion

and reacts with the triethanolamine. The amount of reaction is proportional to the concentration of NO_2 in the air. After an appropriate sampling period (7 to 10 days), the tubes are returned to the laboratory where the triethanolamine in the tubes is treated with solutions of sulfanilamide and N-1-naphthylethylenediamine dihydrochloride, producing a purple solution of an azo dye. The intensity of the purple color, as determined spectrophotometrically ($\lambda = 540$ nm), is directly proportional to the amount of NO_2 that has interacted with the triethanolamine. The experimental results are converted to a daily mean concentration in units of ppbv, parts per billion (1 part in 10^9) NO_2 by volume. The units are finally converted to $\mu g/m^3$, i.e. μg of NO_2 per m^3 air.

Method development and testing, and sample site selection took place in May 1994. Diffusion tubes were initially placed at 26 locations throughout Kelowna. Sites were chosen that were representative of various areas of the city (e.g. light industrial, commercial, residential, semi-rural) with a greater emphasis placed on major traffic areas. Sampling and analyses were carried out during June, July and August, 1994 as part of a Deep River Science Academy Research Project (a summer camp for gifted high school students). On the basis of the data collected, 12 of the sites were further monitored from September 1994 to June 1995. These sites included those found in the preliminary measurements to have the highest NO_2 concentrations. The residential and semi-rural sites, all of which indicated low NO_2 concentrations, were excluded because the site at the KLO Road monitoring station, which was retained, appeared to be representative of these locations.

A map of Kelowna (Figure 2) indicates the location of the 12 sampling sites. Main features included are Okanagan Lake and the major traffic routes, Highways 97 and 33. Kelowna, at an elevation of 350 m is situated near the middle of a 100 km long narrow north-south valley having mountains of approximately 1,500 m immediately to the east and west.

To estimate the accuracy of the technique, diffusion tubes were mounted at the KLO Road Provincial monitoring site (Site-1) and the analyses compared to the BC Provincial monitor data. To improve the precision of the method sampling tubes were always mounted as pairs. Tests were made of laboratory blanks and field blanks.

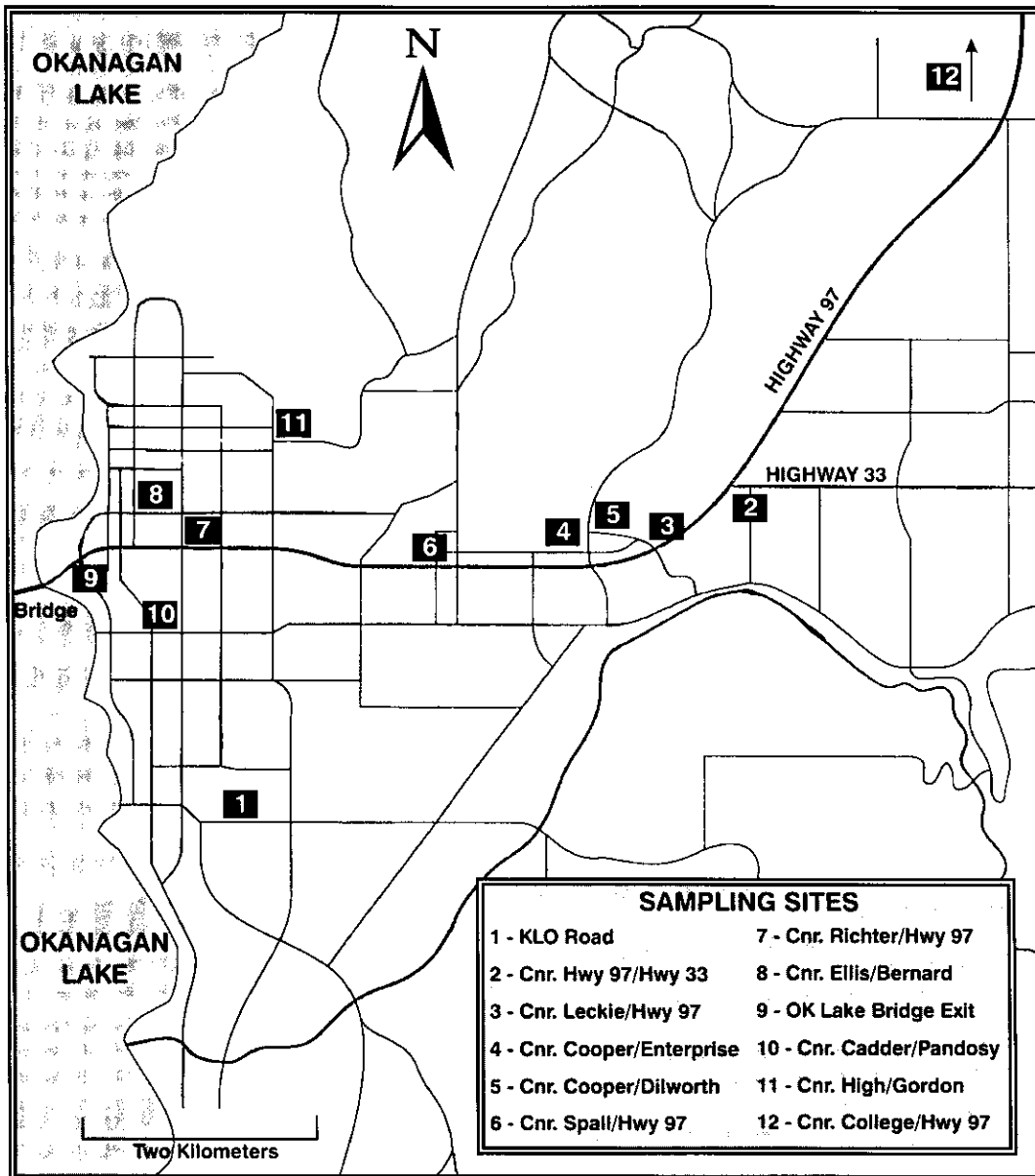


Figure 2. Location of NO₂ sampling sites within the city of Kelowna.

Data Evaluation

As part of a quality assurance and quality control program, the BC Provincial NO₂ monitor at KLO Road is calibrated and checked on a daily basis (Josefowich and Reid 1995). Differences between the Site-1 diffusion tube values and those generated by the monitor were interpreted as being solely due to the inherent inaccuracy of the diffusion

tube method. Comparative data are presented in Figure 3 for 48 sampling periods between June 9, 1994 to June 8, 1995.

For the 48 samples, the mean value obtained by the BC Provincial monitor was 12.0 µg/m³ (SD 3.8 µg/m³) and the diffusion tubes value was 11.6 µg/m³ (SD 4.0 µg/m³). On average the diffusion tube values were 4% lower. The 90

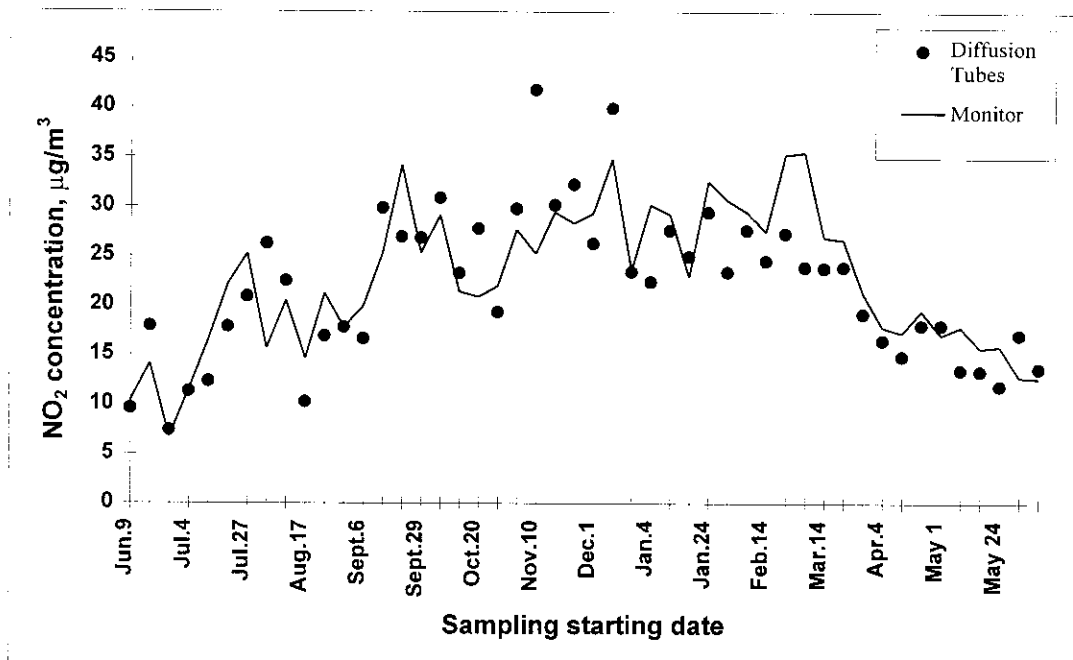


Figure 3. A comparison of the daily average NO_2 concentrations measured at the KLO Rd. sampling site by the BC Provincial Monitor and by the diffusion tube method (this study).

interpercentile range of differences between individual diffusion tube measurements and those generated by the monitor was -25% to +26%. On comparing the values obtained from 46 duplicate pairs of tubes the relative standard deviation was 8.1%. These values compare favorably with passive diffusion tube measurements obtained by Shooter (1993) who quotes an agreement of 15% with other measurement techniques and a precision of 10%, which are of similar magnitude to those reported in other studies (Campbell 1988; Gair et al. 1991; Shooter et al. 1993; Ashenden 1994).

If field blank corrections are included the mean difference decreases from -4% to -15%. Because of this large negative bias, presumably due to leakage and/or contamination, field blank corrections were neglected in subsequent calculations.

Results and Discussion

Table 1 lists the NO_2 concentrations for the 12 sites monitored from June 1994 to June 1995. Gaps in the data are through loss of diffusion tubes, due to their being insecurely attached, or through vandalism (only a minor problem).

From this data set, interpretations are made using (i) the annual arithmetic mean values (AAM), and (ii) the highest sample period values. The AAM values are listed at the foot of Table 1; the highlighted (boxed) values in Table 1 indicate the 3 highest sample period values determined at each site.

The highest AAM values obtained in this study were 49 and 50 $\mu\text{g}/\text{m}^3$ measured at Sites 7 and 6, respectively. Both of these sites are on Highway 97, at two of the city's busiest intersections. These values are lower than the AAM listed as the "Maximum Desirable" Canadian Air Quality Objective for NO_2 of 30 ppbv (about 60 $\mu\text{g}/\text{m}^3$) (Hilborn and Still 1990). They are also substantially lower than the US National Ambient Air Quality Standard (NAAQS) for an AAM listed as 100 $\mu\text{g}/\text{m}^3$ (Nadakavukaren 1995). For comparison, typical AAM NO_2 values are 9 to 15 $\mu\text{g}/\text{m}^3$ for rural areas, 28 $\mu\text{g}/\text{m}^3$ for urban areas (Hewitt 1991) and 85 to 95 $\mu\text{g}/\text{m}^3$ for metropolitan regions, London (Duncan et al. 1987), New York (Goldstein et al. 1988) and Seoul (Nuki 1996).

Relatively high AAM values, from 38 to 46 $\mu\text{g}/\text{m}^3$, were also obtained at other sites on Highway 97 (Sites 2 and 3) as well as sites situated

TABLE 1. Daily average NO₂ concentrations (µg/m³) measured at 12 sampling sites (see Figure 2) Kelowna, BC, from June 1994 to June 1995. The highest 3 values at each site are in bold outline. The final row lists the Average Annual Mean value.

| Start Date | Site 1 | Site 2 | Site 3 | Site 4 | Site 5 | Site 6 | Site 7 | Site 8 | Site 9 | Site 10 | Site 11 | Site 12 |
|------------|--------|--------|--------|--------|--------|--------|--------|--------|--------|---------|---------|---------|
| Jun. 9 | 9 | | | | | | | | | | | |
| Jun. 14 | 9 | | 32 | 32 | 21 | | | | | | | |
| Jun. 22 | 17 | | 41 | 45 | 28 | 62 | 25 | 38 | 51 | 60 | 43 | |
| Jun. 29 | 8 | 21 | 25 | 23 | 13 | 62 | 25 | 38 | 51 | 60 | 43 | 21 |
| Jul. 6 | 8 | 21 | 26 | 26 | 15 | 30 | 9 | 25 | 28 | 38 | 23 | 15 |
| Jul. 13 | 8 | 23 | 34 | 36 | 19 | 40 | 13 | 32 | 43 | 43 | 32 | 23 |
| Jul. 20 | 13 | 34 | 40 | 43 | 21 | 43 | 19 | 40 | 47 | 49 | 41 | 28 |
| Jul. 27 | 17 | 47 | 64 | 64 | 41 | 62 | 30 | 55 | 70 | 66 | 55 | 51 |
| Aug. 4 | 26 | 49 | 47 | 49 | 26 | 45 | 17 | 43 | 57 | 51 | 38 | 36 |
| Aug. 9 | 26 | 43 | 43 | 40 | 30 | 49 | 19 | 47 | 51 | 64 | 32 | 30 |
| Aug. 17 | 9 | 32 | 37 | 34 | 20 | 41 | 52 | 36 | 44 | 50 | 36 | 30 |
| Aug. 25 | 17 | 38 | 44 | 37 | 23 | 47 | 55 | 40 | 45 | 55 | 38 | 30 |
| Sept. 1 | 18 | 39 | 47 | 44 | 26 | 58 | 66 | 48 | 45 | 61 | 44 | 33 |
| Sept. 7 | 17 | 39 | 44 | 43 | 25 | | 54 | 41 | 36 | 50 | | 33 |
| Sept. 15 | 17 | 43 | 46 | 48 | | 57 | 54 | 41 | 36 | 50 | | 39 |
| Sept. 23 | 27 | | 59 | 53 | 39 | 57 | 68 | 53 | 60 | | 56 | 39 |
| Sept. 30 | 27 | 33 | 44 | 37 | 27 | 52 | 0 | 40 | 39 | | 35 | 39 |
| Oct. 7 | 31 | 43 | 48 | 42 | 28 | 50 | 59 | 45 | 42 | | 39 | 29 |
| Oct. 14 | 23 | 35 | 40 | 36 | 23 | 41 | 51 | 36 | 35 | 31 | 33 | 32 |
| Oct. 22 | 28 | 42 | 52 | 43 | 29 | 51 | 54 | 36 | 44 | 35 | 39 | 28 |
| Oct. 29 | 19 | 37 | 40 | 44 | 27 | 49 | 46 | 33 | 32 | 32 | 33 | 32 |
| Nov. 5 | 30 | 50 | 60 | 57 | 32 | 60 | 65 | 46 | 47 | 37 | 43 | 35 |
| Nov. 11 | 42 | 60 | 63 | 62 | 40 | 69 | 72 | 53 | 52 | 55 | 52 | 39 |
| Nov. 18 | 30 | 43 | 54 | 39 | 30 | 43 | 46 | 53 | 62 | 39 | 43 | 32 |
| Nov. 24 | 32 | 54 | 65 | 57 | 37 | 65 | 73 | 55 | 46 | 49 | 48 | 48 |
| Dec. 3 | 26 | 45 | 48 | 44 | 29 | 50 | 60 | 38 | 36 | 36 | 39 | 32 |
| Dec. 13 | 40 | 59 | 68 | 58 | 43 | 79 | 74 | 55 | 49 | 55 | 52 | 45 |
| Dec. 20 | 23 | 51 | 62 | 53 | 34 | 58 | 67 | 48 | 43 | 47 | 41 | 31 |
| Dec. 29 | 23 | 31 | 45 | 35 | 18 | 40 | 48 | 43 | 42 | 34 | 25 | 20 |
| Jan. 5 | 22 | 28 | 43 | 34 | 25 | 38 | 54 | 43 | 33 | 35 | 31 | 25 |
| Jan. 11 | 28 | 37 | 40 | 40 | 31 | 47 | 49 | 38 | 31 | 37 | 35 | 29 |
| Jan. 18 | 25 | 38 | 52 | 43 | 26 | 50 | 61 | 43 | 42 | 39 | 35 | 31 |
| Jan. 25 | 29 | 44 | 53 | 48 | 34 | 47 | 63 | 42 | 35 | 45 | 41 | 34 |
| Feb. 1 | 23 | 39 | 38 | 29 | 27 | 45 | 45 | 37 | 31 | 40 | 46 | 28 |
| Feb. 8 | 28 | 38 | 41 | 33 | 20 | 38 | 45 | 38 | 40 | 38 | 29 | 24 |
| Feb. 15 | 25 | 55 | 56 | 53 | 33 | 61 | 64 | 48 | 42 | 50 | 44 | 32 |
| Feb. 21 | 27 | 54 | 51 | 44 | 29 | 50 | 58 | 44 | 43 | 47 | 37 | 29 |
| Mar. 1 | 24 | 39 | 38 | 36 | 18 | 39 | 45 | 44 | 51 | 46 | 31 | 29 |
| Mar. 8 | 24 | 55 | 57 | 51 | 45 | 60 | 55 | 52 | 54 | 55 | 51 | 38 |
| Mar. 15 | 24 | 42 | 52 | 47 | 35 | 57 | 55 | 48 | 43 | 47 | 44 | 33 |
| Mar. 22 | 24 | 46 | 49 | 43 | 30 | 51 | 56 | 47 | 52 | 50 | 44 | 33 |
| Mar. 29 | 20 | 41 | 42 | 45 | 29 | 52 | 65 | 48 | 42 | 54 | 46 | 26 |
| Apr. 5 | 16 | 41 | 40 | 37 | 25 | 51 | 57 | 42 | 43 | 51 | 42 | 26 |
| Apr. 12 | 15 | 31 | 36 | 36 | 20 | 43 | 45 | 39 | 40 | 41 | 34 | 22 |
| Apr. 20 | 18 | 39 | 39 | 39 | 23 | 49 | 44 | 39 | 51 | 50 | 37 | 23 |
| May 1 | 18 | 34 | 33 | 35 | 24 | 49 | 44 | 39 | 51 | 50 | 37 | 22 |
| May 9 | 13 | 31 | 40 | 37 | 23 | 44 | 48 | 39 | 43 | 49 | 39 | 25 |
| May 17 | 13 | 41 | 45 | 30 | 24 | 48 | 48 | 37 | 44 | 53 | 36 | 25 |
| Jun. 2 | 17 | 39 | 46 | 50 | 31 | 60 | 63 | 46 | 54 | 62 | 46 | 36 |
| Jun. 8 | 14 | 36 | 44 | 41 | 25 | 60 | 63 | 46 | 54 | 62 | 46 | 29 |
| Average | 21 | 38 | 46 | 42 | 27 | 50 | 49 | 43 | 45 | 45 | 38 | 31 |

close to the main commercial and industrial areas (Sites 8, 9, 10 and 11). At Site-12, also on Highway 97, but in a semi-rural area outside of the traffic congestion corridor a lower value, $31 \mu\text{g}/\text{m}^3$, was obtained. The lowest AAM value, $21 \mu\text{g}/\text{m}^3$, was measured at Site-1, adjacent to the KLO Road monitoring station. This is about 40% of the maximum AAM as recorded at Site-6.

At some distance from Highway 97, a decrease in NO_2 concentration is expected, due to less traffic and bulk air motion. This was supported experimentally. Site-3, on Highway 97, had an AAM value of $46 \mu\text{g}/\text{m}^3$; Site-4, one block north of Highway 97, a value of $42 \mu\text{g}/\text{m}^3$; and Site-5, two blocks north of Highway 97, a value of $27 \mu\text{g}/\text{m}^3$.

Maximum sample period values (Table 1) were in the range of 42 to $79 \mu\text{g}/\text{m}^3$, falling well within the guidelines of the BC Air Quality "Maximum Desirable" criterion of $200 \mu\text{g}/\text{m}^3$ for a 24 hour average (Josefowich and Reid 1995). It should be noted that the values quoted in this paper are averaged over the 7 to 10 days required for sampling and are not "true" 24 hour average values.

The highest sample period values were obtained during two time periods, July 27 to August 4, 1994

and November 11 to December 20, 1994. The first period coincided with a large forest fire south of Kelowna which produced a pall of smoke haze for several days. The thick smoke, having reduced the ground level solar intensity, may have interfered with the photochemical breakdown of NO_2 , Equation (3). The second period coincided with an abrupt onset of cold winter temperatures (mean temperatures: October 8.0°C , November -0.5°C) (Environment Canada, monthly meteorological reports 1994) coupled with a period of fairly stagnant air (mean wind speed: November 3.1 km/hr) (Environment Canada, monthly meteorological reports 1994). The lower temperatures would slow down the rate of many of the chemical reactions involved in NO_2 consumption; the static air would trap the NO_2 within the narrow confines of the Okanagan Valley.

The seasonal variation of NO_2 concentrations as measured at two representative sampling sites, Site-1 and Site-6, is compared in Figure 4. Maximum values appear in November and December and minimum values from May through August. On average, winter values are slightly higher than those obtained in the summer. In the summer, although

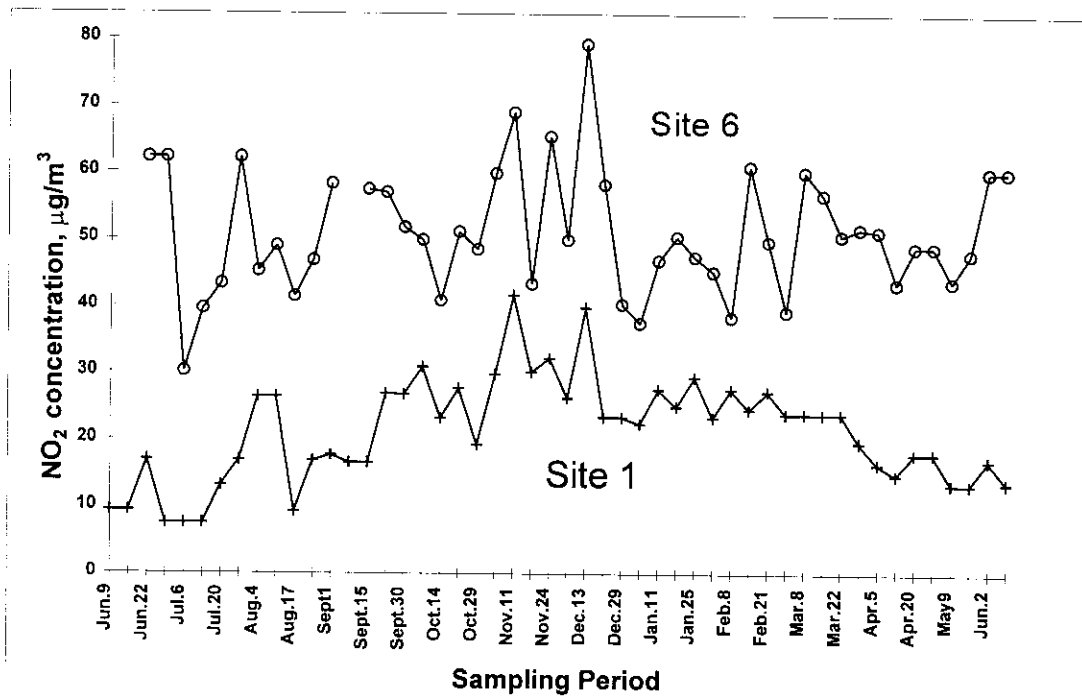


Figure 4. Variations of the daily average NO_2 concentrations as measured at two of the sampling sites. Site-1 (KLO Rd.) recorded the lowest Annual Arithmetic Mean and Site-6 (Chr. Spall/Highway 97) the highest Annual Arithmetic Mean.

there are greater vehicle emissions due to higher traffic flow, the intense sunlight rapidly decomposes the NO_2 , Equation (3). During winter, with fewer hours of sunlight, this photochemistry is not as effective and the NO_2 is not as readily removed. As indicated previously, temperature inversions in winter may also contribute to the higher winter values.

Atmospheric NO_2 also undergoes diurnal variations. Evidence for the role of NO_2 in O_3 formation is shown in Figures 5a and 5b, in which hourly data from the KLO Road monitoring station have been averaged over a one month period. Figure 5a, for August 1994, shows a typical build-up of NO_2 during the morning traffic rush (Wayne 1991; Bunce 1994). Sunlight initiates the breakdown of NO_2 and the formation of O_3 . In the early afternoon, the reaction of O_3 with hydrocarbons and other species dominates the photochemistry. In the early evening, a second traffic induced buildup of NO_2 can be seen. Figure 5b, for November 1994, shows a shape similar to that for the July data, but O_3 production is impaired and the NO_2 concentration remains relatively high, due to the decrease in both sunlight intensity and available hours of sunlight.

Recommendations

Our data provide an important reference point for ambient NO_2 in interior BC. Based on these data, we make the following inferences and recommendations:

- Atmospheric NO_2 concentrations at a number of locations in the city of Kelowna indicate that this gas is not near a critical pollutant level. However, the ability for NO_2 to produce O_3 , particularly during the summer months, is a major concern (Reid 1995).

- The KLO Road atmospheric monitoring station site is about 2 km from the main traffic routes and essentially measures the background concentrations of NO_2 and other gases. The measured spatial distribution of NO_2 indicates that the monitor is not ideally located if peak pollutant values are of interest. This is particularly true for O_3 , as maximum concentrations for this gas are typically found down wind from the source of the primary pollutants. For example, Abbotsford, BC experiences high concentrations of O_3 generated from the NO_x/VOC gases emitted by traffic in Vancouver, BC, which is 50-70 km upwind (Concord Environmental Corporation 1990; Steyn et al. 1990).

- Continued monitoring of pollutant gases such as NO_x , CO and PM_{10} , the initiation of a spatial O_3 monitoring program, combined with a better understanding of the meteorology of the Okanagan Valley is required in order to further evaluate trends of this region's air quality. A data set of appropriate chemical and meteorological parameters could be used to develop a model suitable for predicting future air quality trends for the Okanagan airshed.

- At a local level, air quality concerns have prompted the city of Kelowna to form an Air Quality Technical Steering Committee to address pertinent issues, particularly targeting the problems of inhalable particulates, PM_{10} . The daily publication of an Air Quality Index by the BC Ministries of Environment and Health and a Venting Index by Environment Canada are recent outcomes of this Committee's deliberations. The Regional District of the Central Okanagan is currently preparing a by-law to regulate open burning and the use of wood burning appliances.

- At the Provincial level, in 1995, the BC Government introduced a "Cleaner Vehicles and Fuels - Action Plan" in which auto emission standards and gasoline quality standards, identical to those used in California, will be phased in by 2001. These control strategies, based on limiting VOC and NO_x emissions (Finlayson-Pitts and Pitts 1993; Calvert et al. 1993), are designed to prevent O_3 buildup and smog formation.

One of the authors (GRB) has recently received a grant to construct a portable O_3 monitor (Bognor and Birks 1996). It is intended to use this instrument to carry out spatial and temporal measurements of O_3 , particularly downwind from Kelowna. The development of a passive diffusion tube sampler for O_3 determinations is also being investigated. An additional interest is the unexpected increase in surface concentrations of O_3 during the hours of darkness, 22:00 hours to 5:00 hours, see Figure 5b. As atmospheric O_3 is only generated in the presence of sunlight, a nighttime increase cannot be due to photochemical formation. Unusual upper atmosphere meteorological events may occasionally cause intrusion of stratospheric O_3 into the lower atmosphere. This occurs over a period of a few days when there is gross instability in the jet stream (Steyn et al. 1990) but not when there is ground level stagnant air. In 1994, the nighttime increases in O_3 concentration were observed on 25 of the 30 days in November, as well as for several days in October and December.

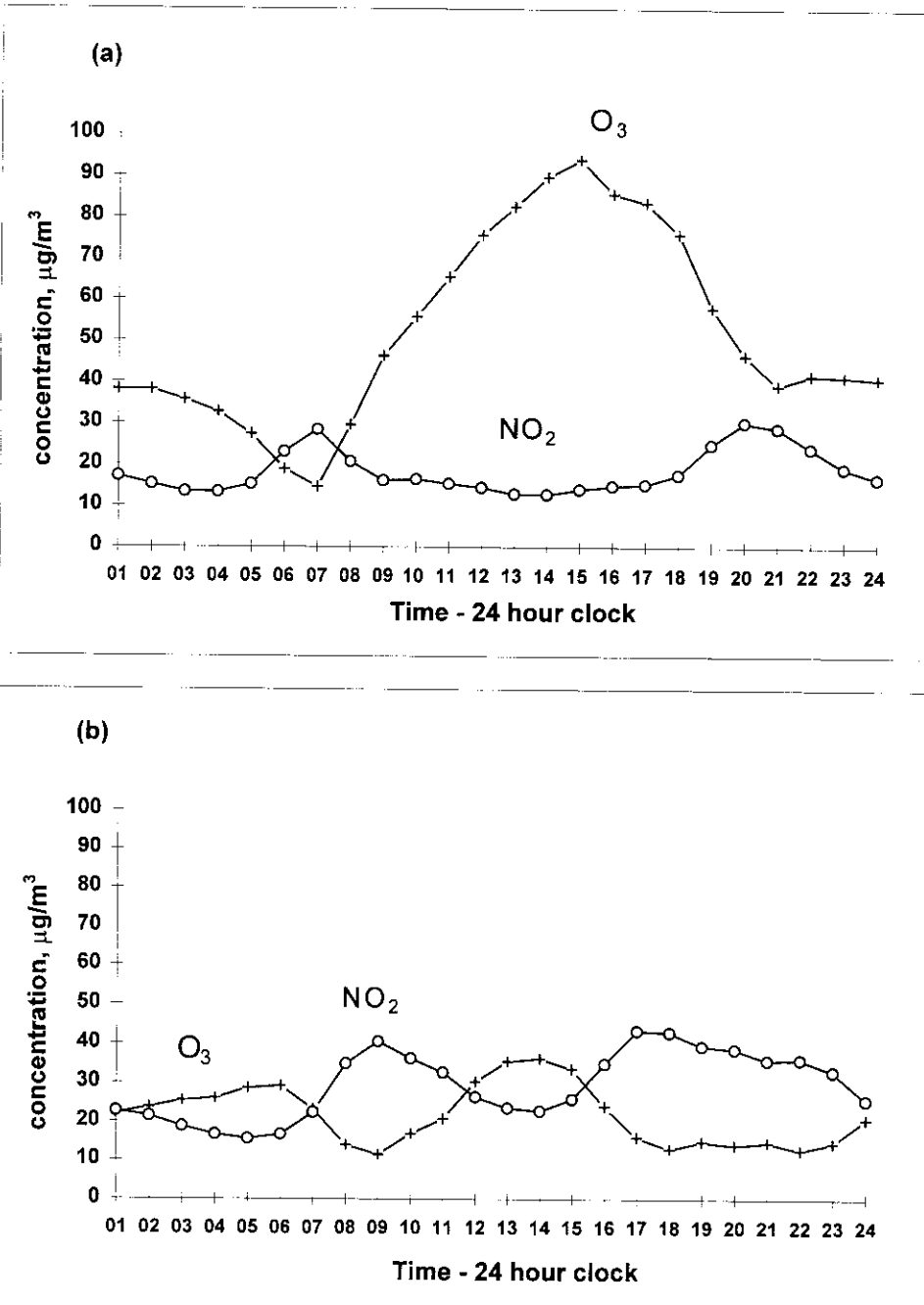


Figure 5. Hourly NO_2 (—o—o—) and O_3 (—+—+—) concentrations, averaged over an entire month, as measured by the BC Provincial Monitor (KLO Rd) for (a) August 1994 and (b) November 1994.

It is possible that daytime O_3 produced at the surface is being convectively transported aloft during daylight hours where it is not encountering sufficient hydrocarbons, sunlight and high enough

temperatures for its efficient removal. This O_3 is then returned to ground level by katabatic winds during the onset of a nighttime inversion. Verification of this mechanism may be established using

the previously mentioned monitor to measure vertical profiles of O₃ concentration.

Acknowledgements

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