FINAL REPORT

VANCOUVER OXIDANT STUDY

AIR QUALITY ANALYSIS

Prepared by

CONCORD SCIENTIFIC CORPORATION

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We acknowledge the willing efforts of the support personnel involved in the preparation of this report.

Claude Davis
Principal Investigator

EXECUTIVE SUMMARY

This report describes an analysis of air quality, meteorological and emissions inventory data as they relate to the oxidants levels in the Greater Vancouver Regional District and Lower Fraser Valley. The study was undertaken in view of the concern over the high ozone levels in the area (some of the highest in Canada) and the regular exceedances of the National Air Quality maximum acceptable ozone level at individual stations.

The primary objectives of the study were to establish an extensive computerized data base with air quality and meteorological data, to determine the relative importance of local precursor emissions and long range transport of pollutants in the resulting high ozone levels (episodes), to characterize the meteorological conditions associated with ozone episodes and to assess the relative roles of precursor emissions in ozone episodes.

As was requested, all the available air quality and meteorological data since 1978 were compiled and organized into a consistent format by establishing an archive. The archive consists of two sets of files - one with records of hourly observations and the other set with

records containing the daily observations. Magnetic tapes of the archived data together with detailed documentation on the format of the tapes have been provided.

Emissions inventory data for the major volatile organics (VOC) and nitrogen oxides (NO_x) sources in the Vancouver area for the years 1972 and 1976 were summarized and projections for 1985 were prepared. Relative to 1976 levels, the projections suggest a 16% decrease in VOC emissions and 25% increase in NO_x emissions. The reduction in VOC emissions is due to the effect of emission control devices on mobile sources. A reactivity classification of 1976 VOC emissions suggest that the reactive VOC are the predominant class and therefore are important in the atmospheric reactions that lead to high ozone levels. It should be noted that existing air quality data provide only total hydrocarbon levels and the absence of data on the ambient levels of reactive hydrocarbons is a deficiency that needs to be redressed in order to better characterize the effects of precursors on ozone formation.

Analysis of the air quality data for the four year period showed that ozone levels increased at some stations but there were no consistent trends for other parameters (NO_2, NO, NO_x Hydrocarbons). The levels of nitrogen oxides generally were lower in the spring and summer months than winter and fall. Total hydrocarbons levels showed relatively less variation throughout the year.

Ozone levels showed strong seasonal dependence with higher levels occurring in the spring and summer months. Ozone station episodes (237 cases with $[O_3] \geq 82$ ppb for 10 or more hours) were identified. Areal episodes (21 cases with station episodes at 3 or more stations on the same day) and persistent episodes (5 cases with areal episodes for 2 or more consecutive days) were also identified. Ozone episodes occurred most often between April and September with most episodes in July and August. During these two months, solar intensity is greatest, and other conditions conducive to the development of land/sea breeze circulation (light gradient winds, relatively large temperature differential between land and water surface) are optimal. The analysis of synoptic weather maps for all episode days showed that the persistent episodes were always associated with a stagnant anicyclonic weather system over the region. There was no indication that long range transport of ozone or its precursors is a factor that contributes to ozone episodes in the GVRD and lower Fraser Valley.

Analysis of the mesoscale meteorological conditions indicated that the sea/land breeze phenomenon was associated with persistent episode days as well as station episode days. More severe episodes in terms of ozone concentrations and duration generally occurred when inland temperatures were higher.

The diurnal variation of ozone levels was such that the peak concentrations occurred most often at 1400 hours, but the peak levels at stations to the east of the GVRD (T10) and in the lower Mainland (Abbottsford (T11) and Chilliwack (T12)) occurred later in the afternoon. This fact together with the wind data implicates the transport of ozone and/or its precursors from the Burrard Inlet area of the GVRD towards the Lower Fraser Valley. The "background" station at Seymour Dam, although exhibiting episodes peaking at ∼ 1400 hours may not be affected by GVRD generated emissions in view of the prevailing winds. The total hydrocarbons from natural sources are likely to be the major contributor to high ozone levels at this station.

Recommendations

This study has clearly identified the important characteristics of high ozone levels in the GVRD and lower Fraser Valley. The occurrence of the high ozone levels in the study area undoubtedly will continue and therefore it is recommended that suitable oxidant control strategies be formulated and implemented.

To achive this objective will require action in two general areas. In the first case there should be some additional work on the meteorology and air quality. Secondly an in depth review of control strategies and the modelling requirements for these strategies is necessary to determine the approach that will best serve the requirements peculiar to GVRD/Lower Fraser Valley region. Specific recommendations in these two areas is as follows:

- Additional analyses of the existing data shown be performed. These analyses should include the development of empirical relationships between ozone and its precursors and selected meteorological parameters, and more detailed analysis of wind data during episodes.

- Continued updating of the air quality and meteorological data archive.

- Establish additional air quality monitoring stations in order to characterize air quality in the southern area of the GVRD and Lower Mainland, and to better characterize the mesoscale transport of pollutants from the GVRD. This requirement should take place in the context of an overall rationalization of air quality and meteorological monitoring objectives.

- Include measurements of ambient levels reactive hydrocarbons (non-methane hydrocarbons).

- Obtain a more detailed understanding of the meteorology associated with episodes. In particular sea/land breeze phenomenon, the local and regional wind fields and the mixed layer depth need to be better characterized by implementing suitable studies.

- The currently available oxidant control strategies and urban air pollution models should be reviewed and assessed. The review and assessment should bear in mind the existing air quality, meteorological and emissions inventory data and the assessment should be based on optimal technical and economic factors.

- The existing emissions inventory data needs to be spatially, temporally and chemically resolved. The provision of such additional data should be consistent with modelling requirements and proposed control strategies.

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1. INTRODUCTION

Oxidant levels in the Greater Vancouver Regional District (GVRD) and Lower Fraser Valley frequently have been in excess of the National Air Quality maximum acceptable level for ozone of 82 ppb. For example, station T7 which has consistently recorded the greatest number of exceedances since 1978, had 134, 84 and 191 exceedances of the maximum acceptable level for ozone in the years 1978, 1979 and 1980. Available data for 1981 showed that 215 exceedances of the maximum acceptable level for ozone occurred at station T7.

There has been substantial local concern over the high ozone levels and the Environmental Protection Service at the request of the GVRD contracted this "Vancouver Oxidant Study". The assessment of the problem and an understqnding of the factors that give rise to or are associated with elevated ozone levels in the study area are essential for the ultimate development of a realistic control strategy.

The primary objective of this study has been to determine if elevated ozone levels result solely from local precursor emissions or whether long range transport of U.S. emitted air pollutants contribute to ozone levels in the study area.

The assessment of the oxidants problem in the Greater Vancouver Regional District (GVRD) and Lower Fraser Valley has been restricted by the lack of a data base in a suitable format although significant amounts of air quality and meteorological data in the area have been available since about 1978. One of the principal objectives of this project has been the establishment of a computerized data base all the Air Quality and Meteorological data available for the GVRD and Lower Fraser Valley since 1978.

The other objectives of this study were as follows:

- To review the available emissions inventory data and prepare projections of emissions for 1985.

- To determine whether elevated ozone levels result from local emissions or from a combination of long range transport of emissions and local emissions.

- To analyze the air quality and meteorological data for the GVRD during the 1978-1981 period.

- To characterize the meso and synoptic scale meteorological conditions associated with elevated ozone levels.

- To characterize the distribution of ozone concentrations in the GVRD and the transport of pollutants from the GVRD to sensitive receptors in the Fraser Valley.

- To determine the relative roles of nitrogen oxides and volatile organics in the formation of ozone.

- To provide recommendations for future air quality monitoring activities, air quality studies, emissions inventory work and oxidant modelling activities that will better characterize the formation and dispersion of ozone in the GVRD.

A comprehensive evaluation to thoroughly satisfy all of these objectives was not possible within the available time and financial constraints. However, it is our view that most of these objectives were met (including the most important) in a comprehensive and satisfactory manner. The extent to which these objectives were met and the manner in which the results are presented in this report are described below.

The acquisition and compilation of the available data and the establishment of the Archive have been comprehensively and completely achieved. The manner in which this was done together with a description of the Archive and recommendations for further work on updating the Archive are presented in Chapter 2.

Comprehensive and complete treatments of the requirements for analyzing the emissions inventory and air qualtiy data have been achieved. The ozone episodes and the synoptic scale meteorological conditions associated with these episodes have also been extensively treated and completely characterized. These aspects are described in Chapters 3 and 4.

The treatment of the mesoscale aspects of ozone episodes has been extensive but represents an area in which the complex topography of the region and the unsuitability of adequate mesoscale transport models have limited the scope and depth of the treatment. Careful examination of the need for additional work in this area is needed and is reflected in the recommendations for future work. It is recognized however that the monitoring network would have been designed to satisfy other air quality monitoring objectives and was not designed specifically to address the oxidant problem in the area. The analysis of the spatial distribution of ozone (and other pollutants) in the GVRD and Lower Fraser Valley has been limited in extent. The treatment for example has not resulted in the generation of isopleth mapping of pollutant levels because of the inappropriate spatial disposition of monitoring stations. Nevertheless, attempts were made to map ozone levels for selected episode days. These maps will illustrate the subjective nature of the preparation of isopleths but nevertheless the maps provide useful indications of the mesoscale factors (wind, temperature, ozone concentrations, transport etc) associated with ozone episodes.

Another area in which the treatment has been limited was the analysis of meteorological and climatological data for the period 1978-1981. This time period is too short to warrant meaningful conclusions being drawn from statistical analysis of meteorological data. However, where appropriate and relevant the necessary statistical analyses of the meteorological data have been performed.

The review of photochemical models on which to base recommendations for future work on model requirements for the GVRD has been limited. This aspect in our view would require a much more extensive and thorough appraisal of the available models and more importantly, an evaluation of the peculiar topographic features of the GVRD in relation to the potential suitability of models for application in the GVRD. The need for further work in this regard is reflected in our recommendations.

The final chapter details the major conclusions of the project and details our recommendations for additional work.

2. DATA ACQUISITION AND MANAGEMENT

The establishment of an Archive containing the available Air Quality and Meteorological data for the GVRD was one of the primary objectives of the study. The sources and format of the data and the manner in which the data were managed to create the Archive and perform data analysis are described in this section. Details of the format and structure of the Archive are presented.

2.1 Air Quality and Meteorological Data Sources

2.1.1 Data from Federal, Provincial or Municipal Government Agencies

Air quality data available for consideration of the oxidants problem in the Vancouver area were acquired from the following sources:

1. GVRD - air quality and wind data from up to 11 monitoring stations.

2. B.C. Ministry of the Environment (BCMOE) - Air quality and meteorological data from two stations (Abbotsford and Chilliwack).

3. Atmospheric Environment Service - Meteorological data from stations in the Vancouver region.

4. Environmental Protection Service (EPS) (Air Pollution Control Directorate (APCD)). Ozone and NO_2 data from NAPS network stations in the GURD.

2.1.2 Other Sources of Air Quality and Meteorlogical Data

A survey of institutions and organizations likely to have acquired air quality data did not reveal any additional sources of air quality data. Potentially useful sources of meteorological data were identified in B.C. Hydro and Power Authority and The University of British Columbia, Department of Georgraphy. In the former case a SF_6 tracer study and dispersion modelling study indicated that limited additional data were available. Meteorological data included mini-sonde data for a limited number of days. These data were examined only in cases for which there was a coincidence of days on which minisonde data are available with ozone episode days.

2.2 Sources of Emissions Inventory Data

Emissions Inventory data were supplied by the Air Pollution Control Directorate (APCD) of the Environmental Protection Services (EPS) of Environment Canada. The data were in the form of tabulated hardcopy pages. Additional material - especially that required for projections, were obtained from a variety of sources. These are referenced in the chapter on Emissions Inventory.

2.3 Format of Air Quality and Meteorlogical Data

The air quality and meteorological data available from the government sources previously identified were acquired for incorporation into the "GVRD Archive". Table 2.1 describes the sources of the data and the format for each type.

2.3.1 Data on Magnetic Tape

The data from the APCD was comprised of O_3 and NO_2 data for those GVRD stations that are a part of the NAPS network. The details of the format of these data are given in Table 2.2. Similarily the details of the data on the tape received from the B.C. MOE are given in Table 2.3. The meteorological data received from the Atmospheric Environment Service (Toronto) were on magnetic tape. The data were in the standard format of the Canadian Climatological Archive.

2.3.2 Hardcopy Data

The hardcopy data were keypunched directly onto a magnetic tape. The following procedures were adopted:

Each hardopy page (containing one month's data for a particular station and parameter) was encoded with the following information.

Table 2.1

Format of Air Quality and Meteorological Data

Source	Data Type	Stations	Format
APCD	Air Quality NO_2, NO_3 only.	T1, T2, T3, T4, T9, T1A	Magnetic Tape
GVRD	Air Quality Wind speed & direction	All "T" Stations, Seymour Dam	Hard copy
BC MOE	Air Quality Wind speed & direction	T11, T12	Magnetic Tape
AES	Meteorological data. Daily record of hourly values and monthly records of daily values	Selected British Columbia stations	Magnetic Tape

Table 2.2

Details of data on Magnetic Tape received from APCD

Tape Density	5250 BPI
Label	Standard IBM label
Record Length	135
Block Size	2700
Tracks	9

Record Details:

Column	Designation	Code	
1, 2	Parameter	06	NO_2
		07	O_3
3, 4	Province Code	10	B.C.
5, 6	City Code	01	Vancouver
7, 8	Location Code	06	T2
		08	T3
		09	T1
		10	T4
		11	T9
		12	T1
9 - 14	Date	YYMMDD	Year, month, day
15	Unused		
16 - 135	Values	24 x 5 hourly values of parameter. Implied decimal XXX.XX units pphm.	

Table 2.3

Details of data on Magnetic Tape received from BC MOE

Tape Density	1600 BPI
Label	Standard DSW = EQU. S310081. S310173. File.
Record Length	149
Tracks	9

Record Details:

Column	Designation	Code	
1 - 4	Blank		
5, 6	Parameter	01	O_3
		02	No data
		03	NO_x
		04	Wind speed
		05	Wind direction
7 - 12	Date	YYYY MM (year, month)	
13 - 19	Station number	0310081 - Abbotsford Airport	
		0300773 - Chilliwack Airport	
20 - 23	Units	PPBV - Parts per billion by volume	
		PPMV - Parts per million by volume	
		KM/H - Kilometers per hour	
		DEGR - Degrees (0-360)	
24 - 25	Day	DD - Day of month 01 - 31	
26 - 145	Hourly mean values	24 values each of 5 columns. Implied decimal between columns 4 and 5. Missing data coded -9999. Data below instrument sensitivity -8888.	

Table 2.3 cont'd

Column	Designation	Code
146 - 149	Daily Average	Implied decimal between positions 143 and 149. Values coded as -8888 and or -9999 are not included in calculation of mean.

a) Page number: A 4 digit number. Each parameter was given a different sequence of numbers.

b) Parameter: A 2 digit number (coded)

c) Year: A 4 digit number. eg. 1978

d) Month: A 2 digit number.

e) Station: A unique 7 digit number for each station.

f) Factor: A 5 digit number to indicate the units and the implied decimal.

These fields were keypunched for each record along with the day of the month, the 24 hourly values and the daily mean. The fields a - f for each record remains the same for each hardcopy page. The first record on each page was verified to ensure the correct entry of the labels a - f.

The records for wind direction of course had no means and were left blank. All the wind data were verified by double entry. The air quality parameters were checked by comparing the keypunched mean with a mean calculated from the punched hourly values. In cases of disagreement, the records were flagged and rekeyed with reference to the appropriate hard copy page.

Notwithstanding the checks and verification procedures, examination of the keypunched data revealed errors of various types. These errors included incorrectly labeled pages and miskeyed fields. The miskeyed fields for the identifier fields (page, number, parameter, year, month, station and factor) were corrected by reference to the hard copy data along with cross tabulations of the numbers of records for each parameter, year, station, month and duplicate records. Final cross tabulations indicate no disconcernable errors due to miskeying of identifier fields.

In the case of the hourly values, the checks involving the comparison of the means while not ensuring absolute accuracy of the data, do provide a cost effective and adequate procedure for keypunching data of this type.

Other difficulties encountered involved the inadvertent duplication of the same data for some stations and months from different sources. For example data for the months September and October, 1981 were received in hardcopy form (and subsequently keypunched) as well as on tapes received from APCD and from BC MOE. Cross tabulation and checking of the complete data set have eliminated these irregularities.

2.4 Establishement of the Archive

The keypunched data along with the tapes provided by BC MOE, AES and APCD were merged and separated into two sets of files. One set of files contain the daily records of hourly values and the other set - consisting entirely of meteorological data - are files with monthly records of daily values. The "Code Book" for the Archive is presented below. The archive was formulated to provide the maximum information available while retaining the greatest amount of familiar features (station numbers, parameter codes, etc).

2.4.1 Format for the GVRD Air Quality and Meteorological Data Archive

The archive consists of two sets of files - one with daily records of hourly values of air quality and meteorological parameters and another with monthly records of daily values of meteorological parameters.

The archive as provided on magnetic tapes has been sorted by parameter and station in chronological order (by year, month, day).

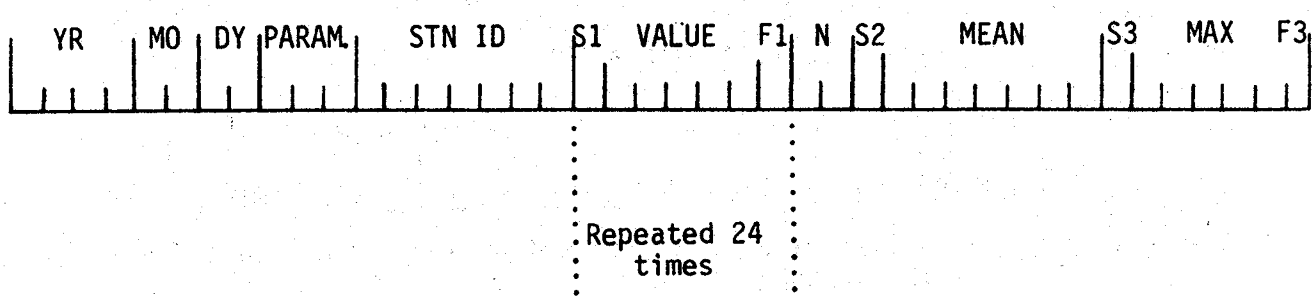
The ordering of the records is as follows:

RECORD NO.	PARAMETER	YEAR	MONTH	DAY	STATION
1	1	1978	1	1	T1
2		1978	1	1	T2
n		1978	1	1	Tn
n + 1		1978	1	2	T1
n + 2					T2
					Tn

2.4.2 Details of Archive

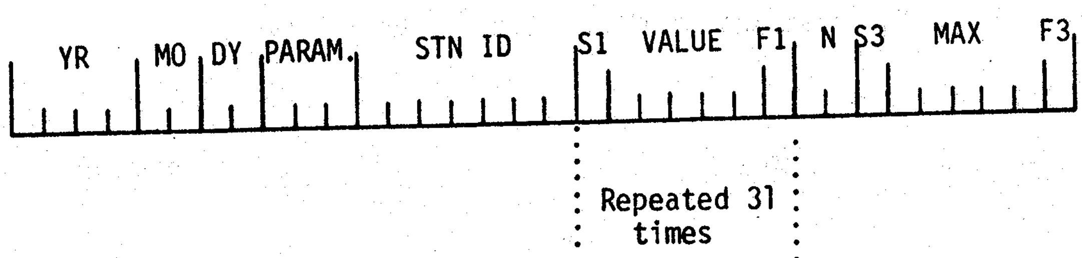
The Format for the Daily Record of Hourly Values is as follows

Record Length = 203



The Format for the Monthly Record of Daily Values is as follows:

Record Length = 244



For the monthly records of daily values, days in excess of the number of days in the month will be coded as -99999M.

Legend

	Length	Field
YR	4	Year e.g. 1978 = 1978
MO	2	Month
DY	2	Day 01 = January etc.
PARAM	3	Parameter. See Table 2.4 for details.
STN ID	7	Station identification. See Section 2.4.3 for details
S1	1	Sign of data value 0 indicates a positive sign - indicates a negative sign > indicates greater than Refers to parameter 206 N Mean not calculated Refers to parameters 133, 156 Note: Monthly records of Daily Values do not include a field for mean.
Value	5	
F1	1	Flag
N	2	number of valid observations
S2	1	Sign of mean

Mean	7	Mean of data values Note: Mean to be calcuated to two additional significant figures.
S3	1	Sign of maximum
Max	5	Maximum data value in record
F3	1	Flag

2.4.2 Additional Field Information

Parameters

The same identification or coding of parameters (elements) as used in the Canadian Climatic Digital Archive has been used.

The additional parameters - i.e. air quality parameters have been coded as detailed in Tables 2.4 and 2.5.

The coding for the parameters incorporate the units. All air quality parameters (except for nephelometer data) are recorded in units of parts per billion.

Table 2.4

Coding for Parameters in the Daily Records of Hourly Values for the GVRD Air Quality and Meteorological Archive.

Parameter Description		Code	Units	Flags
Ozone O_3	O_3	201	ppb	
Nitric Oxide	NO	202	ppb	
Nitrogen dioxide	NO_2	203	ppb	
Total nitrogen oxides	NO_x	204	ppb	
Total hydrocarbons		205	ppb	
Nephelometer or b_{scatt}		206	$10 \times 10^{-4}\ m^{-1}$	
Sea level pressure		073	0.01 Kilopascals	
Dew Point Temperature		074	0.01° C	
Wind Speed		076	km hr^{-1}	
Dry Bulb Temperature		078	0.1° C	
Wet Bulb Temperature		079	0.1° C	
Relative Humidity		080	%	
Hourly Precipitation*		123	0.1 mm	H,I,J
Sunshine*		133	0.1 hrs	E
Wind direction*		156	10's of degrees (36 points)	

*Means for these parameters are not calculated.

Table 2.5

Coding for Parameters in the Monthly Records of Daily Values for the GVRD Air Quality and Meteorological Archive

Parameter Description	Code	Units	Flags
Daily Maximum Temperature	001	0.1° C	E
Daily Minimum Temperature	002	0.1° C	E
Daily Mean Temperature	003	0.1° C	E
Total Rainfall	010	0.1 mm	E,T,C,L,A,F
Total Snowfall	011	0.1 mm	E,T,C,L,A,F
Total Precipitation	012	0.1 mm	E,T,C,L,A,F

2.4.3 Station ID

As far as practicable, the existing station ID's were maintained. The Archive Codes for the various stations are detailed below.

a) All stations listed on Pages 2,3, and 4, Attachement 2: Available Meteorological Data in the RFP. (These stations have 7 column fields).

b) All stations in the NAPS network retained similar coding as detailed below.

GVRD Designation	NAPS Code	Archive Code
T1	100109	0100109
T2	100106	0100106
T3	100108	0100108
T4	100110	0100110
T9	100111	0100111
T1A	100112	0100112

c) For stations operated by the B.C. MOE, the station ID coding is as follows:

GVRD Designation	B.C. Code	Archive Code
T11	0310081	1100030
T12	0310173	0310173

d) Other stations have been coded as follows:

GVRD Designation	Archive Code
T5	0000005
T6	0000006
T7	0000007
T8	0000008
T10	0000010
T13	0000013
Seymour Dam	0000040

2.4.4 Value Field (Including S1 and F1)

The fields S1, Value and F1 are initialized to -99999M. Missing data are indicated by -99999M. Data having a value of zero are indicated by 000000ꝺ where ꝺ designates a blank column. The Flag F1 (as well as F3 - see Section 2.4.7 Fields for S3, MAX F3) is used as follows:

Flag	Definition	Relevant Parameters
blank	Valid data	all parameters
A	Accumulated amount. Previous value C or L.	010, 011, 012
C	Precipitation occurred, amount uncertain Value is 0.	010, 011, 012

E	Estimated	all
F	Accumulated and estimated	010, 011, 012
H	Freezing	123
I	Unadjusted	123
J	Freezing and unadjusted	123
L	Precipitation may or may not have occurred. Value is 0.	010, 011, 012
M	Missing	all
T	Trace. Value is 0.	010-013

2.4.5 N

This field contains the number of valid observations in the record.

2.4.6 Fields S2, MEAN

The field for S2 will have the same qualifications as S1.

The mean for the N observations in the daily record were included but calculated to two additional significant figures, ie., the 7 column field MEAN is xxxxx.xx.

2.4.7 The Fields S3, MAX, F3

The fields S3 and F3 have the same qualifications as S1 and F1.

Note that for the MAX, MEAN and VALUE, the units are the same as implied in the element number.

2.5 Recommendations for Updating Archive

Before additional air quality and meteorological data are entered into the archive the prescribed set of quality control and quality assurance procedures should be followed. The conclusions and decisions arrived at by analyzing and interpreting the data can only be as good as the quality and reliability of the data.

A detailed exposition of precise recommendations for QA/QC procedures is beyond the scope and terms of reference of this project. However, some general and in some cases, specific recommendations for establishing adequate quality of the archive will be presented.

The data in the archive is currently obtained from three networks operated by Municipal (GVRD), Provincial (BC MOE) and Federal (AES) levels of government. For the followoing discussion it will be assumed that the agencies (GVRD, BC MOE and AES) will continue to operate their respective networks and therefore be able to provide the archive with the same range of parameters. The continual addition to or updating of the Archive or its expansion to include other parameters or additional stations will require the following.

A) The establishment of formal relationships between the agencies contributing to the data in order to efficiently update and maintain the archive.

B) The implementation of consistent quality control and quality assurance procedures in cases where the same parameters are monitored by different agencies.

C) The establishment of procedures for the continual updating of the archive.

D) The provision of continual evaluation and analysis of the data to ensure optimal network operation that is consistent with air quality objectives.

3. EMISSIONS INVENTORIES

Emissions inventories exist for the Vancouver Metropolitan Area for 1973 (Lynch et al, 1974) and 1976 (as part of the National Emissions Inventory System, NEIS). For the purposes of this study the species of interest are volatile organic compounds (VOC) and oxides of nitrogen (NO_x). The emissions data pertaining to these two species are given in Table 3.1 with emissions broken down by source category as defined by NEIS. Those sources which emit essentially no VOC or NO_x have been omitted.

The categories considered by Lynch et al (1974) do not completely overlap with those of NEIS - the latter being more detailed. In the case of point sources, the 1973 emissions inventory was largely based on permits issued under the Pollution Control Act of 1967 and therefore generally reflects the maximum rather than the actual emissions from these sources. Further, the permit issuing process was not complete at that time. The 1973 emissions inventory is therefore subject to considerably larger uncertainties than that for 1976.

One amendment has been made to the NEIS data for 1976 and relates to mobile sources. In this category the emission figures supplied by the Mobile Sources Division of APCD are preferred (Dann, 1982). The NEIS data for Vancouver were obtained from an emissions inventory for the Province of Brithish Columbia by scaling according to population, which does not refelect the very different distributions by vehicle type between the province as a whole and the metropolitan area.

Also included in Table 3.1 is a projection of the emissions data to 1985. It must be recognised that this projection is based on estimates of likely growth in a number of sectors, and is subject to considerable uncertainty. The details of how this projection was carried out are given below.

The data for mobile sources were provided by the Mobile Sources Division, APCD, and is based on a number of vehicle operating parameters (eg. average speed, fleet age distribution, etc) using vehicle population figures from Census Canada. Note the projected decrease in VOC emissions resulting from installation of pollution control equipment. Included among these data are totals for vehicle miles travelled for 1976 to 1985, which were used to scale the hydrocarbon emissions relating to tire wear.

Dry cleaning, fuel wood combustion, residential heating, incineration and structural fires were assumed to scale linearly with population. Estimates of population growth were obtained from GVRD population projections (Mennell, 1982). These are based on three scenarios resulting in "Low", "Medium" and "High" projected populations. Because of the current depressed state of the economy the emissions inventory was scaled according to the "Low" figure. Thus a 1976 population of 1,085,000 is assumed to increase to 1,159,000 by 1985, an increase of 6.5%.

Table 3.1

Vancouver Emissions Inventory for Volatile Organic Compounds and Oxides of Nitrogen (tonnes/yr)

Source Sector	1972 VOC	1972 NO_x	1976 VOC	1976 NO_x	1985 VOC	1985 NO_x
Application of surface coatings	5729 (solvent usage)		7739	-	9380	
Diesel oil marketing	3910 (evaporation of gas)	-	139	-	11100	
Gasoline marketing			10924	-		
Diesel Powered Vehicles						
Heavy duty trucks & buses			400	2300	600	4000
Other (construction equipment)			1000	11900	1210	14420
Dry cleaning			1504	-	1600	
Stationary Combustion Sources						
Commercial			94	2067	114	2505
Power generation			100	1153	100	1150
Fuelwood combustion	1006	10069	93	1	100	1
Industrial			121	8298	147	10060
Residential			153	1961	160	2090
Total			561	13480	621	15806
Gasoline Powered Vehicles	(Includes diesel)					
Automobiles	49559	24229	32400	18100	14600	17600
Heavy-duty trucks	17621	9471	2600	1700	3700	2600
Medium duty trucks	-	-	2600	2300	3100	3700
Light duty trucks	4075	2093	2700	1900	1900	2400
Total	71255	35793	40300	24000	23300	26300

Table 3.1 (cont'd)

Source Sector	1972 VOC	1972 NO_x	1976 VOC	1976 NO_x	1985 VOC	1985 NO_x
Non-highway use of gasoline	-	-	2161	1219	2620	1480
Off-highway mobile sources						
Aircraft	336	242	478	402	770	650
Marine	-	-	228	345	360	540
Railroads	-	-	1786	7217	3020	12210
Total			2492	7964	4150	13400
Petroleum refining						
Fuel combustion & incineration	1617	4523	157	1942		
Process			11588	367		
Total			11745	2309	11750	2310
Sewage Sludge incineration	108	108	1	3	1	3
Commercial & Industrial Incineration			14	45	15	50
Structural fires	-	-	342	-	360	-
Tire wear			32	-	46	-
Grand Total	83961	50735	79354	63220	66752	77769

The sectors corresponding to application of surface coatings, commercial and industrial fuel combustion and off-highway use of gasoline and "other" diesel powered engines were assumed to scale with economic growth in the area. Employment was taken as an indicator of the state of the local economy, and GVRD figures are used again (Mennell, 1982). Thus a labour force of 519,000 in 1976 is expected to increase to 629,000 in 1985. This is a 21% increase.

Information on aircraft sources was supplied by the Air Planning and Programming Division of Transport Canada In Vancouver (Hosgood, 1982). It was assumed that the figures for Vancouver International Airport are representative of those for the Vancouver Metropolitan area as a whole, and that the "medium" forecast (as opposed to "high" or "low" made by Transport Canada was appropriate. The resulting data for aircraft movements are summarised in Table 3.2.

These data correspond very well to a linear dependence of movements on year, from which a 1985 value of 350,000 was interpolated. To relate this to emissions for 1985 the assumption must be made that the relative number of different types of aircraft remains approximately constant between the two years. Thus, for example, if there were a large increase in movements of wide bodied aircraft (Boeing 747, DC 10, etc.) in 1985, as compared with 1976, with an accompanying decrease in movements by single engined aircraft, the emissions in 1985 would increase by substantially more than the figures for movements would suggest. However, aircraft are a relatively small source of NO_x and VOC, so this possibility does not introduce significant uncertainties in the emissions inventory as a whole.

Table 3.2

Aircraft Movements: Vancouver International Airport

Year	Movements	
1973	167,837	Actual
1974	180,759	
1975	198,416	
1976	211,102	
1977	232,211	
1978	246,740	
1980	279,130	Forecast
1982	309,730	
1984	336,990	
1986	361,350	

Figures for Marine and Railroad emissions were derived from information contained in a draft report supplied by the Economic and Regional Analysis Branch of Transport Canada in Ottawa (Roy, 1982). For both rail and marine traffic this report gives loadings (in millions of tonnes) for 1978 and 1985, broken down on a regional basis. Also given are growth rates for varous time periods. The growth in traffic quoted for 1973 to 1978 was used to calculate the loadings and unloadings in 1976. The actual figures for rail traffic are given in Table 3.3.

In deriving the 1985 projected emissions for the Vancouver Area it was assumed that emissions could be scaled linearly as the sum of loadings and unloadings, and that the rate of growth in Vancouver was the same as that for the province as a whole.

The corresponding figures for marine traffic are given in Table 3.4.

It can be seen from Table 3.4 that the amount of loading substantially exceeds the unloading. The scaling of emissions for projection to 1985 was based, in this case, on loadings alone, on the premise that this dictates the volume of marine traffic using the port facilities. The assumption has again been made that emissions scale linearly as the freight tonnage, and that the figures for the whole province are representative of those for Vancouver.

Table 3.3

Growth in Rail Traffic in British Columbia

	Loadings	Unloadings
1985 (10^6 tonnes)	53.9	77.6
1978 (10^6 tonnes)	34.1	48.4
Growth 1978-8 (%)	2.8	3.0
1976 (10^6 tonnes)	32.2	45.5

Table 3.4

Growth in Marine Traffic in British Columbia

	Loadings	Unloadings
1985 (10^6 tonnes)	86.2	20.9
1978 (10^6 tonnes)	56.2	20.8
Growth 1973-8 (%)	1.2	0.9
1976 (10^6 tonnes)	54.9	20.4

Pollutant emissions relating to electric power generation in the Vancouver area are relatively small. The only thermal generating station in the area is the Burrard Thermal Generating Plant (BTGP). Historically it has been used solely for standby, emergency purposes, and it is expected to continue in this role in the future (Forrest, 1982). No increase in emissions is therefore expected for 1985.

The Petroleum Association for Conservation of the Canadian Environment (PACE) was approached in an attempt to obtain projected values for emissions relating to the petroleum industry. Unfortunately it appears that no such projections are available. The only literature which has any bearing on the subject (PACE, 1980) reveals that NO_x emissions from British Columbia refinery operations were increased by 10% between 1973 and 1978, but that hydrocarbon emissions were reduced by almost 70% in the same period as a result of the implementation of hydrocarbon control programs. This downward trend is therefore not expected to continue. A PACE report concerned with fugitive emissions associated with diesel and gasoline marketing has not yet been published.

The expected 1985 emissions for the Petroleum Industry have therefore been entered in Table 3.1 as being equal to the 1976 values, noting that the associated uncertainties are large.

Because of their importance in the photochemical processes producting NO_2 and ozone, emissions of volatile organic compounds have been subjected to further scrutiny. The various organic species differ greatly in their reactivity as measured, for example, by their ability to promote ozone production in an irradiated atmosphere containing NO. The 1976 emissions of VOC were therefore broken down by chemical class (Table 3.5) and reactivity (Table 3.6) for each source sector.

These breakdowns were carried out by assuming that the percentage of emissions falling into each class is the same in Vancouver as in Canada as a whole. These percentages are given by Kolomeychuk et al (1981), who also presented a similar breakdown for each province. However, it was felt that the breakdown for British Columbia was less likely to be representative of that for Vancouver than was the breakdown for Canada. The main reason for this is that the forest industry is a large source of hydrocarbons in the province, but not in the city, and the breakdown by class and reactivity for such hydrocarbons is very different from that expected for urban emissions.

The reactivity categorization used in Table 3.6 is as listed in Table 3.7, with the addition of class 0, containing methane which is considered nonreactive, and class 6 containing unidentified compounds. or those of unknown reactivity. Class 1 is least reative, Class 5 most reactive.

Table 3.5

Breakdown of Vancouver 1976 VOC Emissions by Chemical Class (tonne/year)

	Class									
Sector	Paraffins	Olefins	Aromatics	Carbonyls	Methane	Oxygenated Compounds	N containing Compounds	Halogenated Compounds	Other	Unidentified
Application of surface coatings	3083	-	706	1409	-	2455	29	-	57	-
Diesel oil and gasoline marketing	1280	620	105	-	-	-	-	-	-	9058
Diesel powered engines	850	206	59	170	62	-	-	-	53	-
Dry cleaning	361	-	-	-	-	-	-	1143	-	-
Stationary fuel combustion										
Commercial combustion	31	-	4	24	35	-	-	-	-	-
Power generation	56	9	1	6	26	-	-	-	1	1
Fuelwood combustion	12	11	14	4	14	33	-	-	5	-
Industrial combustion	38	-	1	61	21	-	-	-	-	-
Residential Combustion	43	-	2	32	21	7	-	-	21	27
Gasoline powered motor vehicles	14556	8923	7661	2372	4422	-	-	-	2365	-
Non-highway use of gasoline	603	612	482	102	164	-	-	-	199	-

Table 3.5 (cont'd)

Breakdown of Vancouver 1976 VOC Emissions by Chemical Class (tonne/year)

	Class									
Sector	Paraffins	Olefins	Aromatics	Carbonyls	Methane	Oxygenated Compounds	N containing Compounds	Halogenated Compounds	Other	Unidentified
Off-highway mobile sources										
Aircraft	88	213	141	6	10	9	-	-	12	-
Marine	70	62	47	12	17	-	-	-	20	-
Railroads	1084	262	75	218	79	-	-	-	68	-
Petroleum refining	9227	70	444	846	1131	1	-	-	26	-
Incineration	3	2	-	3	2	-	-	-	4	-
Sewage sludge incineration	-	-	-	-	1	73	-	-	-	-
Structural fires	58	44	28	37	45	-	-	-	57	-
Tire Wear	3	5	1	-	-		-	-	-	23

Table 3.6

Classification of Vancouver 1976 VOC Emissions by Reactivity (tonne/year)

Class	0	1	2	3	4	5	6
Applic. of Surface Coating	0	778	158	4992	1565	241	6
Diesel & Gasoline Marketing	0	31	0	1274	80	620	9058
Diesel Powered Engines	62	85	0	844	29	379	0
Dry cleaning	0	0	0	361	1143	0	0
Fuel Comb - Stationary							
Commercial Fuel Comb.	35	9	0	29	1	21	0
Electric Power Gen.	26	22	0	38	0	13	1
Fuelwood Comb.	14	42	0	14	6	11	5
Ind. Fuel Comb.	21	30	0	31	0	39	0
Res. Fuel Comb.	21	16	0	39	1	31	45
Gasoline Powered Motor Veh.	4422	3963	0	13914	5914	12061	0
Non-highway use of gas (Off road use of vehicles)	164	298	0	588	353	758	0
Off highway mobile sources							
Aircraft	7	131	0	25	149	160	6
Marine	17	30	0	69	34	78	0
Railroads	79	109	0	1077	37	483	0
Point Source							
Pet. Ref.	1131	1548	0	7933	267	862	4
Sewage Sludge Incineration	1	0	0	0	0	0	0
Solid Waste Incineration (Ind. & Comm.)	2	6	0	3	0	3	1
Structural Fires	45	134	0	59	14	52	38
Tire Wear	0	0	0	4	0	5	28
Total	6047	7232	158	31294	9620	15817	9192
% of Total	7.6	9.1	0.2	39.4	12.1	19.9	11.6

Table 3.7

Reactivity Categorization of Organic Compounds
(After Trijonis et al, 1978)

Class 1	Class 2	Class 3	Class 4	Class 5
C_1-C_3 paraffins	Mono-tert-alkyl benzenes	C_4+ -paaffins	Prim-& sec-alkyl benzenes	Aliphatic olefins
Acetylene	Cyclic ketones	Cycloparaffins	Dialkyl benzenes	α-methyl styrene
Benzene	Tert-alkyl acetates	Alkyl acety-lenes	Branched alkyl ketones	Aliphatic aldehydes
Benzaldehyde	2-nitropropane	Styrene	Prim-& sec-alkyl alcohols	Tri-& tetra-alkyl benzenes
Acetone		N-alkyl ketones	Chellosolve acetate	Unsaturated ketones
Tert-alkyl alcohols		Prim-& sec-alkyl acetates	Partially halo-genated olefins	Diacetone alcohol
Phenyl acetate		N-methyl pyrrolidone		Ethers
Methyl benzoate				Cellosolves
Ethyl amines		N,N-dimethyl acetamide		
Dimethyl formamide				
Methanol				
Perhalogenated hydrocarbons				
Partially halogen-ated paraffins				

4. DATA ANALYSIS

4.1 Methodology

The analysis and interpretation of air quality and meteorological data have been carried out at two levels. In the first case, the complete data set (Archived data) of air quality data are summarized and described in terms of the temporal variation of each parameter and a limited treatment of the spatial variation of the parameters. In the absence of information on sources of specific pollutants, the analysis of the spatial distribution of pollutants has been limited to a preliminary analysis of relative levels at various stations. The stations in the GVRD are heavily concentrated around the Burrard Inlet in a relatively narrow band with an east-west axis. Any attempts to construct isopleths describing areas with similar concentrations would be subjective. It is however conceivable that attempts could be made to utilize available computerized approaches to construct isopleths for air quality data. However in analyzing the ozone episodes, manual attempts at constructing isopleths have been made and only serve to provide a preliminary picture of the areal distribution of ozone levels as well as to depict the associated wind information.

In the second level, the ozone episodes are defined and the episodes examined in detail. The features of ozone episodes are first identified and characterized. The relationships between ozone and its precursors are briefly examined. The meteorological features that are associated with the ozone episodes are identified and then the interrelationships between the air quality and meteorological parameters are identified. The associated emissions inventory information and established photochemical mechanisms for ozone formation will be considered in order to rationalize the data and allow the formulation of recommendations for future activities to further characterize or control the oxidants in the GVRD area.

In order to perform these analyses, several tabulations and other manipulations of the data set were performed. In view of the time and data processing constraints it was necessary to perform these manipulations on discrete files of data from four sources (EPS, GVRD, BCMOE and AES) rather than on a single merged file consisting of the full archive. A tabulation of the computer analyses performed is given in Table 4.1. All these computer outputs are available as supplementary material and are not included in the report except where relevant.

In discussing the air quality and meteorological data reference to particular monitoring stations will be made using the original GVRD designations (numbers prefixed by T). The data from computer listings however utilized seven digit identifiers for stations. For convenience the correspondence between the GVRD "T notation" and

Table 4.1

Listing of Computer Analyses Performed on GVRD
Air Quality and Meteorological Data

NO.	
1	AES Listing for Episode Days Parameters 73, 74, 76, 78, 79, 80, 156.
2	AES Listing for Episode Days Parameters 69, 70.
3	AES Listing for Episode Days Parameter 133.
4	GVRD1, GVRD2A, GVRD2B, BCMOE Ozone Station Episodes.
5	Ozone Episodes - GVRD1, GVRD2A, GVRD2B, BCMOE O_3 Max, Daily Mean, HRMAX.
6	GVRD2 Listing for Parameter 206 (Nephelometer) for Episode Days.
7	GVRD2 Listing for Parameter 204 (Total Nitrogen Oxides) for Episode Days.
8	GVRD2 Listing for Parameter 201 (Ozone) for Episode Days.
9	GVRD2 Listing for Parameter 202 (Nitric Oxide) for Episode Days.

Table 4.1 (Cont'd)

NO.	
10	GVRD2 Listing for Parameter 203 (Nitrogen Dioxide) for Episode Days.
11	GVRD1 File Parameter NO_2 for Episode Days.
12	GVRD1 File Parameter O_3 Episode Days.
13	BC MOE Listing for Episode Days Parameter 76, 156, 201.
14	GVRD2B Listing for Episode Days Parameter 76, 156.
15	AES Parameter 123 Listing for Episode Days
16	Wind Direction Report BC MOE Episode Days (Three most frequently occurring directions and their frequency on episode days).
17	Wind Direction Report BC MOE (Three most frequently occurring directions and their frequencies on episode days).
18	Seasonal Report for GVRD1 File.
19	Annual Ozone Report For GVRD1 File by Station.
20	GVRD2 Listing for Parameter 205 (Total Hydrocarbons) for Episode Days.
21	Wind Directions for Episode Days, Day Hours and Night Hours for Episode Days.

Table 4.1 (Cont'd)

NO.	
22	Monthly Summary for NO_2 Parameter 203 (No. of Hours, Monthly Mean, % Obs., Max. 1 Hr., Max. 24 Hr., No. of Hrs > Accept. (1 Hr and 24 Hr.)
23	Monthly Summary for NO Parameter 202.
24	Means for Episode Days Parameter 203 NO_2 at Selected Stations.
25	Cross Tabulations of Keypunched Wind Data. Listing of October - November 1981 Data.
26	Monthly Summary for Ozone Parameter 201 Statistics.
27	Monthly Summary for NO_x Parameter 204.
28	Monthly Summary for HC Parameter 205 Statistics. No. Hours, Mth. Mean, Obs. Perc., Max 1 Hr., Max 24 Hr.
29	Means for Episode Days NO Parameter 202.
30	Monthly Summary for HC/Parameter 205 Hourly Means for Each Month.
31	Monthly Summary for NO_x Parameter 204 Hourly Means for Each Month.
32	Monthly Summary for NO_2 Parameter 203 Hourly Means.
33	Monthly Summary for NO Parameter 202 Hourly Means.
34	Annual Summary for NO_x Parameter 204.

Table 4.1 (Cont'd)

NO.	
35	Seasonal Summary for NO_x Parameter 204.
36	Annual Summary for NO Parameter 202.
37	Seasonal Summary for NO Parameter 202.
38	Annual Summary for NO_2 Parameter 203.
39	Seasonal Summary for NO_2 Parameter 203.
40	Annual Summary for HC Parameter 205.
41	Seasonal Summary for HC Parameter 205.
42	Hourly Means for Episode Days Parameter 205 HC Selected Stations.
43	Hourly Means for Episode Days Parameter 204 NO_x Selected Stations.
44	Monthly Summary for Ozone Parameter 201 Statistics. No. Hours, Mth. Mean, Obs. Perc., Max. 1 Hr., Max 24 Hr., N. Desir., N. Accept., N. Tot.
45	Annual Summary for Ozone Parameter 201.
46	Seasonal Summary Report for Ozone Parameter 201.

Table 4.1 (Cont'd)

NO.	
47	Wind Direction Frequencies for All Day, Night and Daylight Hours Selected Stations. All Available Data by Year and For All Years.
48	Wind Direction Frequencies for Night Hours by Year for Selected Stations.
49	Wind Directions for All Dates, All Hours, Day Hours, Night Hours. All Dates by Year.
50	Ozone Data for All Stations, Episode Days Only.
51	Frequencies of Hours of Maximum Ozone Levles for Episode Days.
52	Multiple Linear Regression Statistics No. 1.
53	Wind Directions for Episode Dates Selected Stations. All Hours, Day Hours, Night Hours.
54	Hourly Means for Episode Days Parameter 204.
55	Check on Duplicate Records for Parameter 203.
56	Check on Wind Data Records For Duplication.
57	Listing of Available Wind Data for Episode Days Selected Stations 7, 110, 106, 844.

Table 4.1 (Cont'd)

NO.	
58	Check on Ozone Data for Duplicate Records
59	Check on Wind Data for Duplicate Records No. 2.
60	Check on Wind Data for Duplicate Records No.3.
61	Monthly Ozone Report for GVRD1 File N.Days, Mth. Mean., Max. 24 Hr., No. Exceedances.
62	Multiple Linear Regression No.2.
63	AES Listing. Stn. 1108447 V. Intl. Airport (WD, WS, Temp., R.H., Total Cloud)
64	AES Listing Stn. 1100030 Abbotsford Airport (WD, WS, Temp., R.H., Total Cloud)

the Archived designators of stations is reproduced (Table 4.2). The station at Seymour Dam which does not have a "T" designation will be referred to as "40" an abbreviation of the Archive number "0000040". Figure 4.1 shows a map of the GVRD and the locations of the various stations.

4.1.1 Description of Monitoring Stations

Most stations are located around the Burrard Inlet in an East-West alignment. All but three stations are near water bodies, (sea, Fraser River or a lake) and are at low level except for T4, 85 m above mean sea level (amsl), T7 - 40 m amsl and T7 ∿160 m amsl.

The characteristics of each station are briefly described below:

T1 - central urban site. Automobile emissions likely to be dominant. Plenty of greenery in the immediate vicinity of the sensors.

T2 - mixed residential (single family and duplex), park, light industrial (brewery, warehousing) and small office.

T3 - mixed industrial (liquid oxygen bottling plant, hydro substation, iron works, sawmill). Near Fraser River.

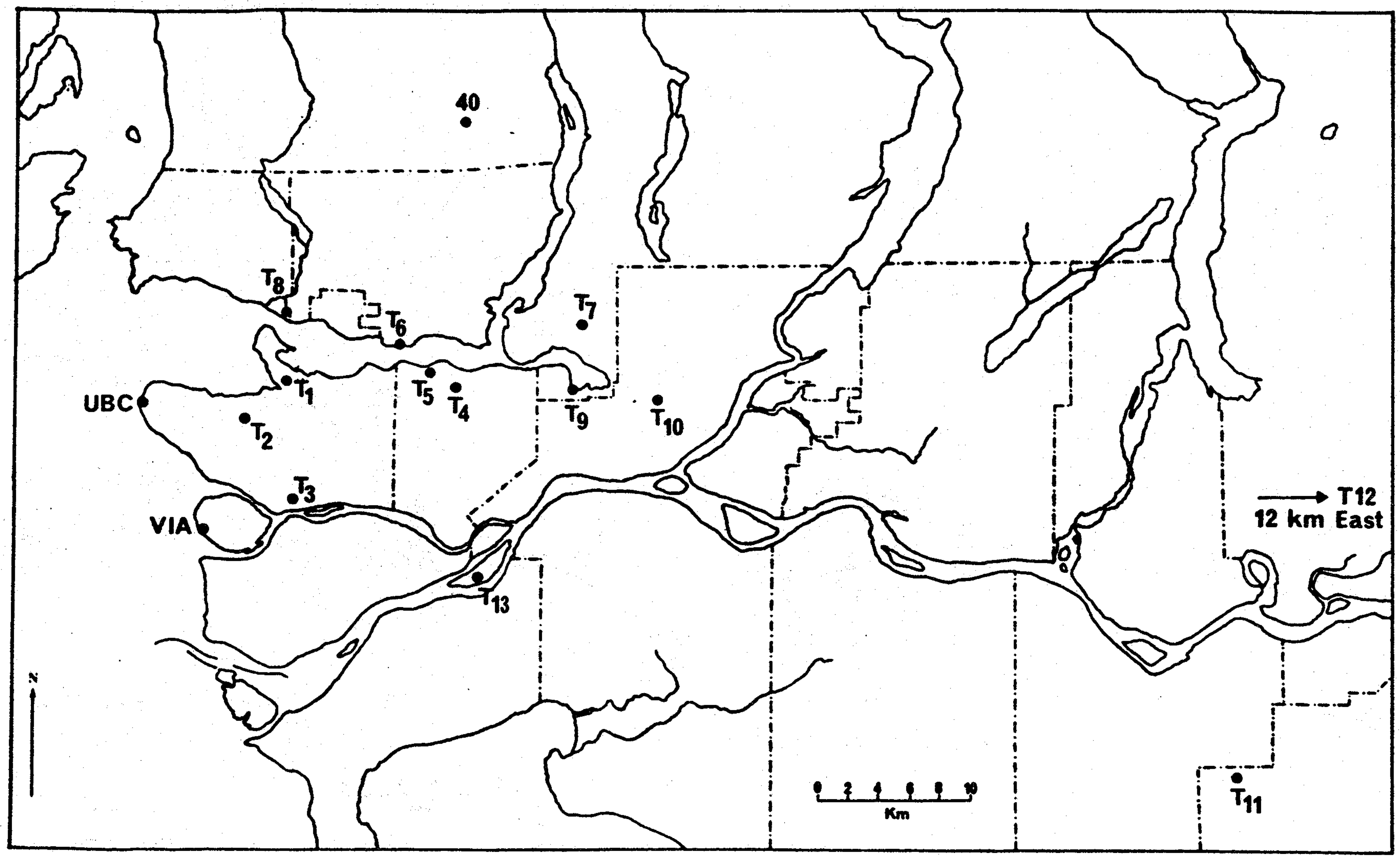
Table 4.2

Station Identification Used In Text

GVRD Description	Location	Archive Code
T1	BC Hydro Park	0100109 *
T1A	BC Hydro Park	0100112
T2	GVRD Office	0100106
T3	Manitoba Works Yard	0100108
T4	Kensington Park	0100110
T5	Confederation Park	0000005
T6	GVRD Beach Works	0000006
T7	Anmore Elemen. Sch.	0000007
T8	Lions Gate STP	0000008
T9	Rocky Point Park	0100111
T10	Dept. of Highways	0100010
T11	Abbotsford Airport	1100030
T12	Chilliwack Airport	0310173
T13	Annacis Island STP	0000013
40	Seymour Dam	0000040

* Similar but not identical location as of April 1980. Identified as T1A (GVRD) and 0100112 (Archive Code)

4.1 MAP OF GVRD SHOWING LOCATION OF MONITORING STATIONS



T4 - site at school in a park and residential area. Within few hundred metres of Hastings highway and within 1 kilometer or so of Shell refinery. Station is elevated $\sim$ 85m amsl and about 40m above the refinery.

T5 - park with residential surroundings. Hastings St. 1 block to S and Chevron refinery few blocks to N but depressed by $\sim$ 40m.

T6 - mixed industrial (shipyards, warehousing, paint and sand-blasting shop, cement mixing, Hooker Chemical plant). Close to harbour and fairly open.

T7 - school in mixed coniferous/deciduous woodland with a few scattered houses. Ioco refinery and Burrard Thermal Generating Plant to the W. Elevation $\sim$ 160m amsl.

T8 - open flats under Lions Gate Bridge. Sewage treatment plant, harbourside storage, trees. Virtually at sea level and extremely exposed to wind. Bridge span is almost fully elevated above.

T9 - park by waterside. Wood processing, coal/sulphur loading terminals to W, otherwise mixed residential/commercial along Lougheed Highway 1 block to S.

T10 - 1 block form Lougheed Highway, fairly open site in mainly commercial landuse.

T11 and T12 - at airports.

40 - heavily forested site in protected water district. Site near Seymour Lake ∿ 24km N of N Vancouver

4.2 Air Quality Data Analysis

In this section the air quality for the GVRD over the period 1978-1981 is summarized. The data for O_3, NO_2, No, NO_x and hydrocarbons are summarized in turn.

For purposes of the analyses of the air quality data in cases where several stations are located in a particular area one representative station from each area will be selected for closer scrutiny. Thus stations T2, T8, T1 and T3 may be designated as being in the western portion of the study area, T6, T5, T4 and T13 in the central Burrard Inlet area and T7, T9 and T10 in the eastern section of the Burrard inlet. Stations T2, T4 and T7 were therefore selected as the representative stations for these areas and graphic illustrations of data from these stations will be used. However in cases where data for these stations are unavailable or insufficient other stations will be selected for graphic illustrations. The stations at Seymour Dam (40) and the Abbottsford and Chilliwack airports will be specifically discussed.

4.2.1 Ozone

Annual and Seasonal Variation

Statistical summaries of the annual ozone levels at all stations for the years 1978 to 1981 are presented in Appendices B1.1 - B1.4. In the case of 1981, the data are incomplete and are included only for reasons given below.

The summary indicates the amount of data collected at each station expressed as the number of days in the year. The concentrations for various percentiles (10, 25, 50, 75, 90 and 99) are given together with the annual arithmetic mean. the maximum 1 hour and 24 hour mean concentrations. The number of exceedences of the 1 Hour Federal air quality objectives (Desirable, Acceptable and Tolerable levels) are also given in the tabulation.

An abbreviated summary of the data in Appendices B1.1 - B1.4 is given in Table 4.3.

The Canadian National 1 year arithmetic mean maximum acceptable level of 15 ppb is exceeded each year during the period, 1978 to 1980, at stations T7 and T11 (Abbotsford). Exceedance of this annual standard also occurred at T4 in 1978, T5 in 1978 and 1980, T9 in 1980 and T12 in 1979. The available data for 1981 suggests that exceedances of this standard may be recorded for T5, T7, T9, T11 and T12.

Table 4.3

Annual Mean Ozone Concentrations At GVRD Stations

Station	Location	Annual Mean (ppb) 1978	1979	1980	1981
T5	Confederation P	16 (64)*	14 (73)	16 (87)	19 (85)
T6	GVRD Beach Works	11 (98)	12 (97)	13 (85)	15 (50)
T7	Anmore Elemen Sch	22 (85)	25 (82)	26 (90)	27 (82)
T8	Lions Gate STP	12 (97)	14 (87)	10 (92)	9 (32)
T10	Dept. of Highways	15 (59)	14 (81)	14 (84	13 (73)
40	Seymour Dam	-	-	14 (54)	14 (36)
T2	GVRD Office	10 (89)	11 (98)	9 (99)	11 (77)
T3	Manitoba Works Y	12 (88)	12 (95)	12 (96)	12 (47)
T1	B.C. Hydro Park	7 (90)	9 (92)	4 (25)	-
T4	Kensington Park	17 (94)	15 (89)	10 (87)	12 (71)
T9	Rocky Point Park	12 (86)	15 (78)	18 (83)	18 (65)
T1A	B.C. Hydro Park	-	-	7 (59)	8 (45)
T12	Chilliwack A	-	22 (85)	14 (82)	18 (82)
T11	Abbotsford A	19 (88)	22 (88)	20 (81)	18 (72)

* Figures in parenthesis are the percent of possible daily observations for the year.

The four year period is a relatively short time in which to determine long term trends in the data. Indications of an increase in ozone levels over the period - see Table 4.3 - are shown for T6, T7 and T9. There was not a consistent trend in ozone level (as indicated by the annual arithmetic mean) for all stations over the period. Station T7 consistently recorded the highest annual mean ozone levels. The Seymour Dam station (40) and the Lower Fraser Valley stations T11 and T12 (Abbottsford and Chilliwack respectively) are outside the GVRD but the ozone levels recorded (see for example Table 4.3) do not allow these stations to be described as background stations. Of all the stations T11 consistently recorded the second or third highest annual mean value, while the annual mean for Chilliwack ranked between second and fifth highest. The annual mean ozone levels at Seymour Dam ranked 5th or 7th in the two years for which data were available.

The National one hour Air Quality Objective for ozone define a Maximum Desirable, Maximum Acceptable and Maximum Tolerable levels of 51, 82 and 153 ppb respectively. The tolerable level was exceeded at two stations in 1978; T7 and T10, four stations in 1979; T5, T4, T9 and T11, and at two stations in 1980; T7 and T9. The available data for 1981 showed that six stations recorded exceedances; T5, T7, T10, T4 and T9. There was a significant increase in the number of hours for which exceedances of the tolerable level occurred at all stations in 1981 compared to previous years. There are similar trends when the exceedance of the acceptable level are considered.

The exceedances of these air quality objectives for the study area are summarized in Tables 4.4 and 4.5. The total number of station days on which ozone measurements were made is indicated as well as the numbers of hours for which the various exceedances were recorded. Since additional monitoring stations were established in the latter years the data were "normalized" by expressing the exceedances per day of data (record). The dramatic increase in ozone levels in 1981 is again reflected.

Seasonal Variation

The ozone data on a seasonal basis for the four years 1978-1981, are presented in Appendices B2.1 - B2.4. A summary of these data are presented in Table 4.6. The seasons are defined on a calendar month basis (January to March ≡ Winter, etc.). The summary for the Fall period reflects three, instead of four, fall seasons since the data for Fall 1981 was incomplete.

The highest levels were recorded in the spring period (April - June) and somewhat lower levels in the fall. The fall and winter periods were typically a factor of two lower than in the spring and summer periods. The number of exceedances of the three National Air Quality objectives for ozone by season is shown in Table 4.6. The data clearly show that the greatest number of exceedances occur in summer and then spring.

Table 4.4

Exceedances Of Canadian National Air Quality Objectives

For Ozone In The GVRD 1978 - 1981

Year	Total No. Of Hours			Stn. Days
	Desirable Level	Acceptable Level	Tolerable Level	
1978	1684	276	10	3426
1979	2298	278	8	3818
1980	2077	318	10	4039
1981*	(1852)	(466)	(40)	(2980)

* Incomplete data for 1981

Table 4.5

Number Of Exceedances Per Record (Day) Of

Canadian National Air Quality Objectives

For Ozone In The GVRD 1978 - 1981

Year	Exceedances / Station Day		
	Desirable Level	Acceptable Level	Tolerable Level
1978	.49	.081	.003
1979	.60	.073	.002
1980	.51	.079	.002
1981*	.62	.156	.013

* Incomplete data for 1981

Table 4.6

Exceedances Of Canadian National Air Quality Ozone Objectives By Season In The GVRD 1978 - 1981

Season	No. Of Hours Of Exceedances Desirable Level	 Acceptable Level	 Tolerable Level
Winter	353	17	1
Spring	3464	397	12
Summer	3926	908	54
Fall*	157	26	1

* Excludes fall 1981

Table 4.7

Summary of the Seasonal Mean Ozone Concentrations at GVRD Stations 1978-1981

Station	Location	Seasonal Mean (ppb)			
		Winter	Spring	Summer	Fall
T5	Confederation P	12 (72)*	21 (94)	18 (92)	11 (45)
T6	GVRD Beach Works	9 (73)	18 (81)	13 (100)	7 (80)
T7	Anmore Elemen Sch	20 (73)	33 (88)	28 (96)	17 (89)
T8	Lions Gate STP	9 (73)	19 (78)	12 (80)	6 (94)
T10	Dept. of Highways	11 (72)	20 (84)	16 (76)	8 (66)
40	Seymour Dam	5 (11)	13 (11)	18 (47)	9 (29)
T2	GVRD Office	8 (86)	17 (94)	12 (95)	5 (100)
T3	Manitoba Works Y	7 (70)	20 (77)	15 (93)	6 (93)
T1	B.C. Hydro Park	5 (70)	14 (48)	8 (43)	4 (62)
T4	Kensington Park	10 (76)	20 (85)	16 (92)	8 (95)
T9	Rocky Point Park	10 (78)	23 (95)	19 (74)	6 (75)
T1A	B.C. Hydro Park	8 (24)	10 (37)	8 (13)	4 (31)
T12	Chilliwack A	12 (53)	25 (66)	22 (73)	12 (61)
T11	Abbotsford A	18 (75)	27 (80)	19 (93)	15 (88)

* Numbers in parenthesis are percent of possible daily observations for the year.

Monthly Variation

Monthly summaries of the ozone data for each station were prepared and detailed the number of one hour observations, the percentage of data recovery, the monthly mean, the maximum 1 hour level in the month at each station and the numbers of exceedances of the three Federal Air Quality Objectives for ozone. These data are available as supplementary material. Figures 4.2 and 4.3 illustrate the differences in ozone levels at three stations for 1979 and 1980. These figures also show the seasonal variation (highest levels in the summer and spring months) as well as the range of ozone levels at different stations in the same time period. The data for station T4 may be misleading since these were only 36% and 53% data recovery for May and June respectively.

Diurnal Variation

Summaries of hourly means for each month at each station were also prepared. The summary indicated, for each station, the maximum and minimum 1 hour observation in the month, the number of observations and the mean of all observations in the month. The diurnal variation of ozone levels is illustrated in Figures 4.4 - 4.7 in which the data for three stations is shown for 4 months - one month from each of the 4 seasons.

The differences in the diurnal variations, for summer and spring months on the one hand, and for fall and winter months on the

FIGURE 4.2

MONTHLY MEAN OZONE CONCENTRATIONS AT SELECTED STATIONS IN 1979

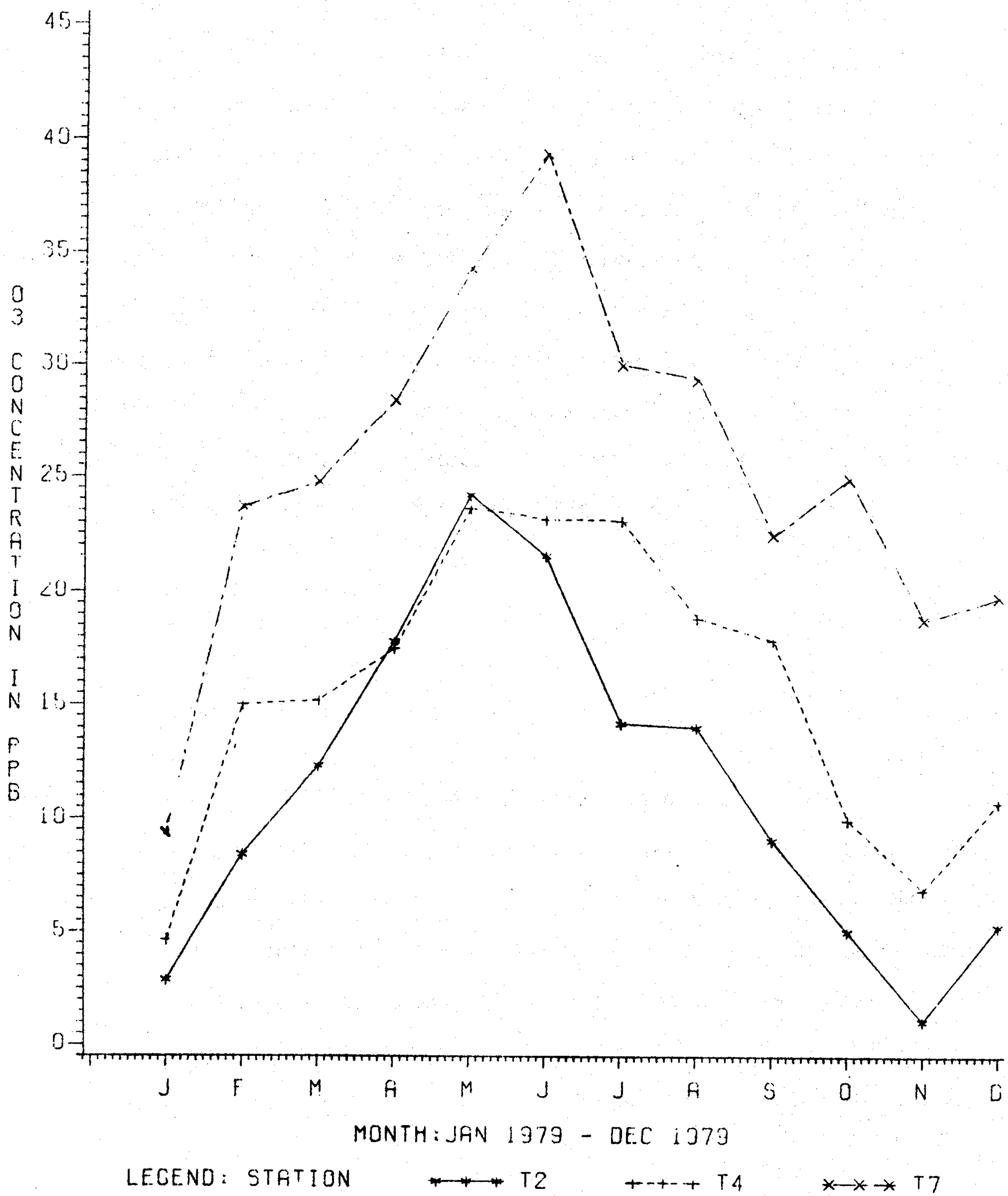


FIGURE 4.3

MONTHLY MEAN OZONE CONCENTRATIONS AT SELECTED STATIONS IN 1980

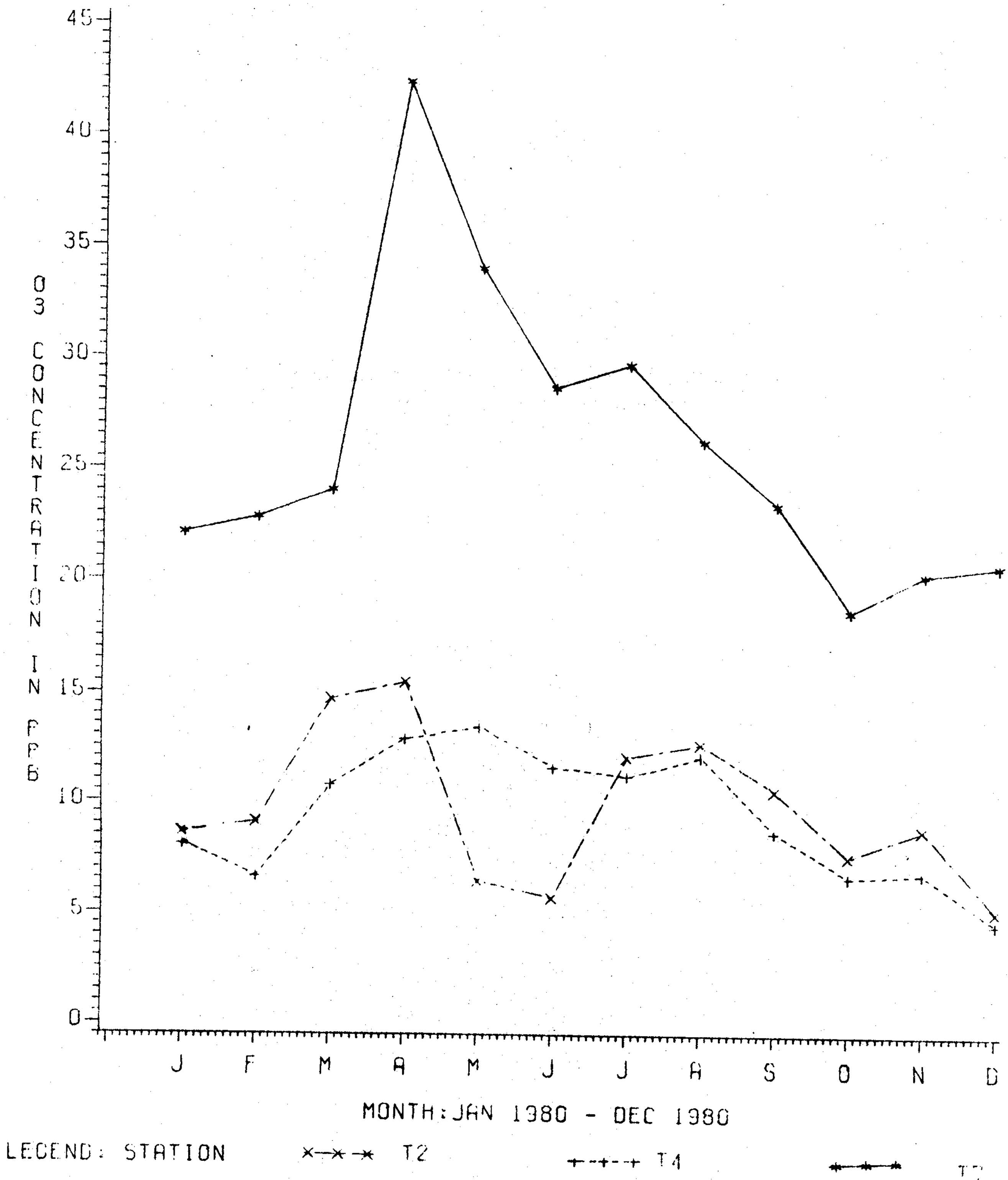


FIGURE 4.4

DIURNAL VARIATION OF MEAN OZONE LEVELS AT SELECTED GVRD STATIONS: DECEMBER 1980

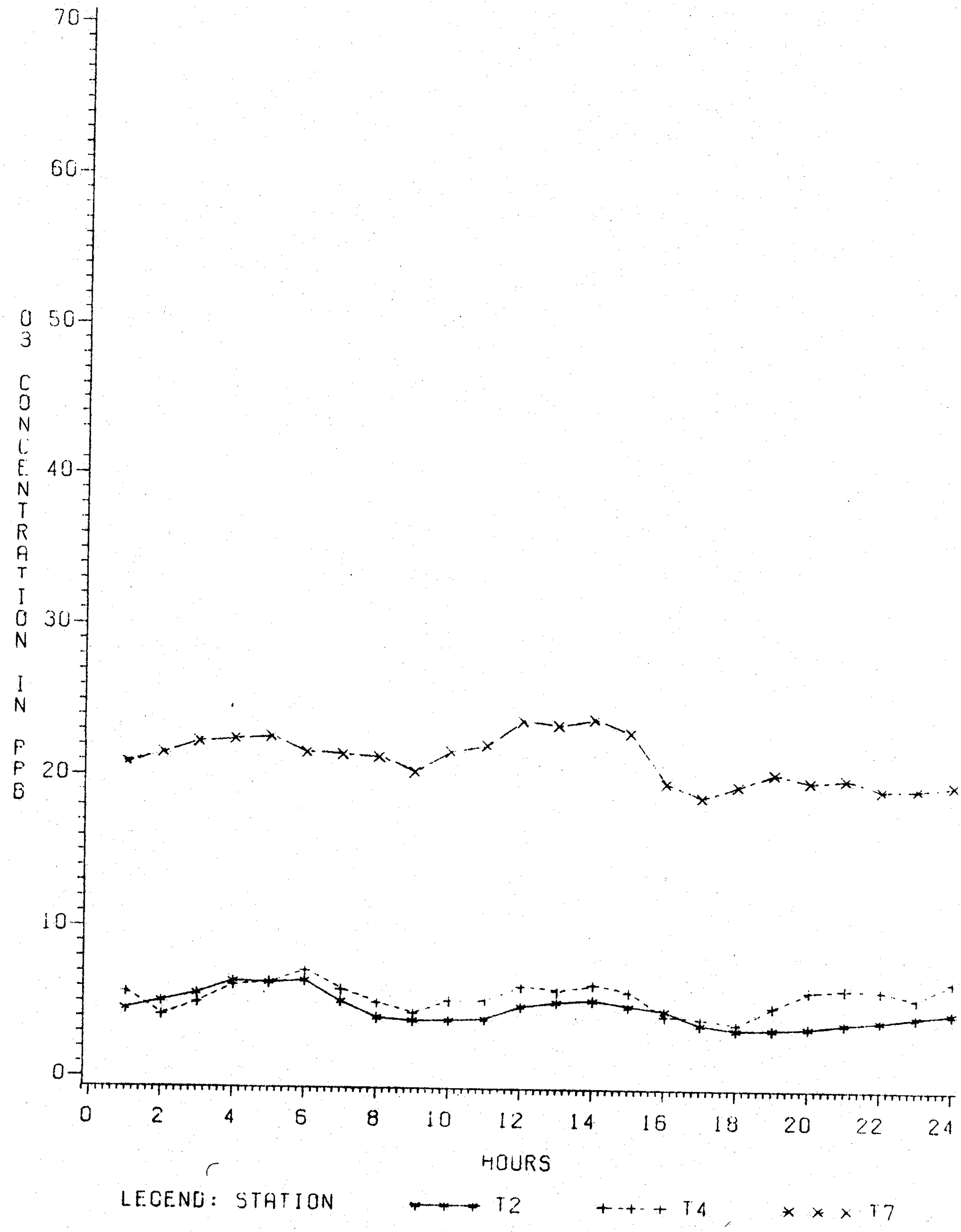


FIGURE 4.5

DIURNAL VARIATION OF MEAN OZONE LEVELS AT SELECTED GVRD STATIONS MARCH 1980

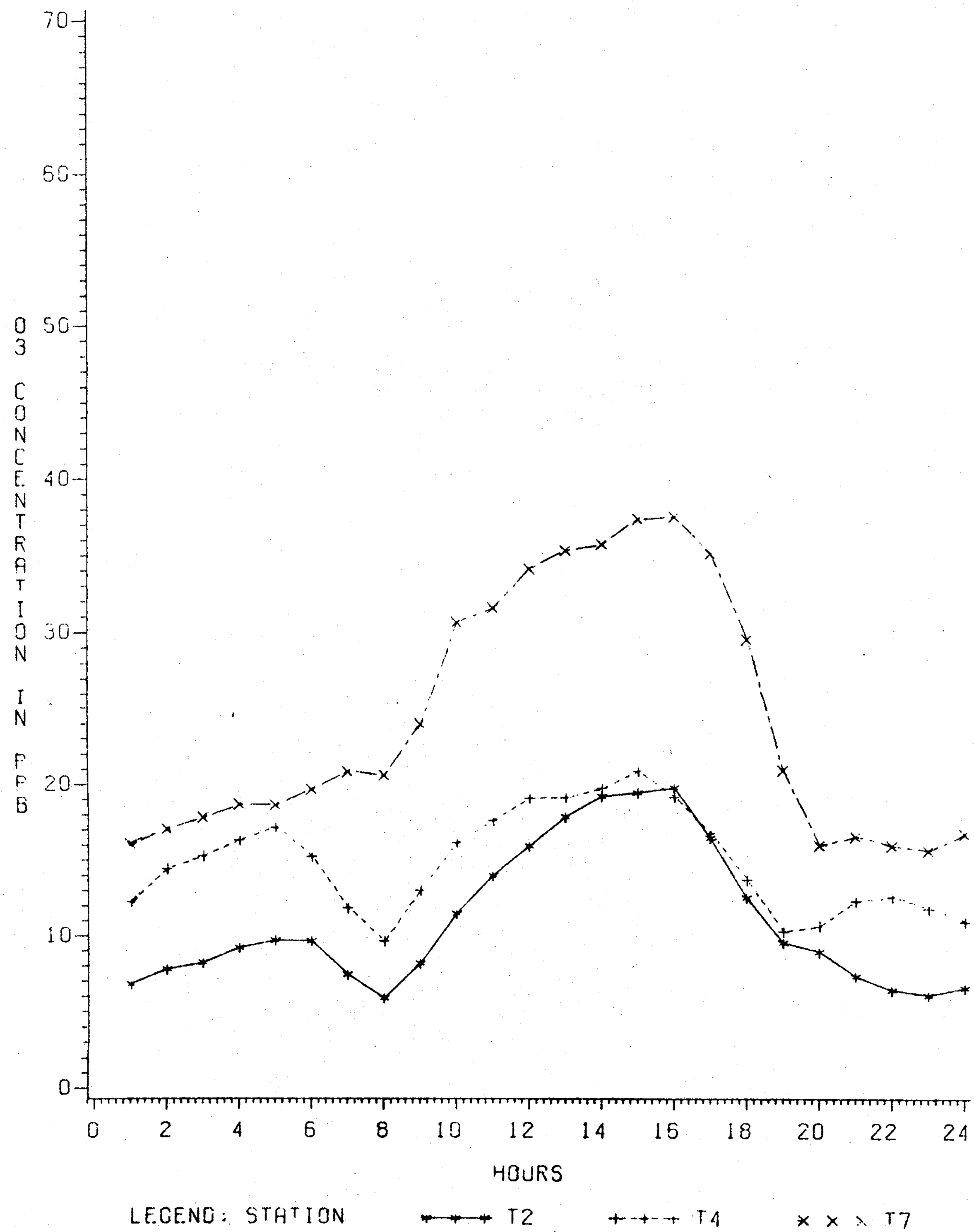


FIGURE 4.6

DIURNAL VARIATION OF MEAN OZONE LEVELS AT SELECTED GVRD STATIONS JUNE 1981

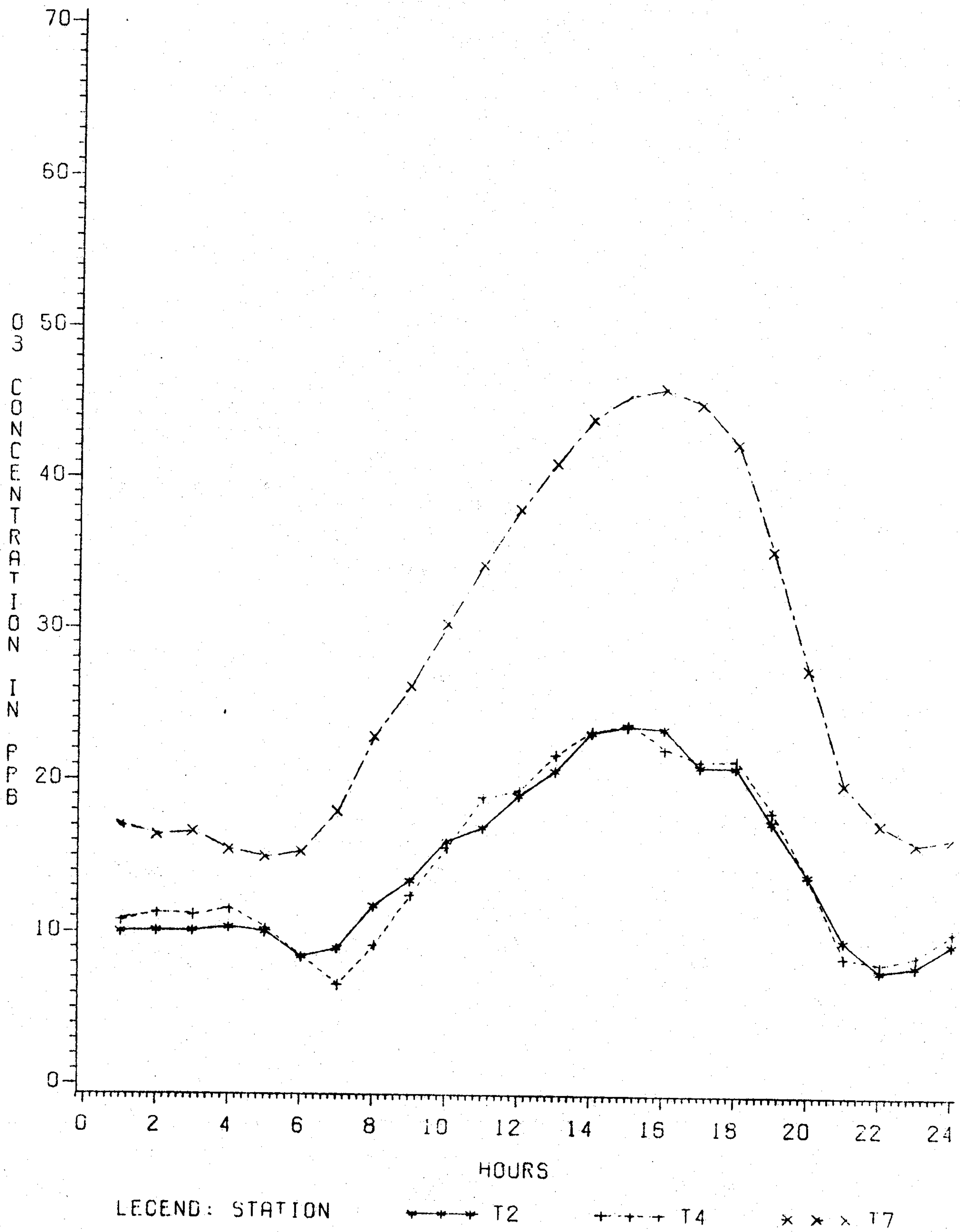
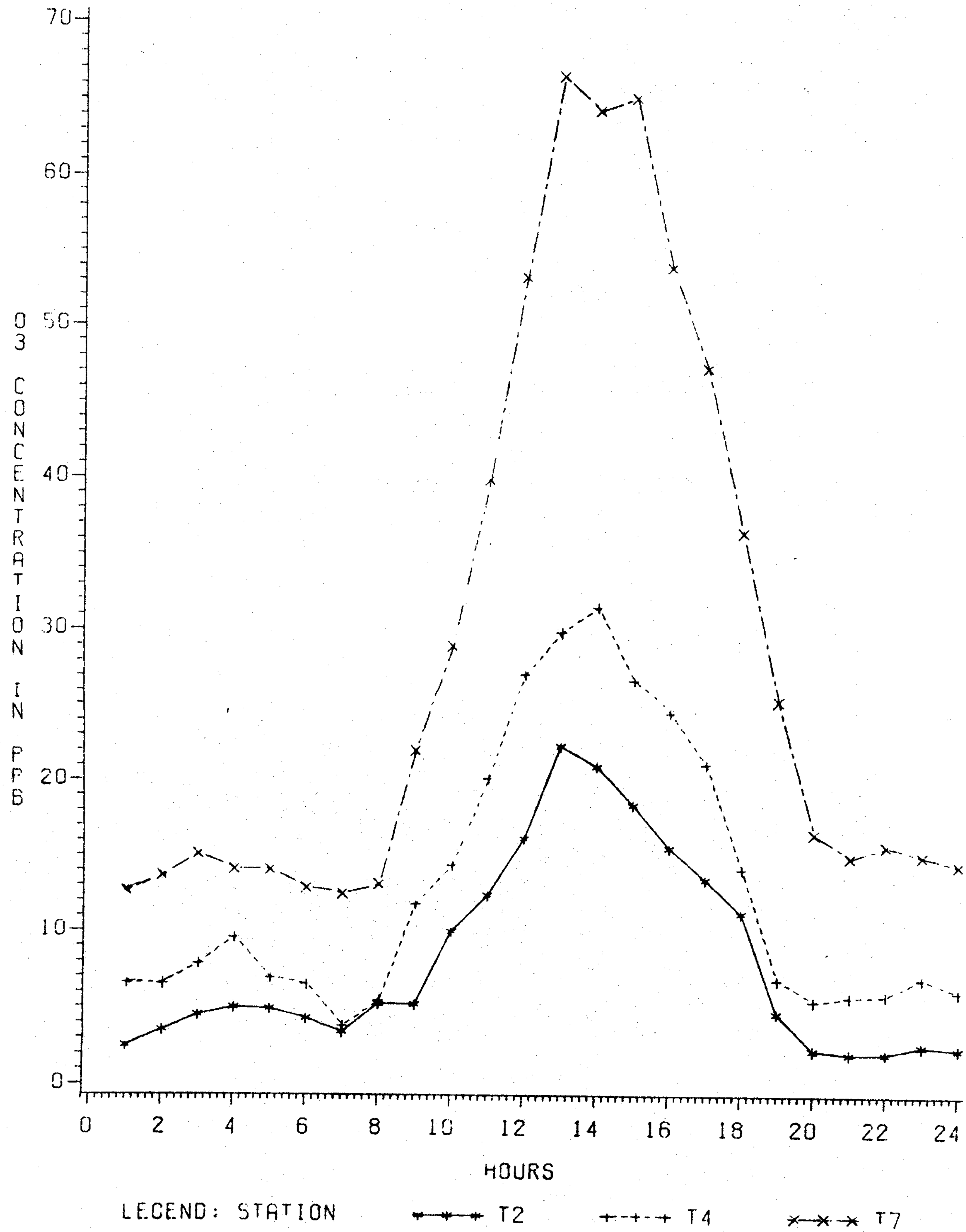


FIGURE 4.7

DIURNAL VARIATION OF MEAN OZONE LEVELS AT SELECTED GVRD STATIONS SEPTEMBER 1981



other, are striking. The peak ozone level occurs at ~ 1400 hours and a second peak is sometimes observed early in the morning ~ 0400 - 0600 hours. The constancy of the ozone levels throughout the day in December (a fall month) is not surprising since sunshine is a determining factor in generating ozone levels. The diurnal patterns shown in Figures 4.4 - 4.7 are consistent with the seasonal variation in ozone levels as previously described.

4.2.2 Nitrogen Dioxide

Annual, seasonal, monthly and diurnal statistical summaries were made for the NO_2 data. The temporal variation and the relationship of the NO_2 levels to the Federal Air Quality objectives for NO_2 are discussed.

Annual and Seasonal Variation

Details of the annual and seasonal statistics for the available NO_2 data for the four years 1978 - 1981 are given in Appendices B3.1 - B3.4, and B4.1 - B4.4. Summaries of the data are presented in Tables 4.8 and 4.9. The annual means for NO_2 at each station and the percentage of days in the year for which observations were made are indicated in parenthesis.

The data suggest little change in the NO_2 levels over the four years. The annual means summarized in Table 4.8 for different stations show relatively little variation.

Table 4.8

Annual Mean Nitrogen Dioxide Concentrations

Station	Location	Annual Mean (ppb)			
		1978	1979	1980	1981
T5	Confederation P	20 (64)*	22 (84)	22 (87)	25 (55)
T6	GVRD Beach Works	19 (75)	18 (69)	22 (70)	22 (61)
T7	Anmore Elemen Sch	8 (38)	18 (64)	20 (88)	16 (70)
T8	Lions Gate STP	18 (83)	19 (95)	19 (84)	42 (4)
T10	Dept. of Highways	27 (8)	20 (41)	17 (96)	18 (57)
40	Seymour Dam	-	-	-	-
T2	GVRD Office	24 (84)	24 (83)	22 (99)	24 (14)
T3	Manitoba Works Y	27 (82)	24 (76)	19 (85)	23 (47)
T1	B.C. Hydro Park	34 (31)	29 (89)	28 (23)	-
T4	Kensington Park	25 (91)	16 (58)	22 (88)	23 (76)
T9	Rocky Point Park	19 (77)	16 (44)	23 (27)	21 (87)
T1A	B.C. Hydro Park	-	-	29 (69)	33 (88)
T12	Chilliwack A	-	-	-	2 (1)
T11	Abbotsford A	-	-	-	14 (7)

* Numbers in parenthesis are the percent of possible daily observations for the year.

Table 4.9

Seasonal Mean Nitrogen Dioxide Concentrations

Station	Location	Seasonal Mean (ppb) Winter	Spring	Summer	Fall #
T5	Confederation P	27 (44)*	16 (74)	22 (85)	25 (93)
T6	GVRD Beach Works	20 (53)	19 (71)	21 (86)	21 (70)
T7	Anmore Elemen Sch	16 (58)	14 (76)	18 (65)	21 (62)
T8	Lions Gate STP	22 (71)	15 (64)	16 (73)	22 (72)
T10	Dept. of Highways	17 (40)	15 (49)	21 (51)	17 (66)
40	Seymour Dam	-	-	-	-
T2	GVRD Office	24 (75)	23 (92)	23 (89)	23 (96)
T3	Manitoba Works Y	25 (67)	21 (75)	20 (88)	31 (68)
T1	B.C. Hydro Park	34 (51)	30 (32)	24 (42)	32 (24)
T4	Kensington Park	23 (91)	21 (78)	23 (67)	22 (81)
T9	Rocky Point Park	20 (67)	14 (58)	22 (58)	21 (47)
T1A	B.C. Hydro Park	42 (22)	34 (44)	25 (49)	28 (32)

* Numbers in parenthesis are the percent of possible observations

\# Excludes Fall 1981

The National Air Quality objectives (Maximum Tolerable 24 hour levels and the Annual Arithmetic Mean) are never exceeded for NO_2. The maximum acceptable 1 hour level was exceeded twice for the period (T7, October 12, 1979 and T1, October 6, 1978). The maximum acceptable 24 hour average was exceeded once - at T1 (October 6, 1978).

Monthly and Diurnal Variation of NO_2

The statistics for the monthly and diurnal NO_2 levels have been tabulated and include the amount of data for each month - in terms of the number of hourly values and as a percentage of possible values, the maximum 1 hour and 24 hour means and the numbers of exceedances of National Air Quality standards.

The variation of the monthly mean values indicates a pattern in which higher levels generally occur in the February - April and again in the September - November periods. These features are illustrated in Figure 4.8 in which the monthly means for stations T7, T2 and T4 during 1980 are plotted.

The diurnal variation of NO_2 is illustrated in Figures 4.9 - 4.12 for stations T2, T4 and T7. The increase in NO_2 between 0600 and 0900 consistently occurs. In cases where there are two NO_2 peaks (the second increase starting at ~ 1600), this pattern is consistent with NO_2 from mobile sources in morning and afternoon traffic as well as with the atmospheric photochemistry of nitrogen oxides.

FIGURE 4.8

MONTHLY MEAN NITROGEN DIOXIDE LEVELS AT SELECTED GVRD STATIONS IN 1980

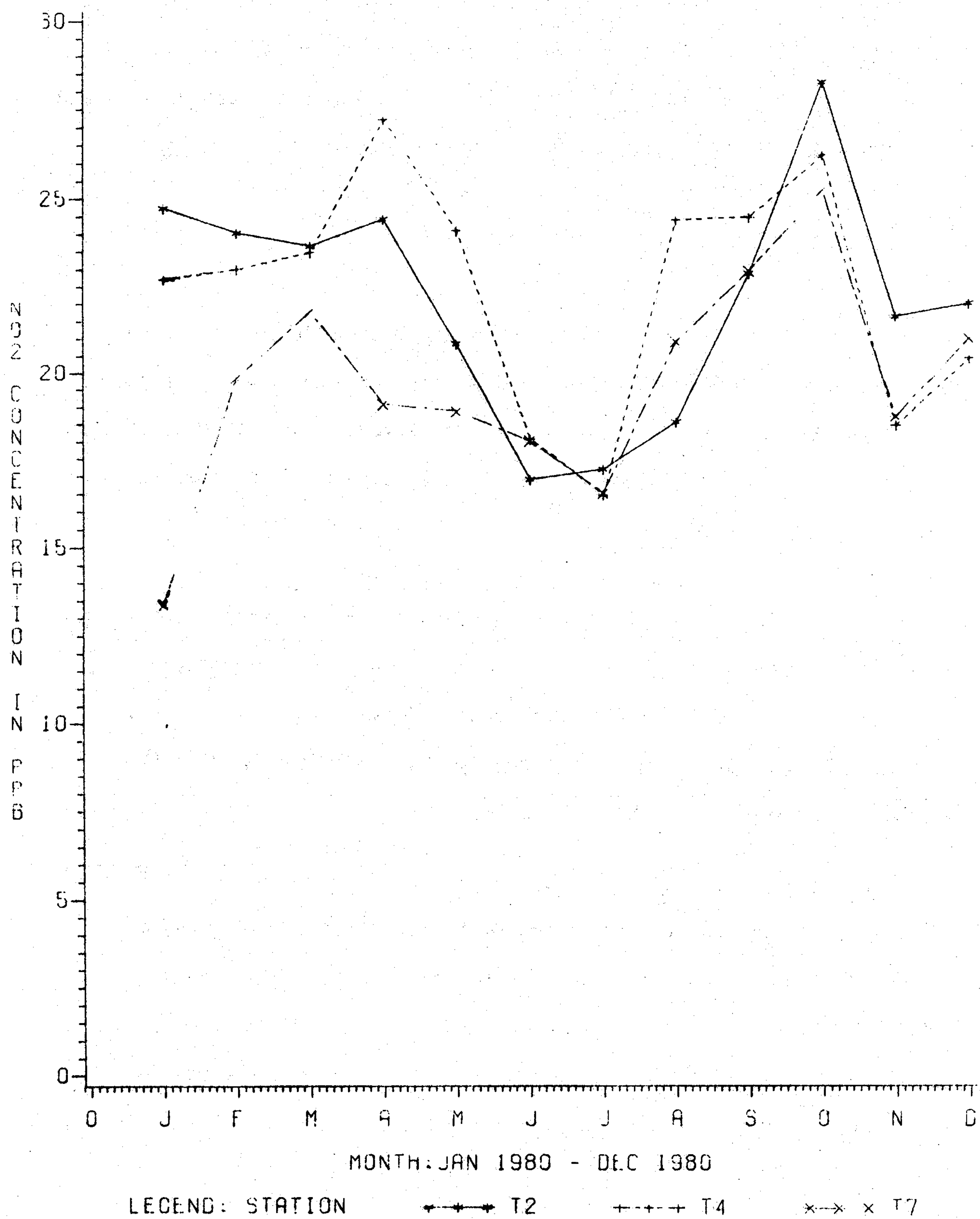


FIGURE 4.9

DIURNAL VARIATION
MEAN NITROGEN DIOXIDE LEVELS
SELECTED GVRD STATIONS JANUARY 1980

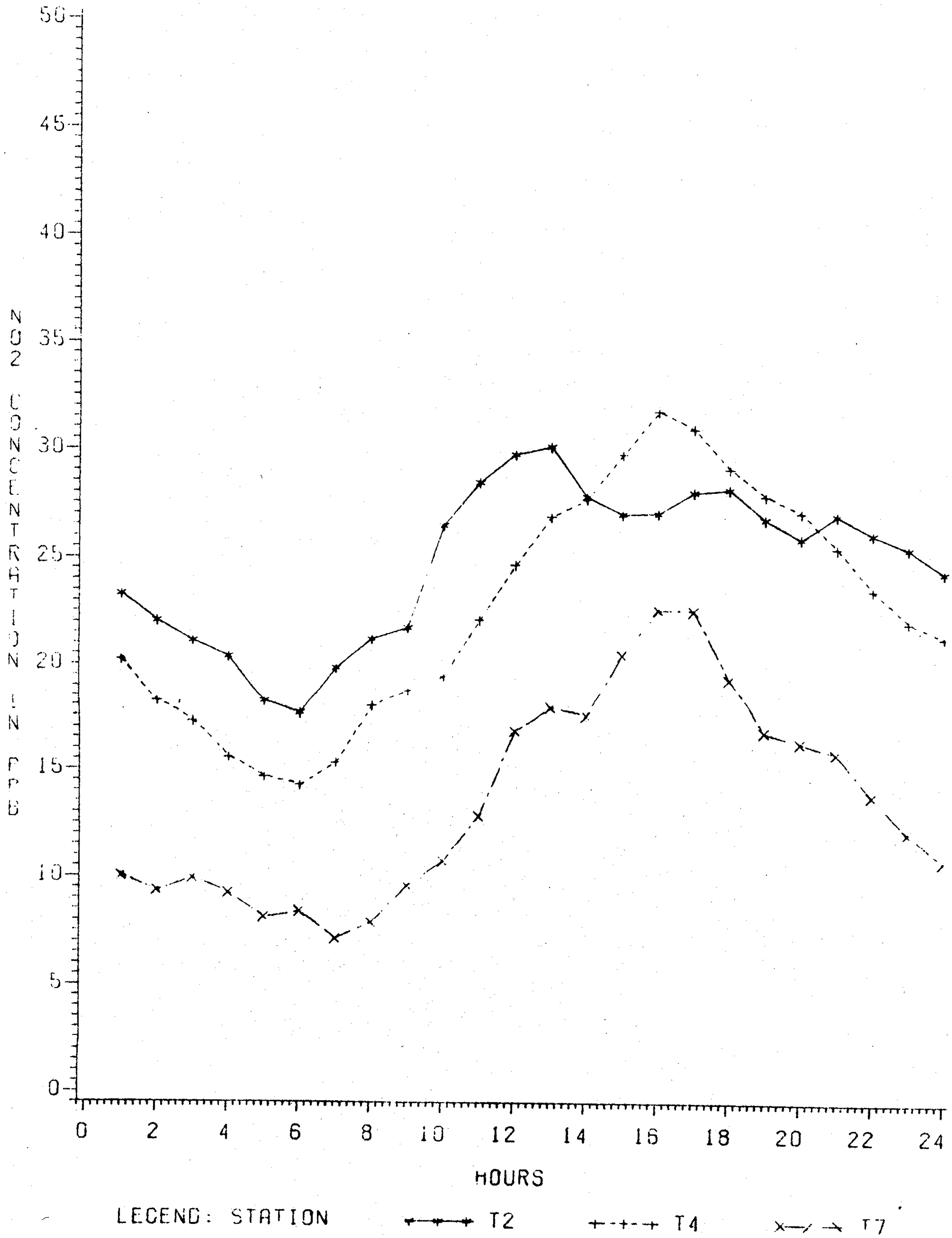


FIGURE 4.10

DIURNAL VARIATION
MEAN NITROGEN DIOXIDE LEVELS
SELECTED GVRD STATIONS: APRIL 1980

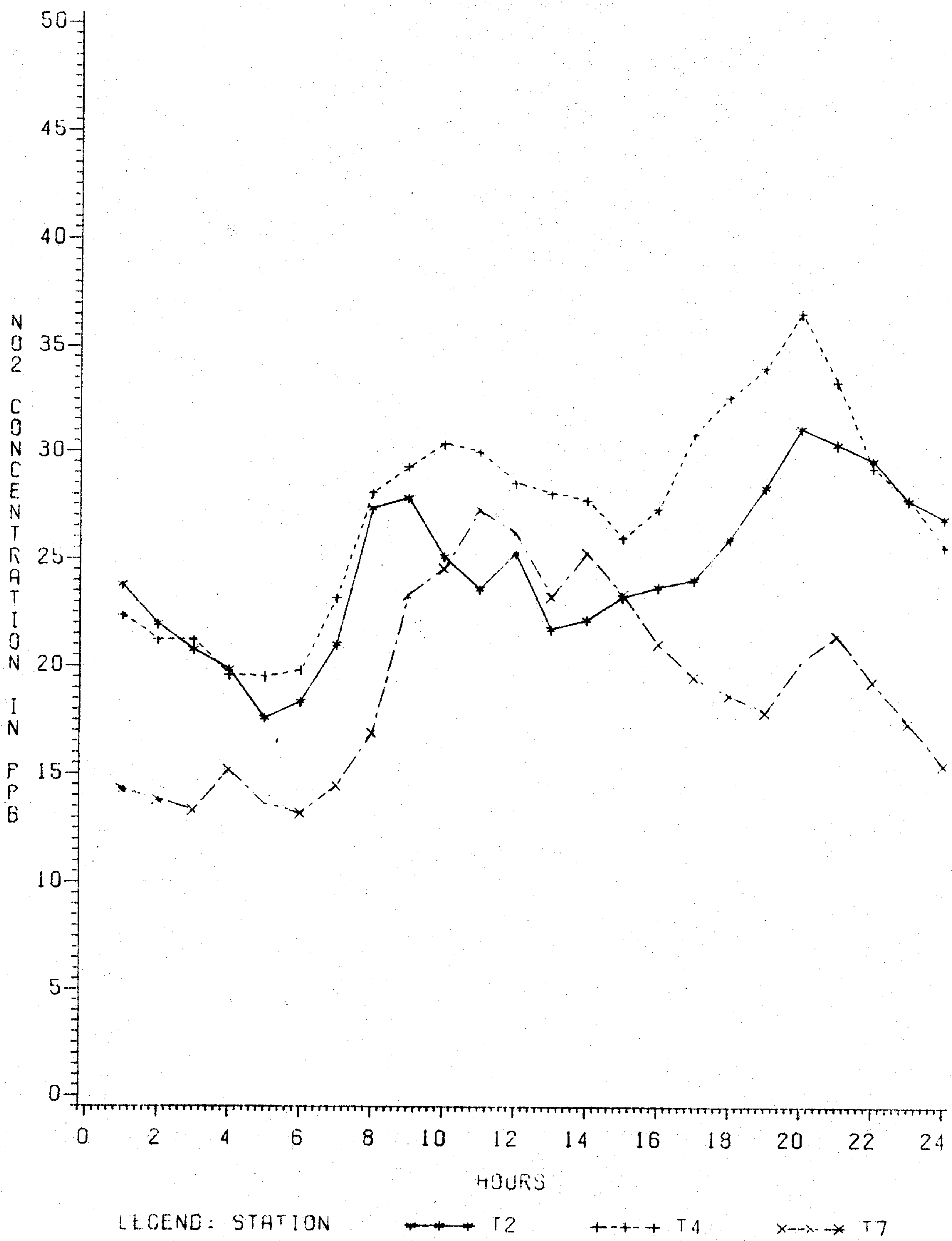


FIGURE 4.11

DIURNAL VARIATION
MEAN NITROGEN DIOXIDE LEVELS
SELECTED GVRD STATIONS JULY 1980

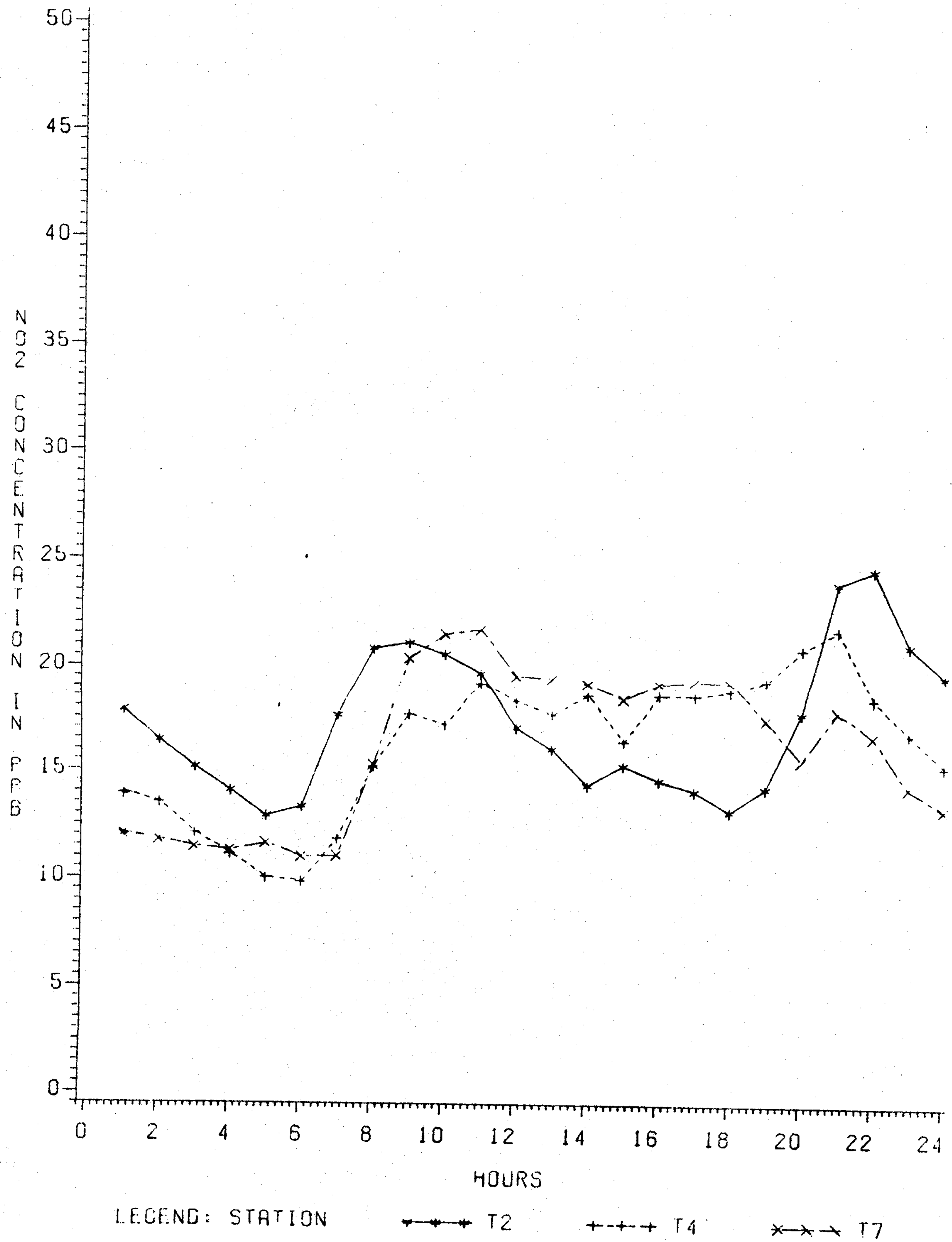
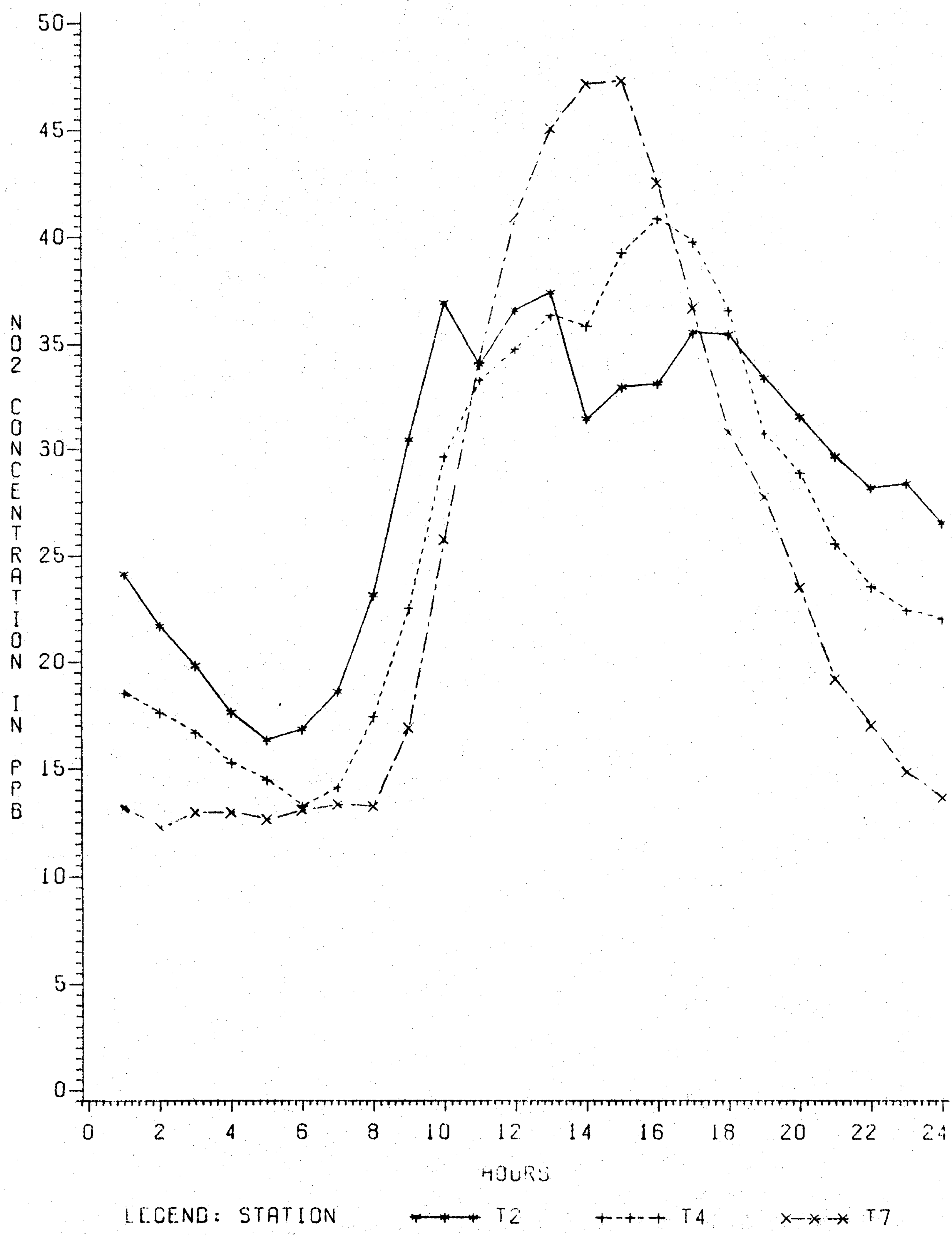


FIGURE 4.12

DIURNAL VARIATION
MEAN NITROGEN DIOXIDE LEVELS
SELECTED GVRD STATIONS OCTOBER 1980



4.2.3 Nitric Oxide

Nitric oxide data have been available only since 1980. The statistical summaries of the data for 1980 and 1981 (Appendices B5.1 - B5.2) show that seven stations in 1980 and, so far, one station in 1981 have more than 75% of data for the year. Table 4.10 is a summary of annual statistics for NO. It is premature to determine conclusively whether the 1981 annual mean NO levels will show an increase over those for 1980 since the data for 1981 are incomplete. The highest 1% of the NO 1 hour values and the maximum 25 hour mean levels at most stations in 1981 are significantly higher than in 1980. Unless there is a dramatic change in the NO levels in the outstanding period in 1981, it would be safe to conlude that NO levels would have increased significantly in 1981 over 1980.

Of the nitrogen oxides emitted from combustion sources, the predominant species is nitric oxide. Nitric oxide is converted to NO_2 (and other nitrogen species) by reactions with ozone and peroxy radicals (see Section 7). The wide range of NO levels at different monitoring stations is indicative of the strong influence of nearby sources (for high NO levels) but in cases where the ozone concentration is high, the depletion of NO will result. Notable is the generally high level of NO at T1 or T1A which has relatively low ozone levels and conversely the low NO levels at T7 at which ozone levels are highest. Another manifestation of the effect of atmospheric reactions of NO is the low level of NO in spring and summer compared to winter and fall (see Figure 4.13).

Table 4.10

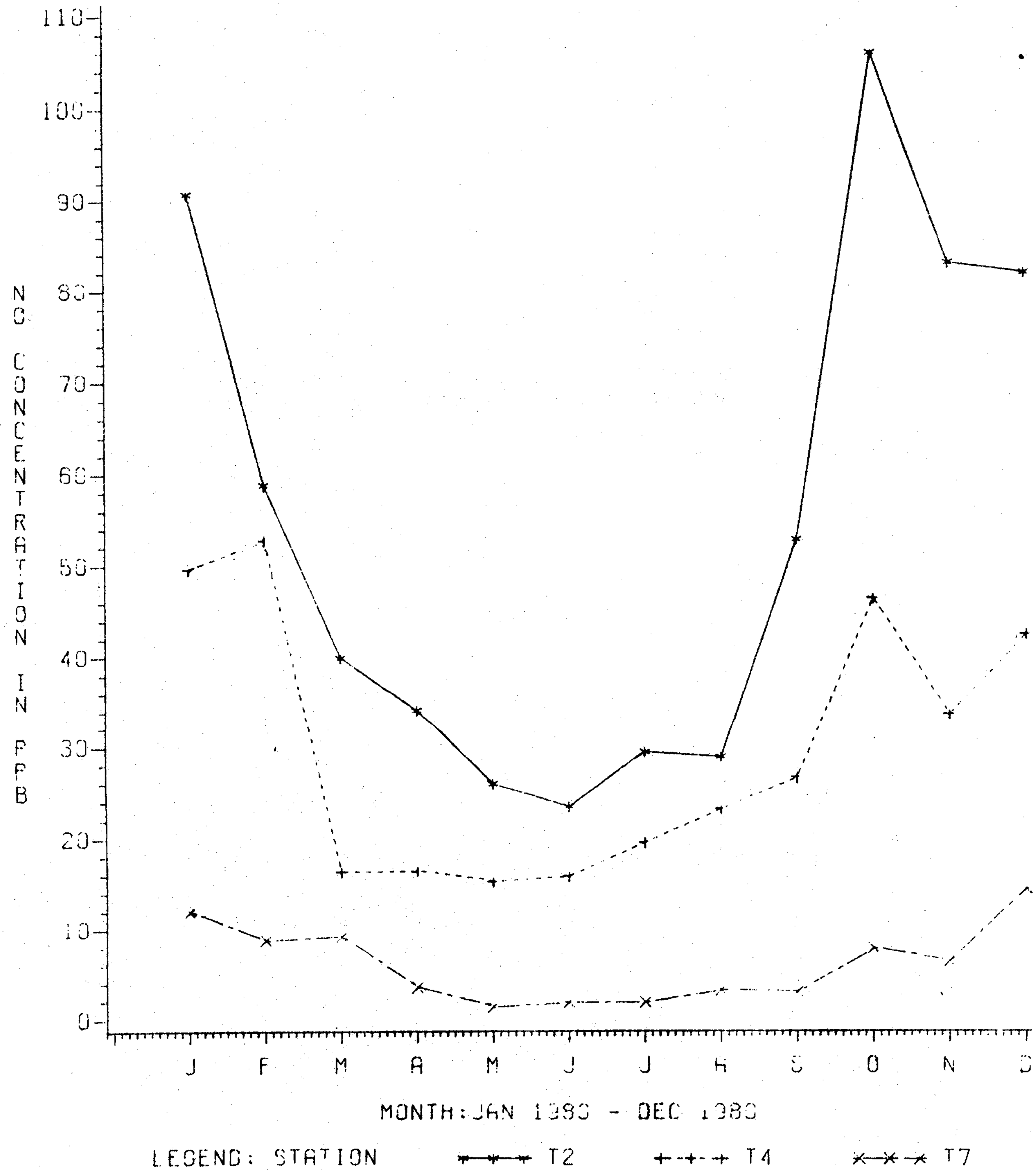
Annual Mean Nitric Oxide Concentrations

Station	Location	Annual Mean (ppb)*	
		1980	1981
T5	Confederation P	27 (85)	31 (48)
T6	GVRD Beach Works	36 (69)	39 (55)
T7	Anmore Elemen Sch	6 (86)	9 (59)
T8	Lions Gate STP	32 (81)	54 (5)
T10	Dept. of Highways	48 (91)	47 (48)
T2	GVRD Office	55 (97)	58 (67)
T3	Manitoba Works Y	43 (77)	74 (38)
T1	B.C. Hydro Park	75 (26)	-
T4	Kensington Park	31 (86)	67 (67)
T9	Rocky Point Park	49 (26)	44 (76)
T1A	B.C. Hydro Park	79 (64)	97 (77)

* Numbers in parenthesis are the percent of possible daily observation for this year.

FIGURE 4.13

MONTHLY MEAN NITRIC OXIDE CONCENTRATIONS AT SELECTED GVRD STATIONS IN 1980



Seasonal Variation

Since less than two years data are available, the analysis of seasonal variations is not feasible. Any inferences on the seasonal variation of NO can be obtained from examining the monthly variations of NO levels.

Monthly and Diurnal Variation of NO Levels

Summary statistics for the monthly NO levels are available in supplementary material. These summaries detail for each station the number of hours of data, the monthly mean NO level, the percent of observations and the maximum 1 hour and 24 hour mean levels. For each month, the hourly means for each station have been tabulated.

Figure 4.13 shows the variation of the monthly mean NO levels at three stations: T7, T2 and T4 for 1980. The NO levels are consistently higher during the colder months, September - March, and relatively lower during the summer months. This probably reflects the efficient depletion of NO by ozone which reaches higher levels in the summer than in winter months.

The diurnal variation of NO is shown in Figures 4.14 - 4.17 in which the mean hourly values for each hour in the months of February, May, August and November 1980 are plotted. The diurnal variation is characterized by two peaks in the NO levels. These peaks are typical of mobile

FIGURE 4.14

DIURNAL VARIATION OF MEAN NITRIC OXIDE LEVELS AT SELECTED GVRD STATIONS FEBRUARY 1980

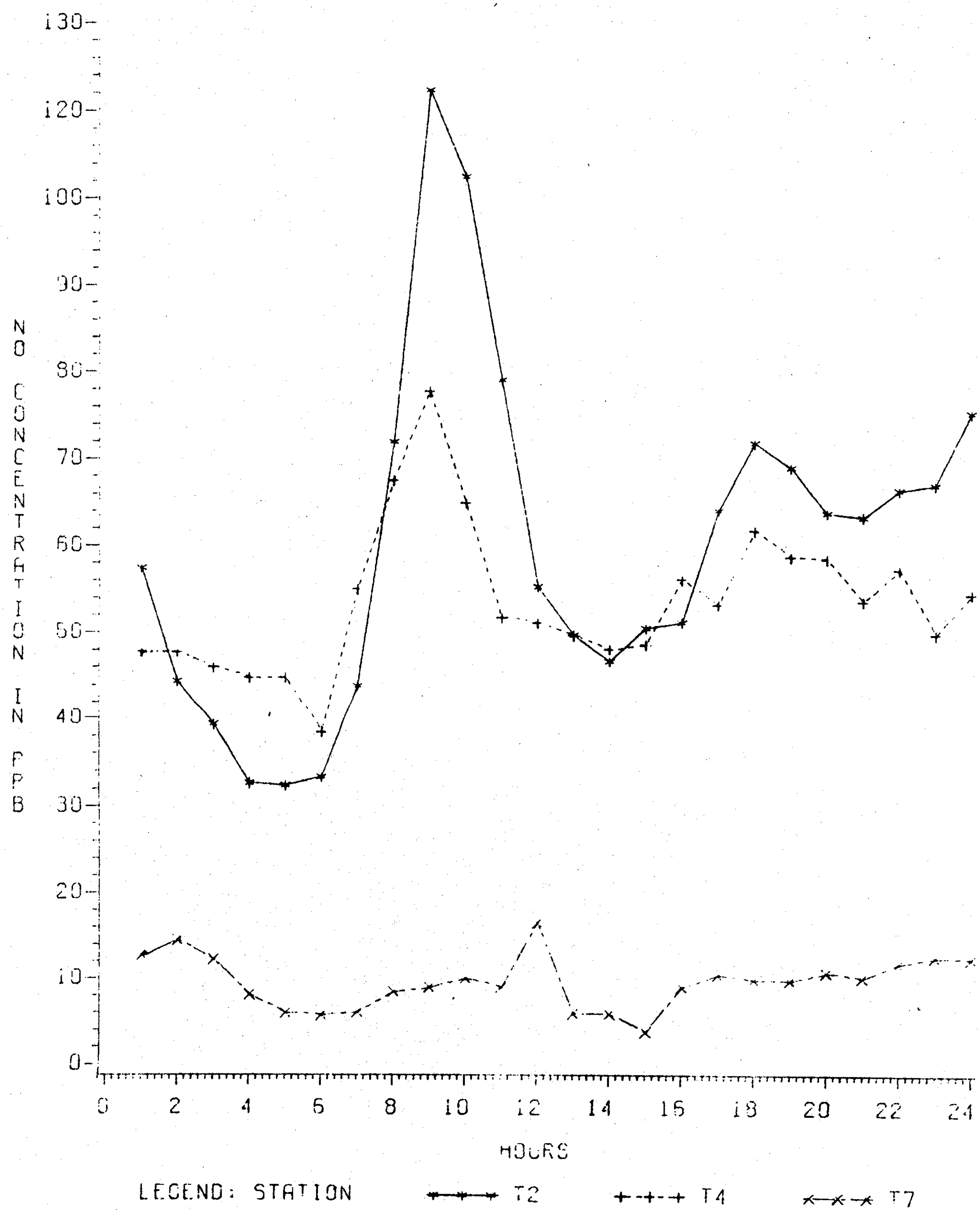


FIGURE 4.15

DIURNAL VARIATION OF MEAN NITRIC OXIDE LEVELS AT SELECTED GVRD STATIONS MAY 1980

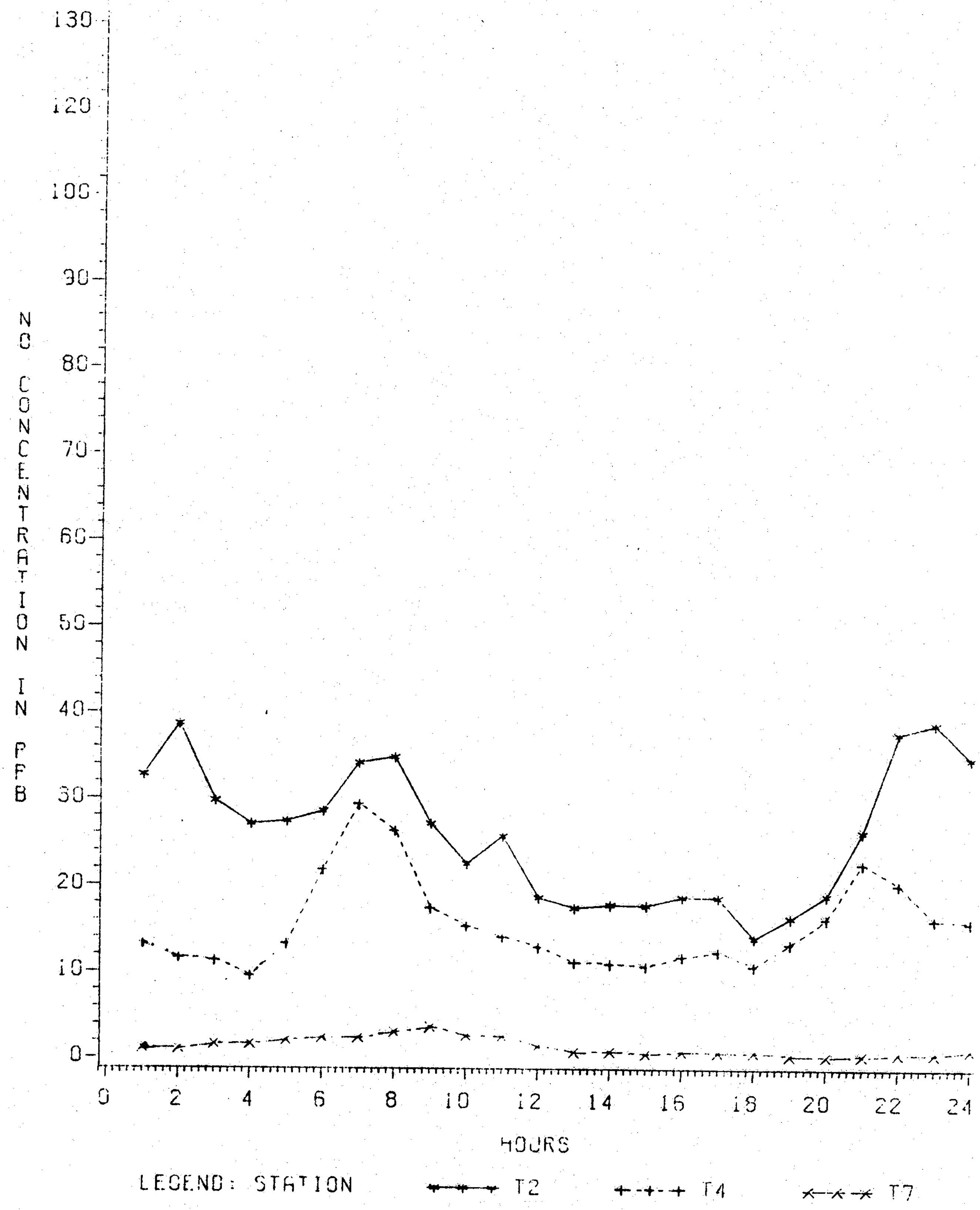


FIGURE 4.16

DIURNAL VARIATION OF MEAN NITRIC OXIDE LEVELS AT SELECTED GVRD STATIONS AUGUST 1980

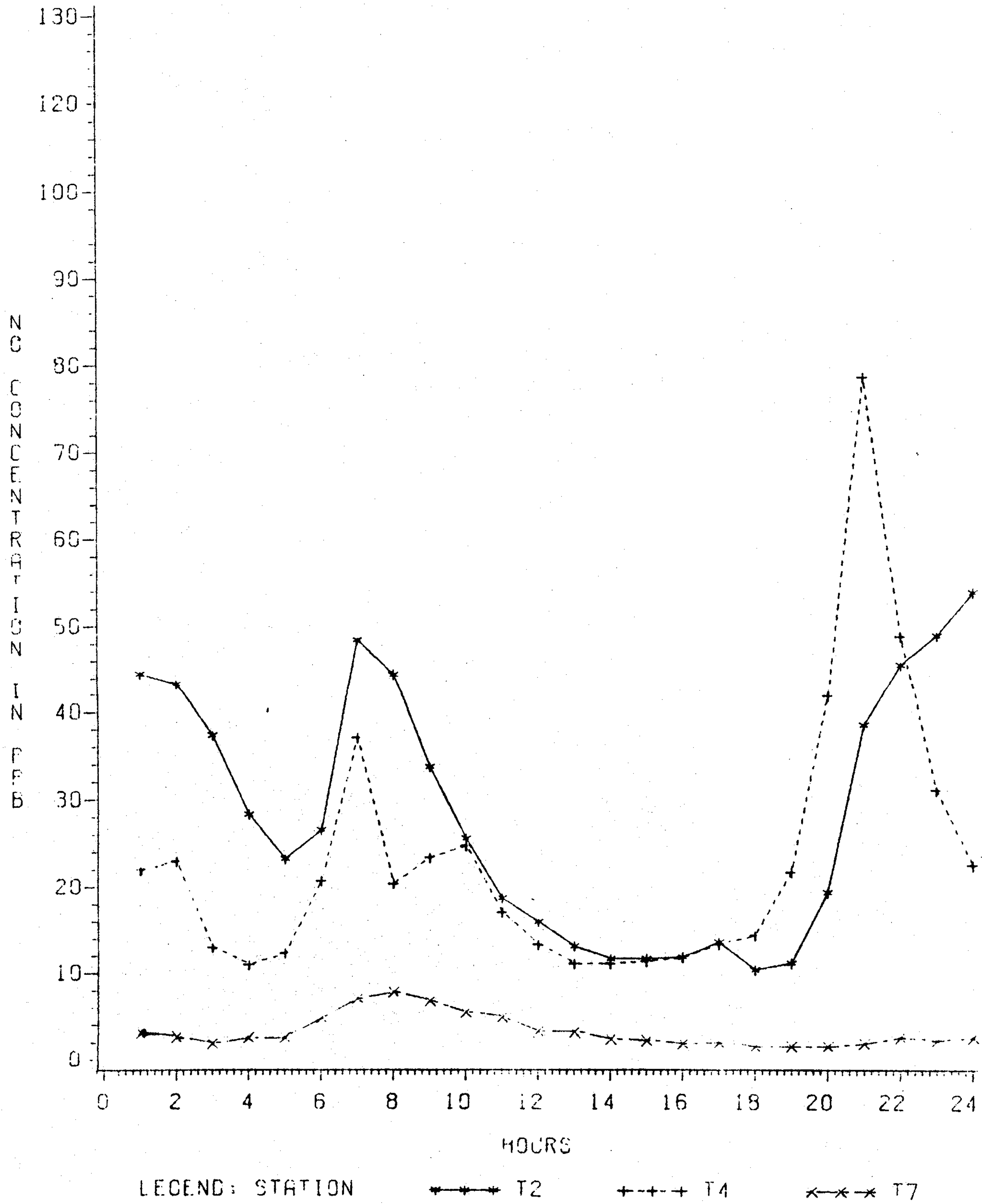
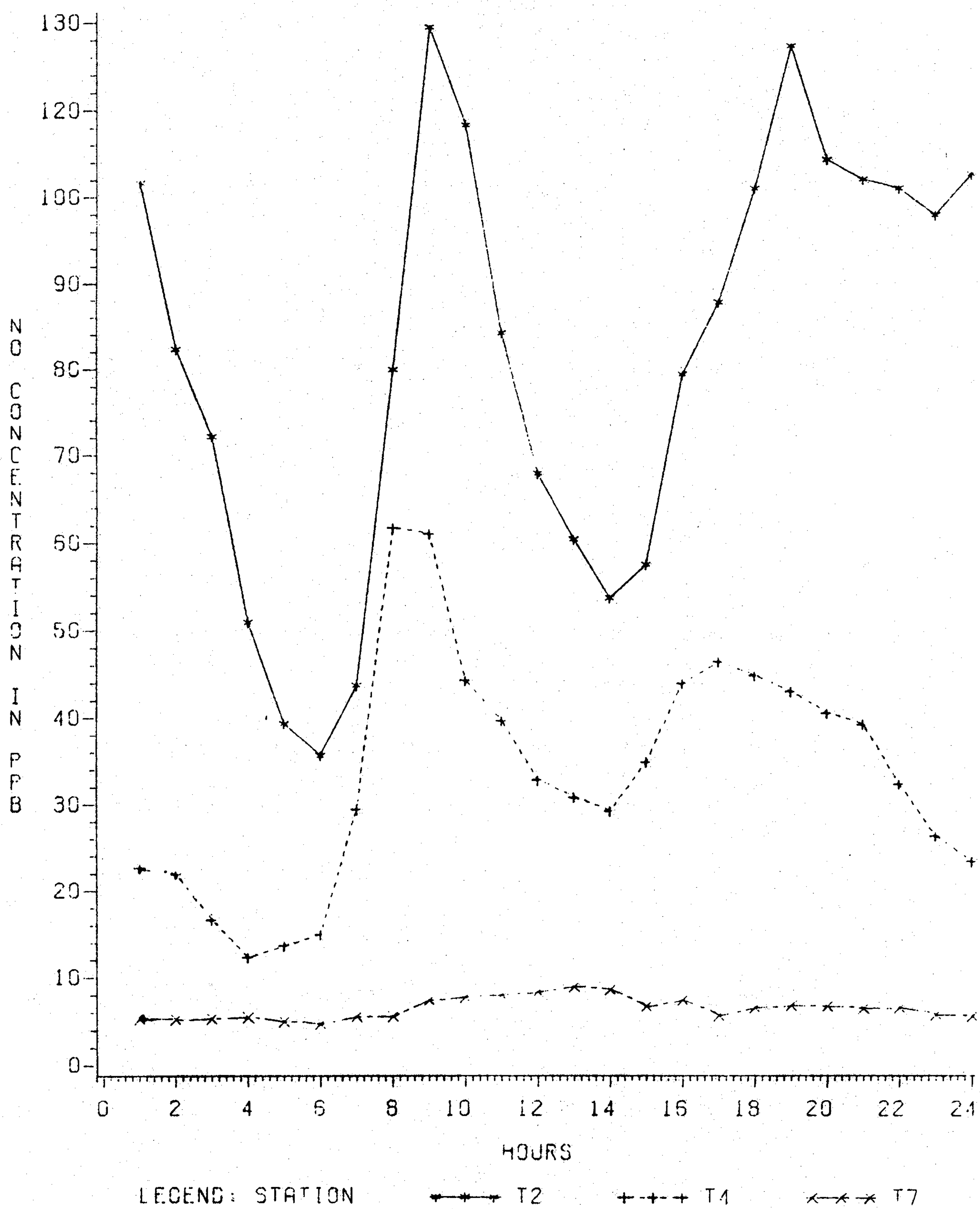


FIGURE 4.17

DIURNAL VARIATION OF MEAN NITRIC OXIDE LEVELS AT SELECTED GVRD STATIONS NOVEMBER 1980



sources. In the afternoon the presence of ozone which forms after the NO morning peak depletes the NO peak expected to result from the afternoon traffic.

4.2.4 Total Nitrogen Oxides (NO_x)

The NO_x measurements are the sum of NO and NO_2, consequently the patterns of temporal and spatial behaviour of NO_x may be expected to be similar to NO and NO_2. However, in view of the conversion of NO to NO_2, which is very dependent on ozone concentration inter alia, the pattern of behaviour for NO_x can not be always simply related to either NO or NO_2.

Annual and Seasonal Variation

Data for total nitrogen oxides have been available since January 1980. Statistical summaries of the annual data are presented in Appendices B6.1 - B6.2. Annual means and the percentage of data for each station are given in Table 4.11. The lowest annual mean NO_x level is found at station T7 while the highest is at T1. The strong influence of sources of NO_x is again apparent in view of the wide range of NO_x levels found at the various stations.

The seasonal variation of NOx levels may be discerned only on the basis of the limited data for less than two years. The seasonal variation may be therefore just as adequately determined by examining the monthly variation of NO_x levels.

Table 4.11

Annual Mean Total Nitrogen Oxides Concentrations

At GVRD Stations

Station	Concentration / ppb *	
	1980	1981
T5	50 (85)	58 (48)
T6	59 (68)	62 (55)
T7	27 (86)	26 (60)
T8	51 (81)	92 (4)
T10	66 (91)	64 (48)
T2	77 (97)	82 (67)
T3	58 (79)	91 (39)
T1	106 (26)	NA**
T4	54 (85)	91 (66)
T9	73 (27)	66 (76)
T1A	110 (55)	130 (77)

* Numbers in parenthesis are the percent of possible daily observation for this year.

** Not available.

Monthly and Diurnal Variation of NO_x

The variations of NO_x levels at 3 stations during 1980 are shown in Figure 4.18. The pattern is very similar to that for NO in which highest levels at each station are found in the winter months.

The diurnal variations of NO_x at selected stations are shown in Figures 4.19 - 4.22. The variation for stations T2 and T4 show two peaks undoubtedly due to NO emissions from morning and evening traffic. In addition the depletion of NO_x by reaction with hydrocarbons would be a significant factor in reducing the NO_x levels in daylight hours.

4.2.5 Total Hydrocarbons

Annual Variation

The data for ambient hydrocarbon levels in the GVRD is more limited in that data at only three stations are available for periods in 1979 while for 1980 and 1981 limited data are available at five stations. The annual statistics are given in Appendices B7.1 - B7.3. A summary of these data is presented in Table 4.12.

The paucity of the data do not allow conclusive determination of trends in the levels but indications are that the levels have increased since 1979 except possibly for station 40 (Seymour Dam) where the data is incomplete.

FIGURE 4.18

MONTHLY MEAN TOTAL NITROGEN OXIDES AT SELECTED GVRD STATIONS IN 1980

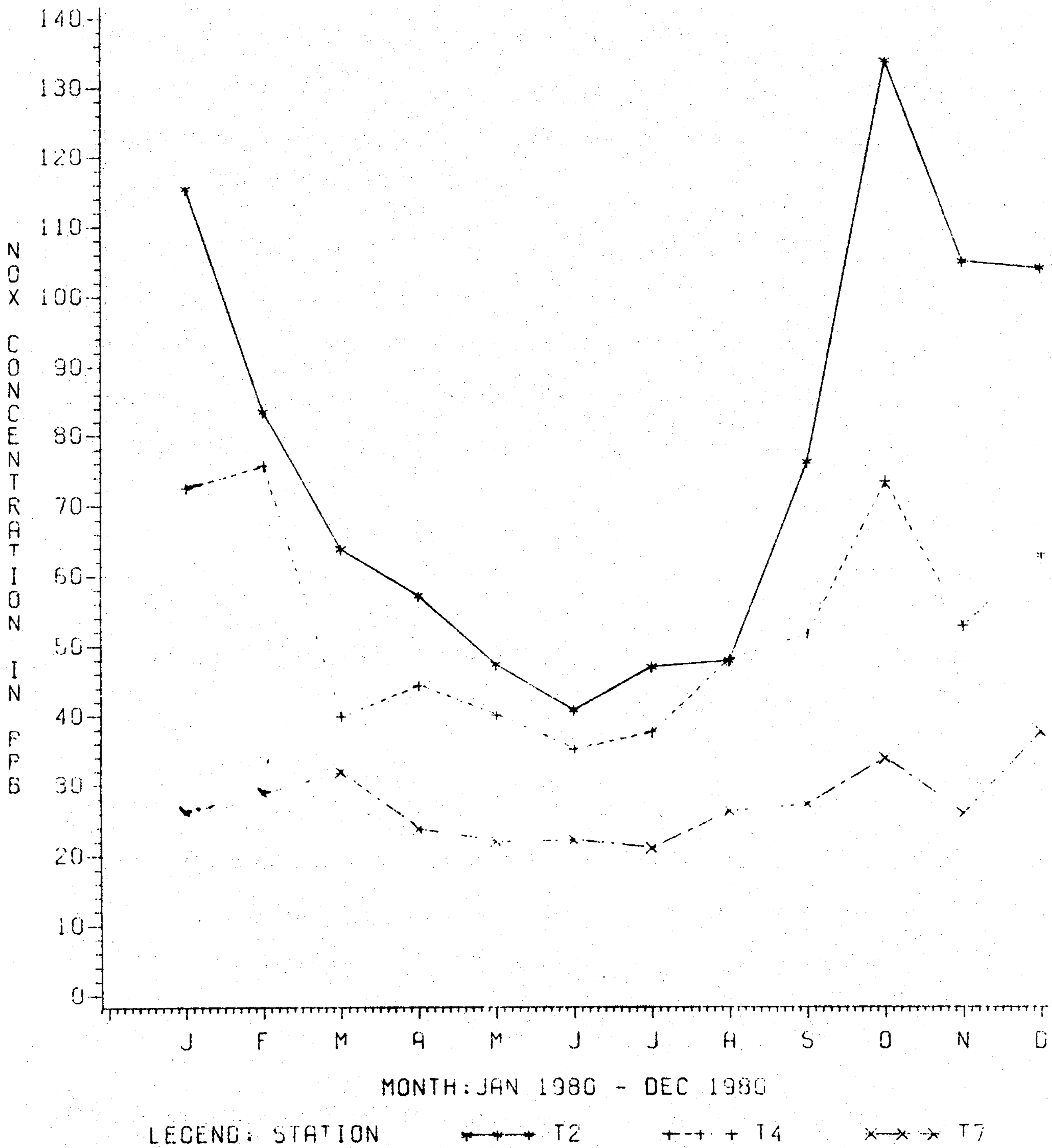


FIGURE 4.19

DIURNAL VARIATION
MEAN TOTAL NITROGEN OXIDES LEVELS
SELECTED GVRD STATIONS FEBRUARY 1980

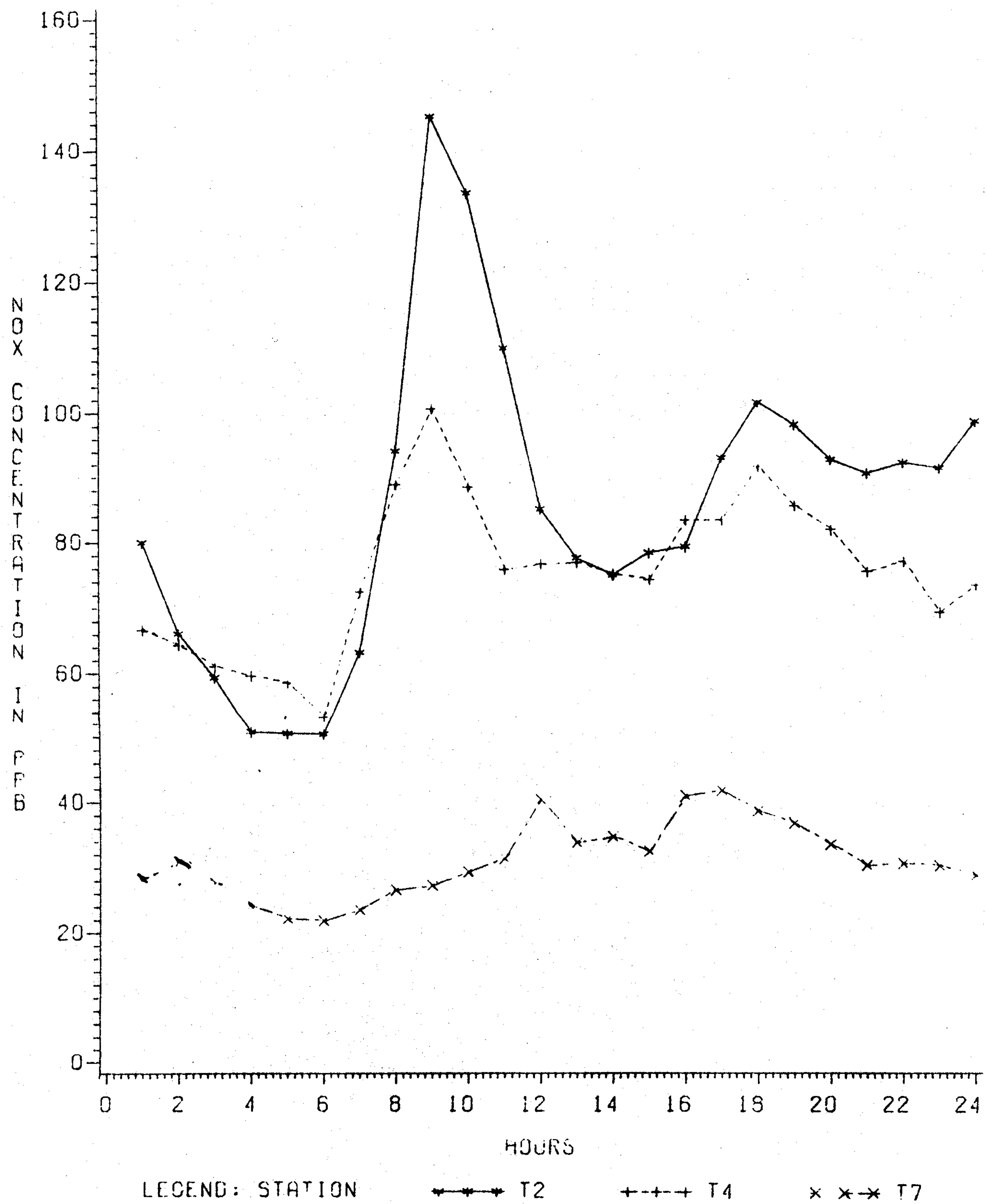


FIGURE 4.20

***DIURNAL VARIATION
MEAN TOTAL NITROGEN OXIDES LEVELS
SELECTED GVRD STATIONS MAY 1980***

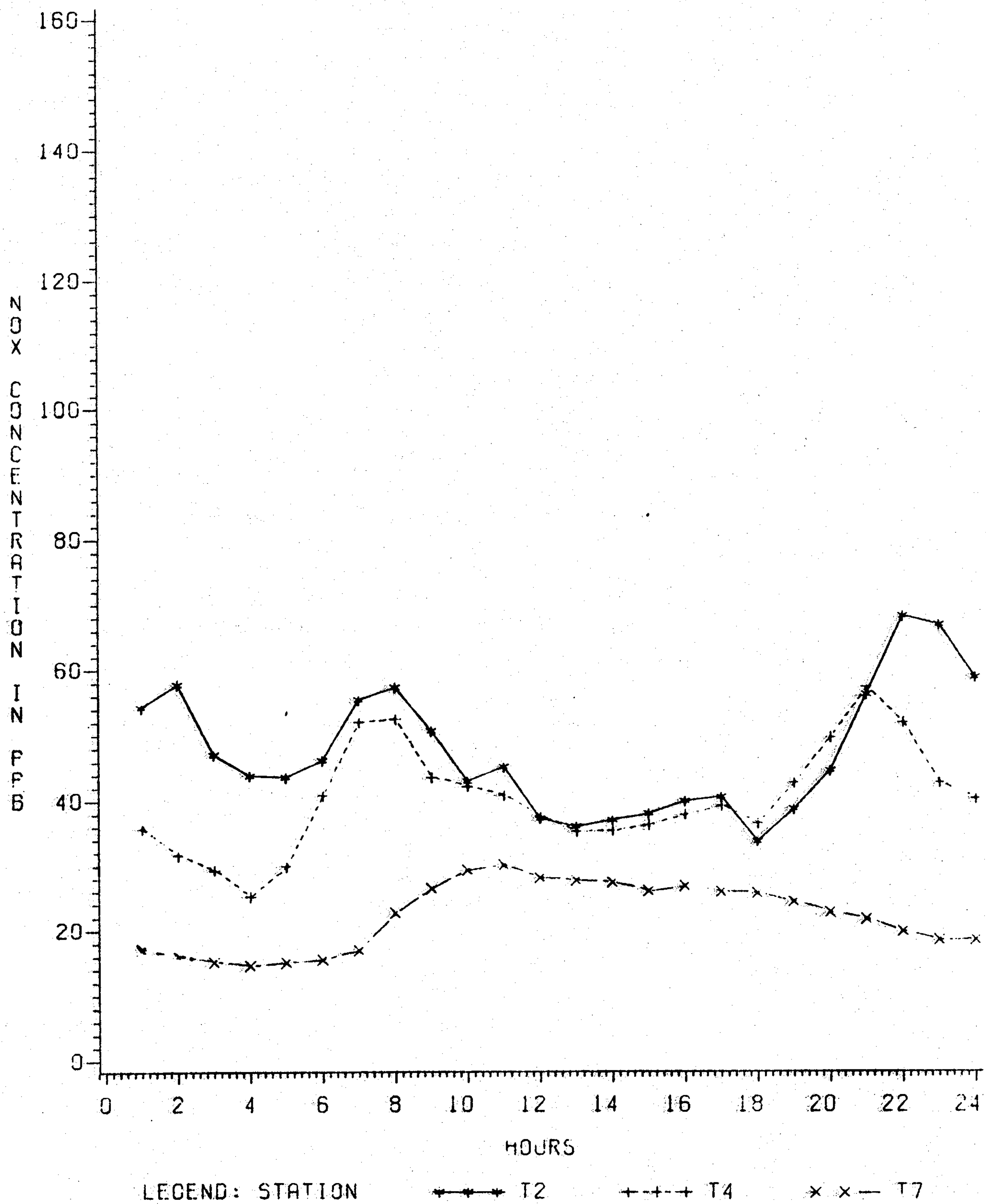


FIGURE 4.21

DIURNAL VARIATION
MEAN TOTAL NITROGEN OXIDES LEVELS
SELECTED GVRD STATIONS AUGUST 1980

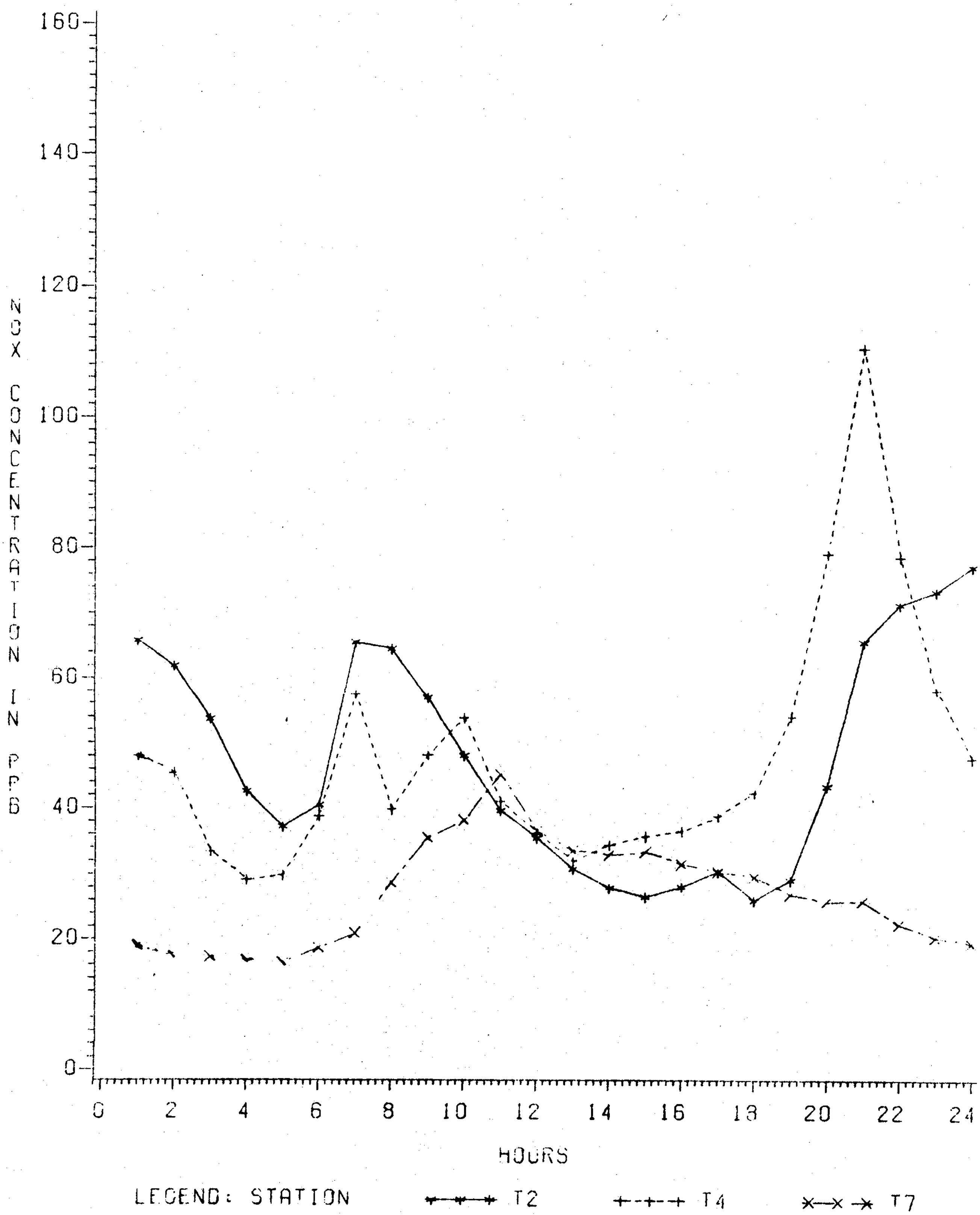


FIGURE 4.22

DIURNAL VARIATION
MEAN TOTAL NITROGEN OXIDES LEVELS
SELECTED GVRD STATIONS NOVEMBER 1980

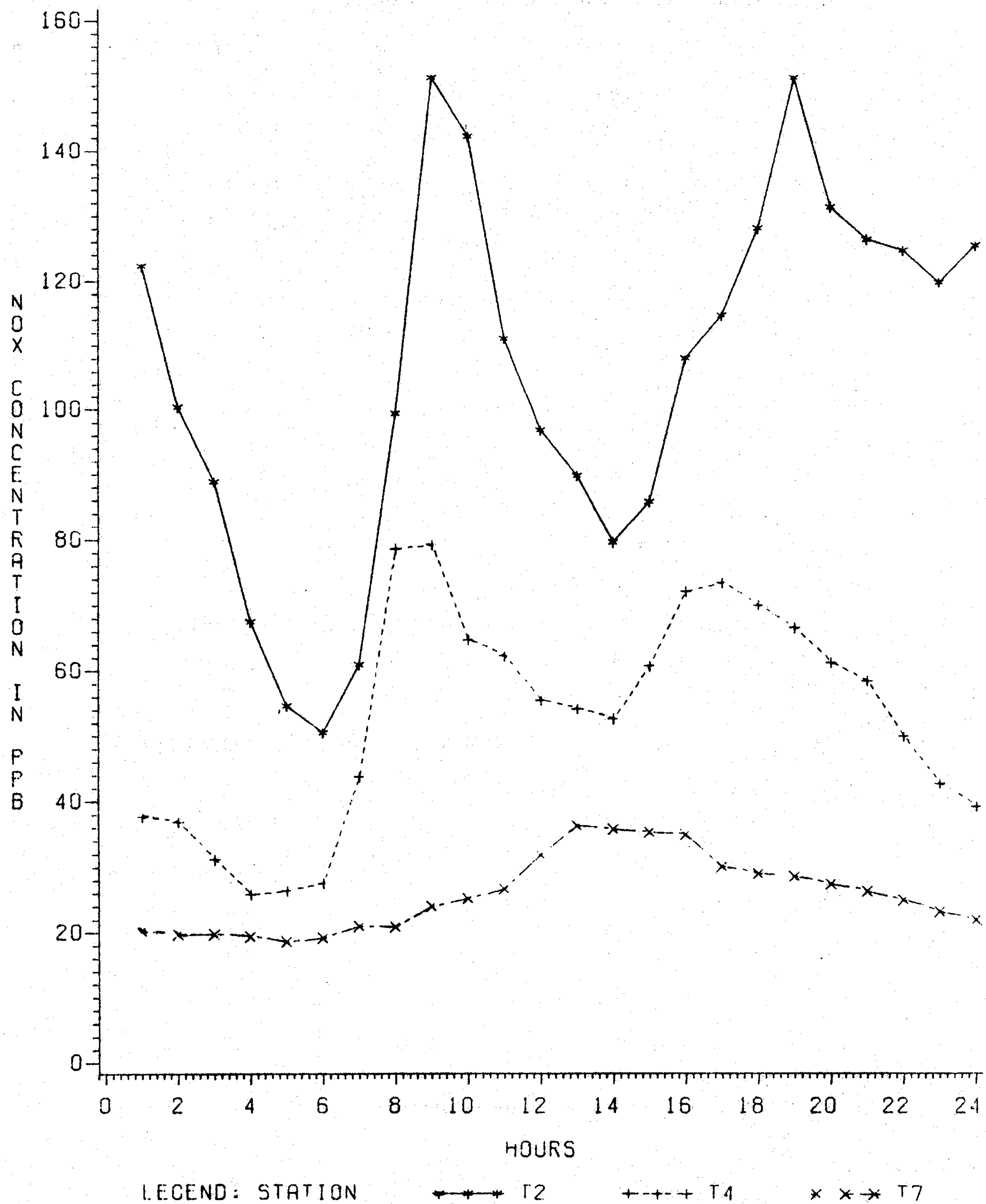


Table 4.12

Annual Mean Total Hydrocarbons Concentrations

Station	Location	Annual Mean (ppb) *		
		1979	1980	1981
T7	Anmore Elemen Sch	3253 (69)	2579 (58)	2399 (94)
40	Seymour Dam	-	2367 (35)	1586 (16)
T2	GVRD Office	2667 (86)	2672 (95)	2439 (53)
T4	Kensington Park	-	2275 (2)	2730 (56)
T9	Rocky Point Park	3563 (18)	2653 (69)	2145 (52)

* Numbers in parenthesis are the percent of possible daily observation for this year.

Bearing in mind the low data recovery it may be conditionally asserted that the hydrocarbon levels are more uniformly distributed over the monitoring sites and therefore show less influence to sources than the other pollutants.

The limited data also do not allow firm conclusions to be made on the seasonal variation of hydrocarbon levels.

Monthly and Diurnal Levels

Figure 4.23 shows the monthly mean Total Hydrocarbon levels at three stations for 1980. There are indications that the levels in the May-September period are lower than those in the cooler months. The range of concentrations for the three stations is 2500 $\pm$ 500 ppb which is a much less marked variation (between stations as well as over the year) than that shown by the other pollutants.

Diurnal Variation

Figures 4.24 - 4.27 show diurnal variation at three stations for four months. In each case the levels at station T7 remain fairly constant throughout each hour of the day for all months. The November and February plots show that increases in total hydrocarbons at T2 and T9 occur at ~ 0800 and 1600 hours corresponding to morning and evening rush hour traffic. These increases are, however, superimposed on very high total hydrocarbon levels. It could be inferred that the mobile

FIGURE 4.23

MONTHLY MEAN TOTAL HYDOCARBONS AT SELECTED GVRD STATIONS IN 1980

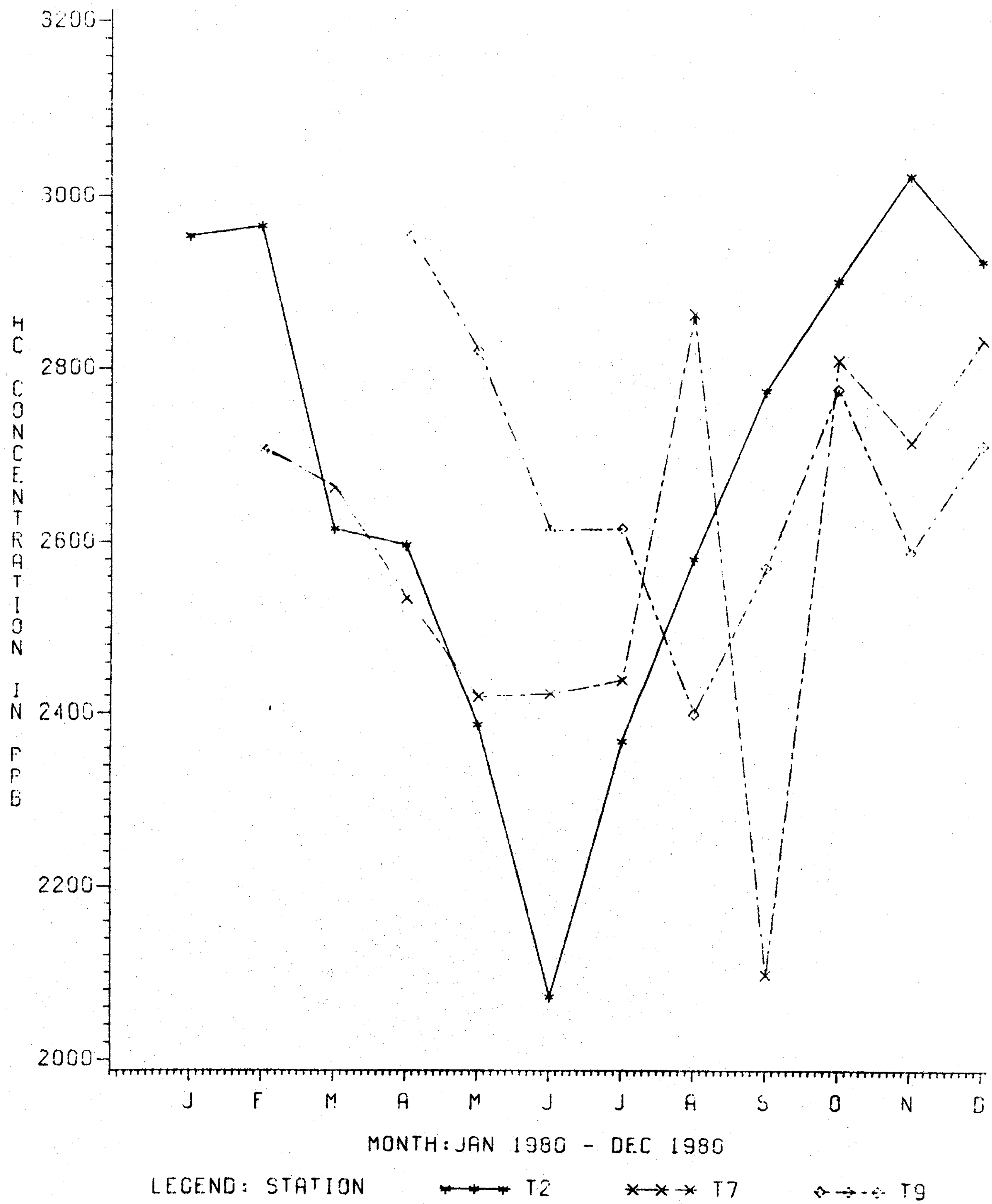


FIGURE 4.24

DIURNAL VARIATION OF TOTAL HYDROCARBONS AT SELECTED GVRD STATIONS FEBRUARY 1980

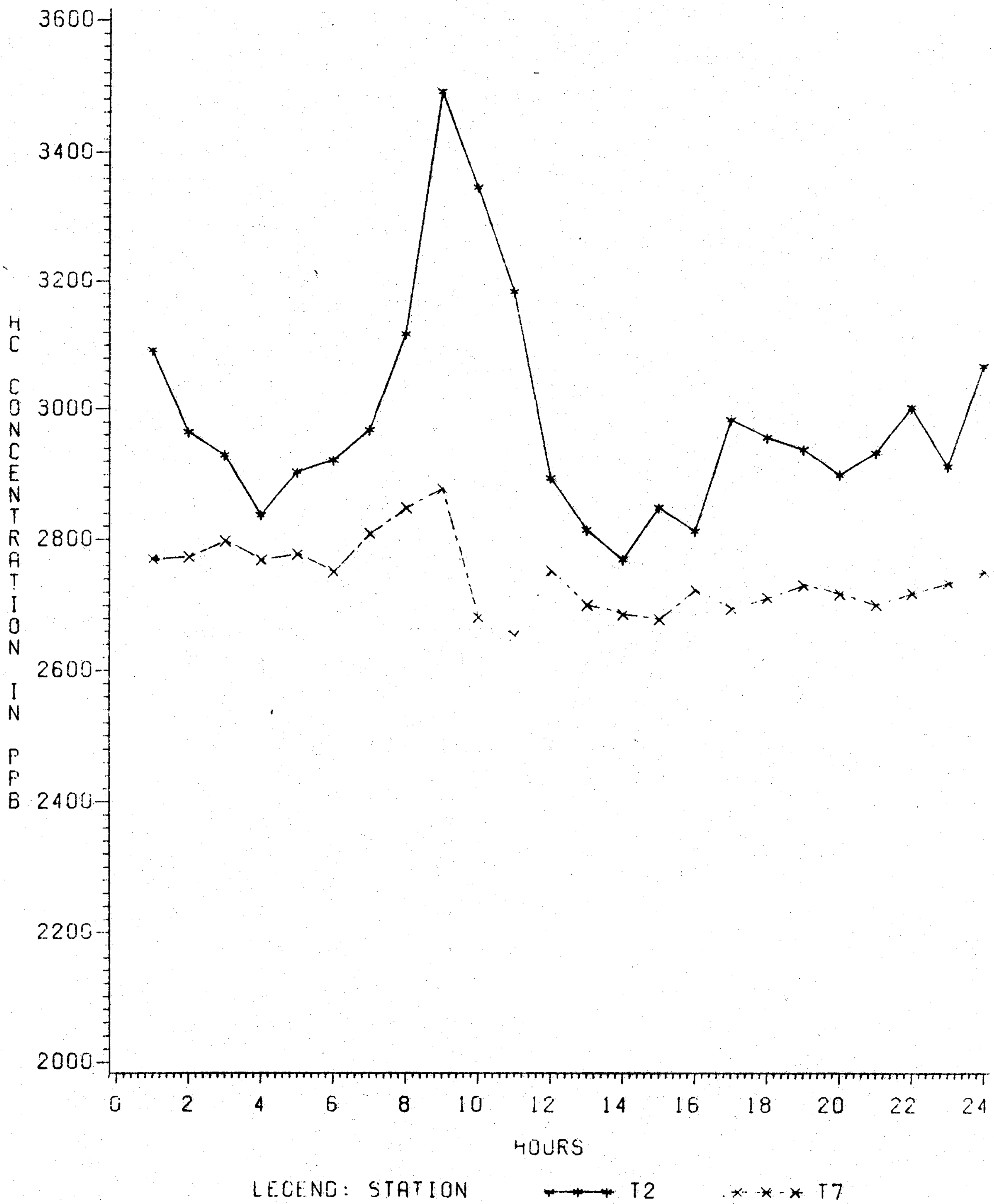


FIGURE 4.25

DIURNAL VARIATION OF TOTAL HYDROCARBONS AT SELECTED GVRD STATIONS MAY 1980

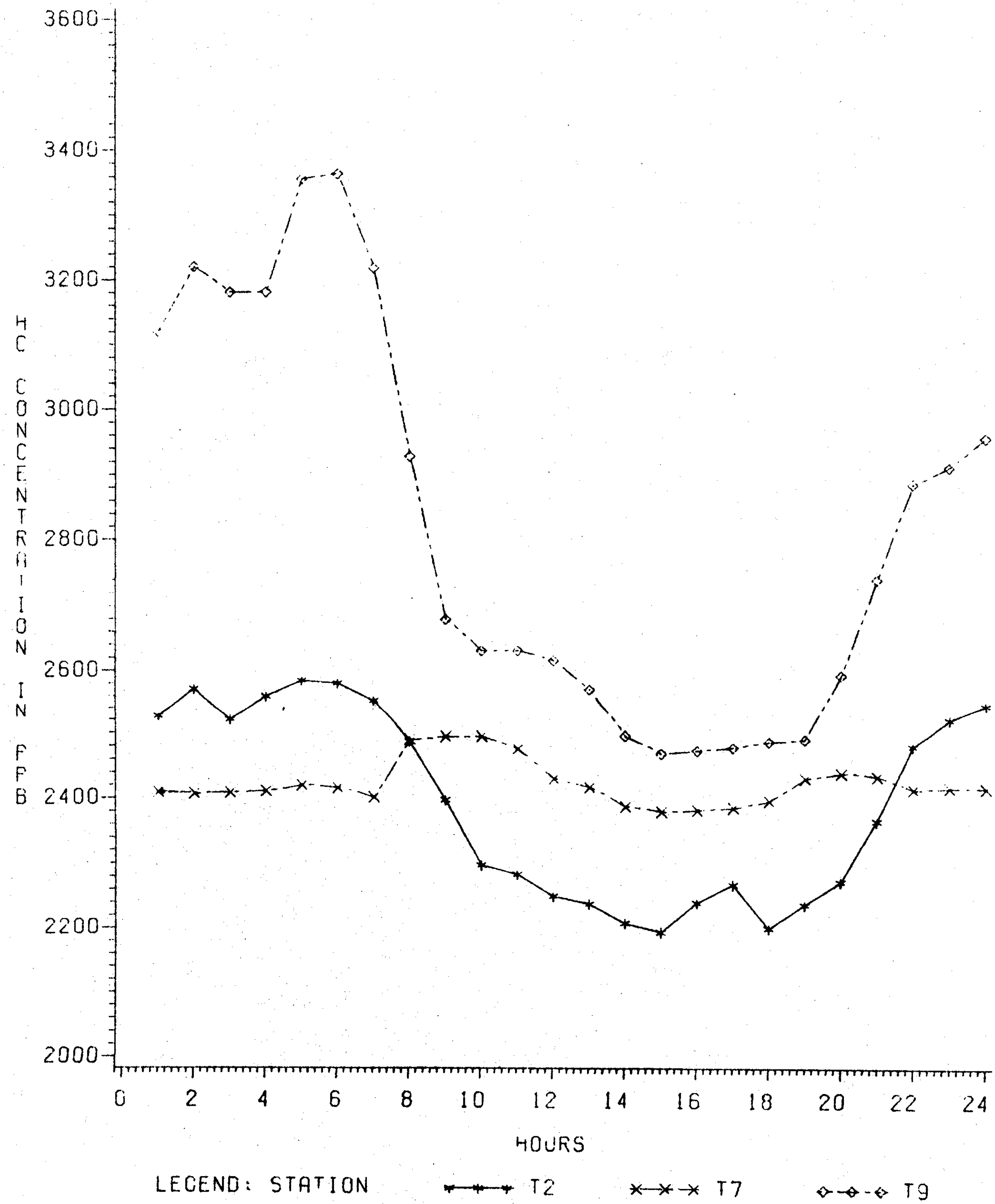


FIGURE 4.26

DIURNAL VARIATION OF TOTAL HYDROCARBONS AT SELECTED GVRD STATIONS JULY 1980

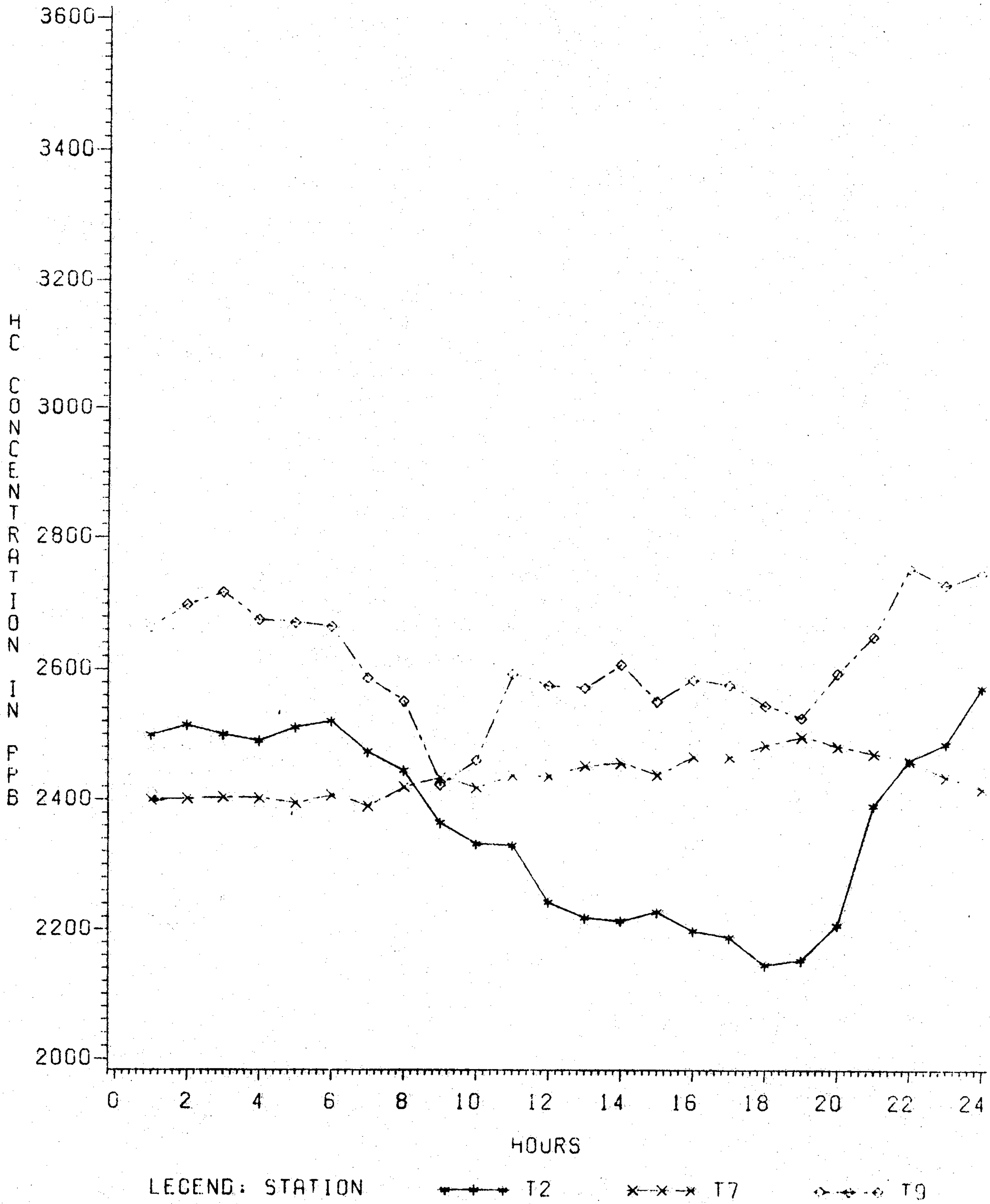
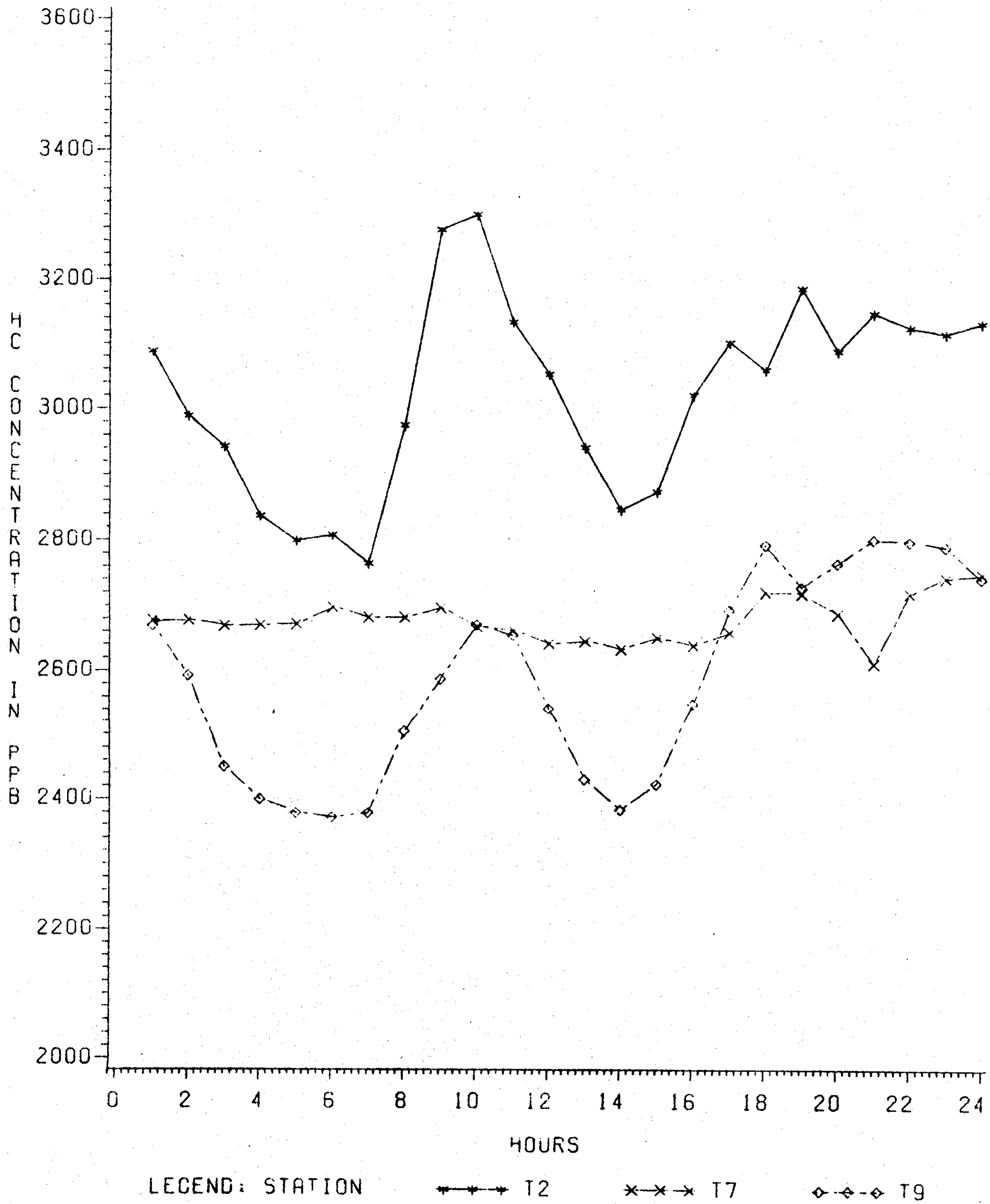


FIGURE 4.27

DIURNAL VARIATION OF TOTAL HYDROCARBONS AT SELECTED GVRD STATIONS NOVEMBER 1980



sources of reactive hydrocarbons constitute a small part of the emission of total hydrocarbons. The patterns for May and July are different in that the total hydrocarbons actually decrease in the morning rush hour time. This decrease is likely to be due to better mixing and hence dilution of pollutants once solar heating becomes effective. Peak levels of total hydrocarbons occur late in the evening starting at ~ 1900 hours.

The available emissions inventory indicate that mobile sources of volatile organic compounds account for ~ 51% of these emissions. The emissions inventory data do not have any temporal or spatial resolution. It is therefore inappropriate to comment on the differences in the diurnal variation of total hydrocarbons at different times of the year or for different locations in terms of emissions.

5. OZONE EPISODE ANALYSIS

In order to determine the controls on the occurrence of ozone episodes, we first suggest some definitions, and use them to stratify the data according to criteria to describe magnitude, spatial extent and persistence of significant ozone levels (Section 5.1). Having defined ozone episodes, we proceed to examine their temporal (Section 5.2) and spatial (Section 5.3) distribution. We then return to study some of the finer features of the diurnal ozone curve, particularly for those cases with unusual times of maximum ozone concentration (Section 5.4). The chapter concludes with a summary (Section 5.5).

5.1 Criteria for Ozone Episodes

In order to quantify the severity of the occurence of high ozone levels, ozone episodes were defined and identified. The criteria for episodes were designed to describe:

a) a critical exposure level
b) a duration
c) spatial distribution
d) persistence.

The exposure level and duration aspects were incorporated into the establishment of criteria that define <u>station episodes</u>. These criteria are:

i) The 1-hour average ozone concentration should be equal to or exceed 82 ppb at a station on a particular day;

ii) The ozone concentration should be equal to or greater than 20 ppb for at least 10 hours (including the hour or hours of the maximum level) for the same station on the same day.

The upper level of 82 ppb was selected to coincide with the current Canadian National maximum acceptable 1 hour level. This level is a convenient and familiar frame of reference.

The lower level of 20 ppb was arbitrarily selected and was chosen to be above 'normal' or non-episode minimum levels.

Analysis of all the available data showed that these criteria were satisfied in 237 cases. Since two or more different stations often satisfied the criteria on the same day, there were 139 different days - episode days - which were identified.

Additional criteria were imposed to define the spatial extent of episodes and also the persistence over an extended period of time. These criteria were:

iii) Station episode conditions should occur at 3 or more stations on the same day;

iv) Episodes should persist (at 3 or more stations) for two or more days.

An areal episode is defined as satisfying criteria iii) and for a persistent episode, both criteria iii) and iv) are met.

The statistics on the various episodes as defined above are given in Table 5.1.

5.2 Annual and Seasonal Distribution of Episodes

The monthly occurrence of station episode days over the four year period is summarized in Table 5.2. Plots of the variation of the number of occurrences of station episode days by month over time entire period and for each year are shown in Figures 5.1 and 5.2 respectively. It should be noted that complete data for 1981 are not available but the unavailable data (mostly September - December 1981) would not significantly affect the pattern since few station episode days occur in these months.

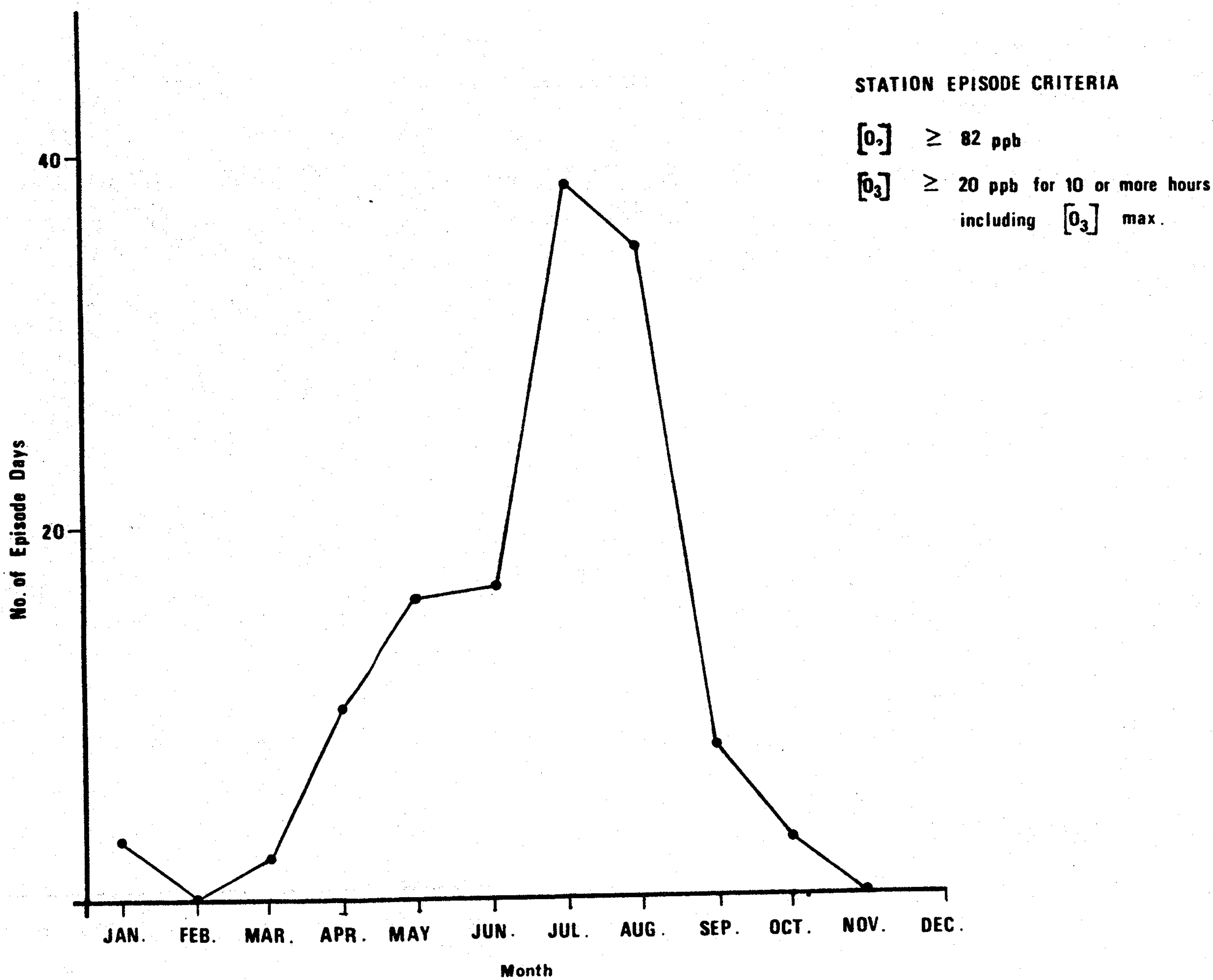
The data in Table 5.2 and Figures 5.1 and 5.2 clearly indicate that high ozone levels consistently occur most frequently during the six (6) month period, April to September. Most episode days occur in the months

Table 5.1

Statistics On Ozone Episode Criteria

Criteria	Designation	Frequency
1) $[O_3] \geq 82$ ppb:$[O_3] \geq 20$ ppb for 10 or more hours	Station Episode	237
2) Criterion 1 at 3 or more stations	Area Episode	21
3) Criterion 2 for 2 or more consecutive days	Persistent Episode	5
4) Days on which station episodes occurred	Station episode days	139

5.1 FREQUENCY OF STATION EPISODE DAYS BY MONTH 1978 - 1981



5.2 STATION EPISODE DAYS FOR EACH MONTH FOR EACH YEAR 1978 - 1981

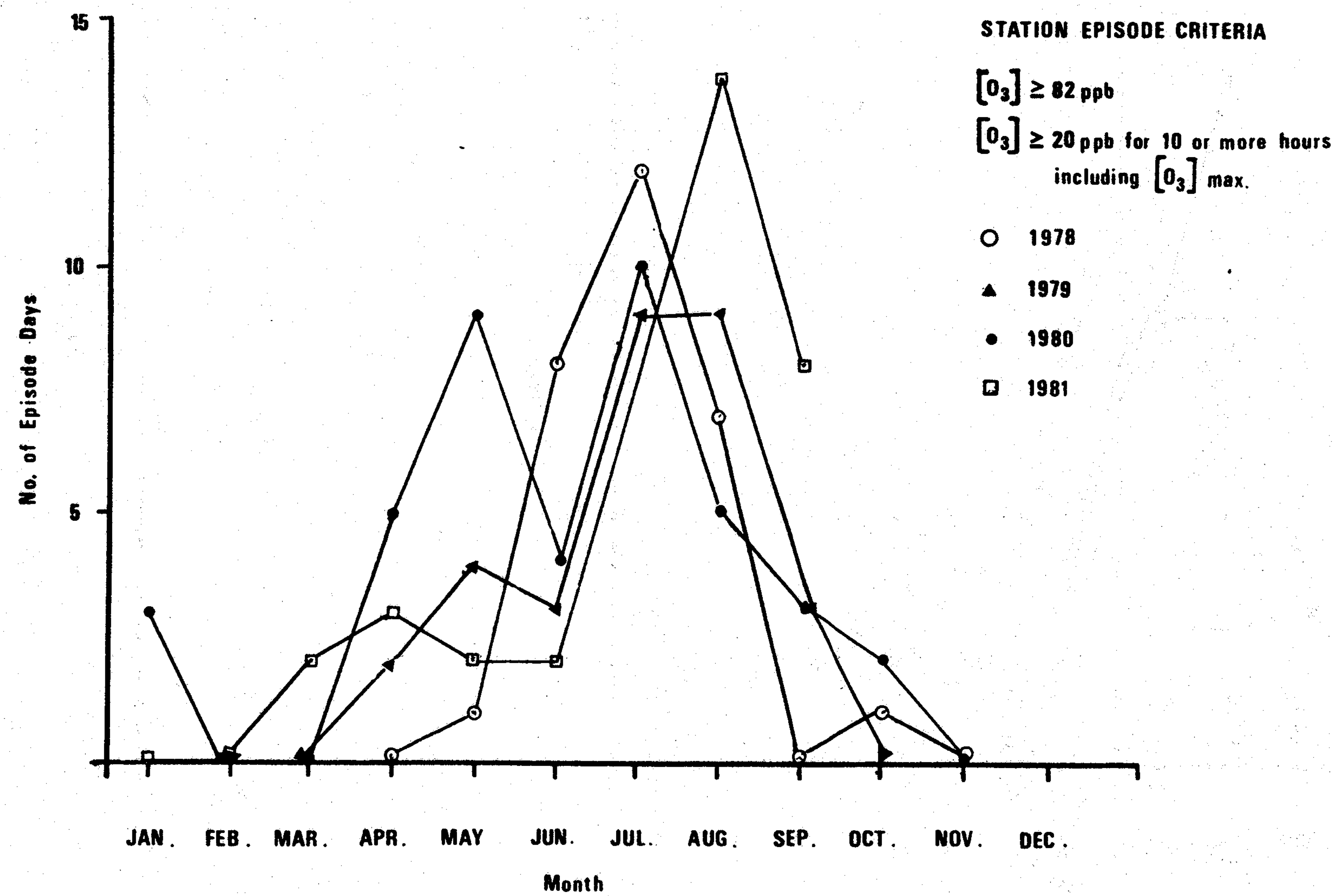


Table 5.2

Occurrence of Station Episode Days By Month 1978 - 1981

Month	Number of Observations				Total
	1978	1979	1980	1981	
Jan.	0	0	3	0	3
Feb.	0	0	0	0	0
Mar.	0	0	0	2	2
Apr.	0	2	5	3	10
May	1	4	9	2	16
June	8	3	4	2	17
July	12	9	10	8	39
Aug.	7	9	5	14	35
Sept.	0	3	3	8	14
Oct.	1	0	2	-	3
Nov.	0	0	0	-	0
Dec.	0	0	0	NA*	0
Total	29	30	41	39	139

*Not available

July and August. This corresponds to the months with highest temperatures and greatest amounts of sunshine.

5.3 Spatial Distribution of Episodes

The frequency with which station episodes occurred at the various stations are tabulated (Table 5.3) and illustrated graphically in Figure 5.3. Station T7 shows the highest number of episodes, followed by T9, T5, T4 and T10. Interestingly, the number of episodes at Seymour Dam (40) is also high considering the limited time for which data have been available (since 1980).

The location of T7 together with the low NO or NO_x levels at this station but high ozone levels must mean that precursors generated upwind (west) of this station are responsible for the high ozone levels at T7. Similar but less striking situations probably exist for stations T9, T4 and T5. The relatively infrequent occurrence of ozone episodes at stations T1, T2, T3 and T8 but high concentration of precursors (NO or NO_x and hydrocarbons) clearly indicates that the precursors are transported away from these stations by westerly flows.

5.4 Features of Diurnal Variation of Ozone Levels

The variation of ozone levels at GVRD stations throughout the course of a day followed the classic pattern as found elsewhere (Stern, 1968). Figures 5.4 and 5.5 illustrate the ozone levels on

5.3 OZONE STATION EPISODES AT VARIOUS GVRD STATIONS.

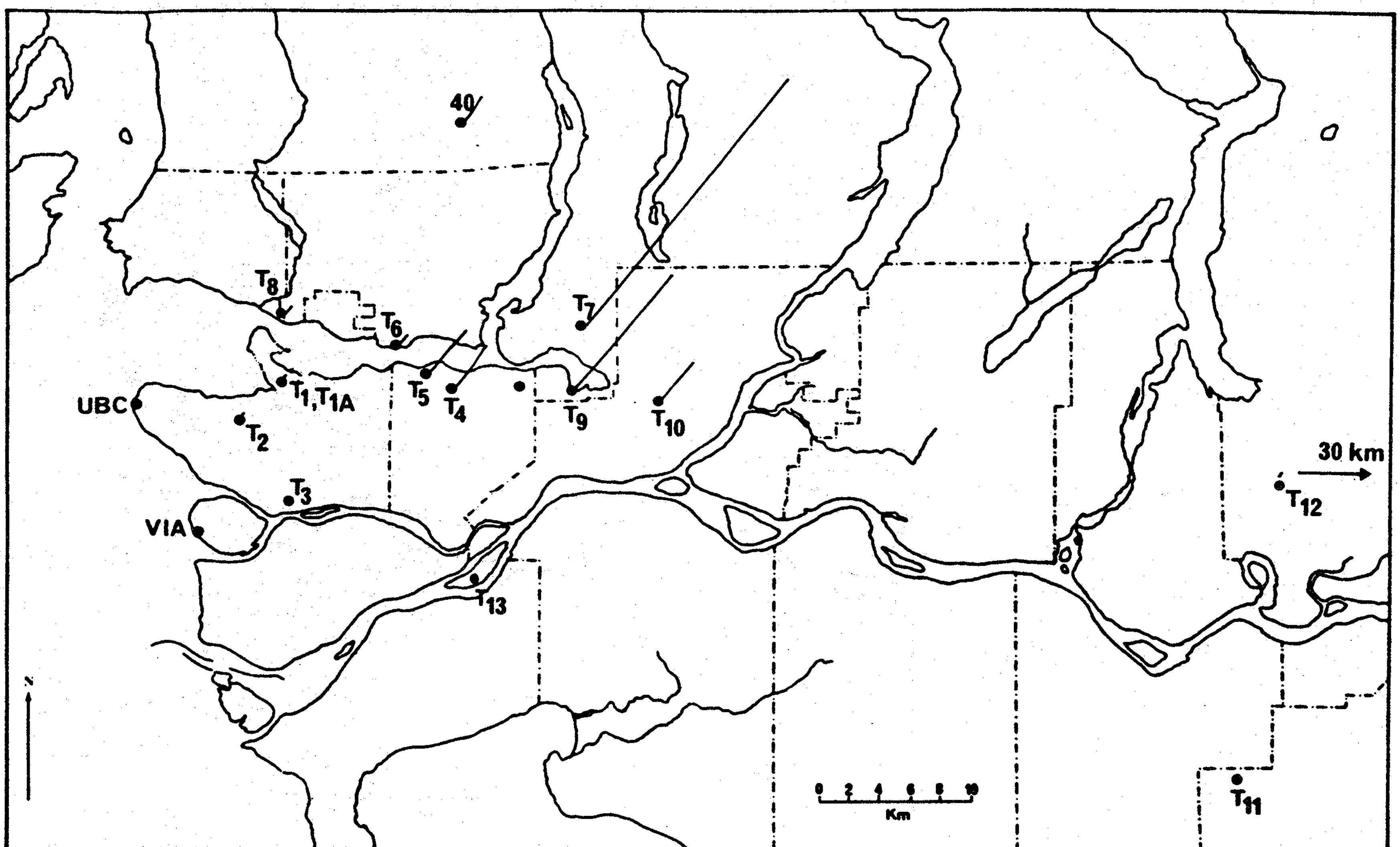


Table 5.3

Numbers of Occurrences of Station Episodes

1978 - 1981

Station	Number of Station Episodes (1978 - 1981)
T5	19
T6	4
T7	106
T8	3
T10	16
T11	1
40	11
T2	4
T3	4
T1	1
T4	17
T9	49
T1A	0
T12	2
Total	237

the same day for different stations (Figure 5.4) and on consecutive days for Station T7 (Figure 5.5). The maximum ozone concentration occurs most frequently between 1100 and 1800 hours. Occasionally a secondary maximum occurring late in the evening, 2000 - 2200 hours, is evident. The distribution of the hour at which O_3 maximum occur for episode days is illustrated in Figure 5.6. Most maxima occur between 1300 and 1600 hours, which coincides with time of maximum solar intensity/surface heating.

Individual cases for which maximum ozone levels did not occur between 1100 and 1800 hours are listed in Table 5.4.

The cases were examined individually primarily to determine whether or not there was any reason to suspect the accuracy of data and then to attempt explanation. One potential explanation would be the possibility of long range transport of ozone into the area. In the first two cases of unusual peak ozone levels, no data for NO, NO_2, NO_x or HC were available. Both days showed O_3 peaks that were broad and the increase started around noon but an additional increase occurred after 1600 hours on both days. On those days no other station showed late O_3 maximum values. Station T10 is the most easterly station (except for T11 and T12) and it is likely that the late maximum is in part the result of transport of ozone from the vicinity of station T9 towards T10. This effect is particularly striking on June 4, 1978. Figures 5.7 and 5.8 show some of the ozone data for June 3 and 4 respectively and illustrate the late peaking of ozone at T10.

FIGURE 5.4

OZONE CONCENTRATIONS AT SELECTED GVRD STATIONS ON AN EPISODE DAY:JULY 21,1978

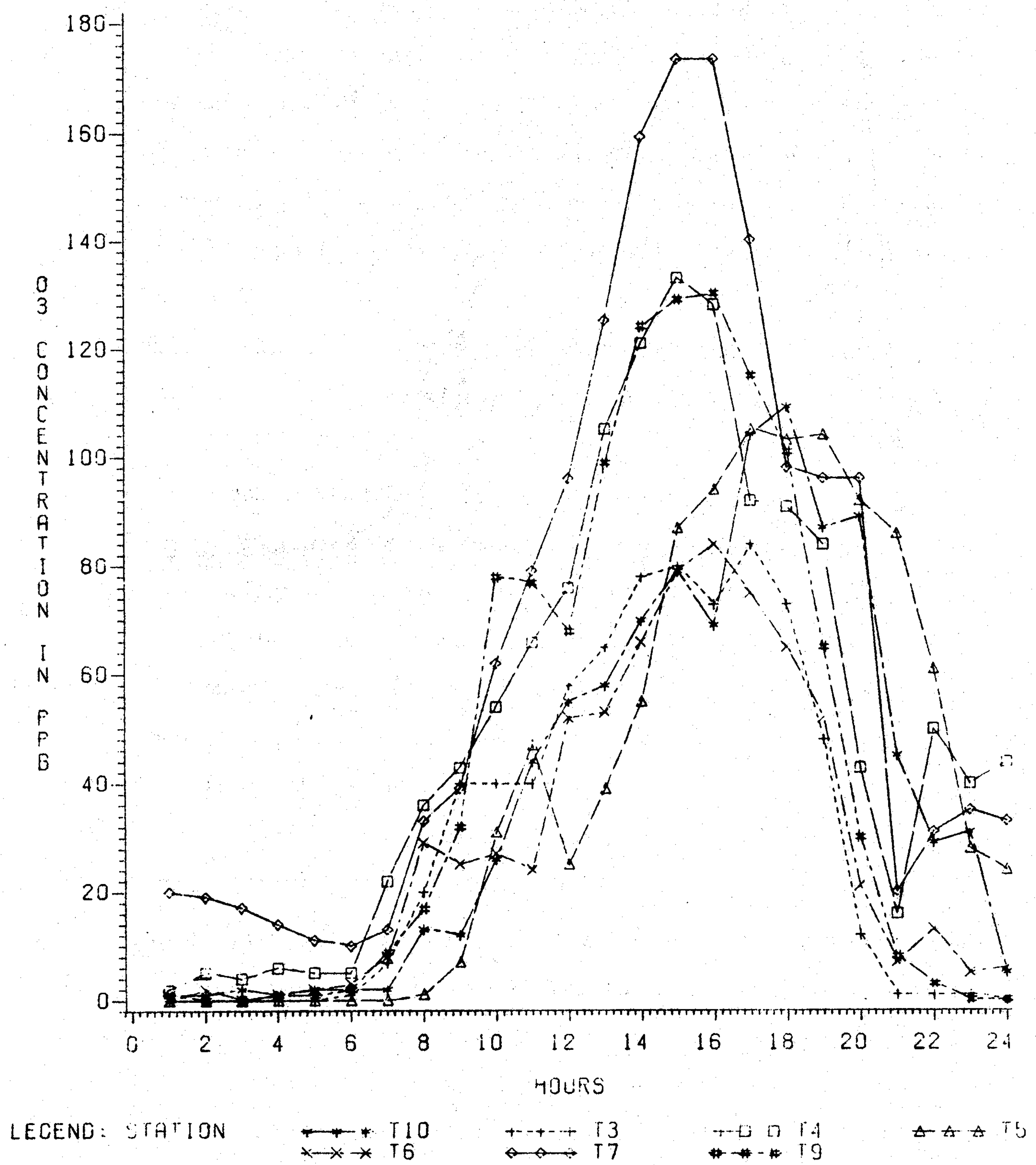
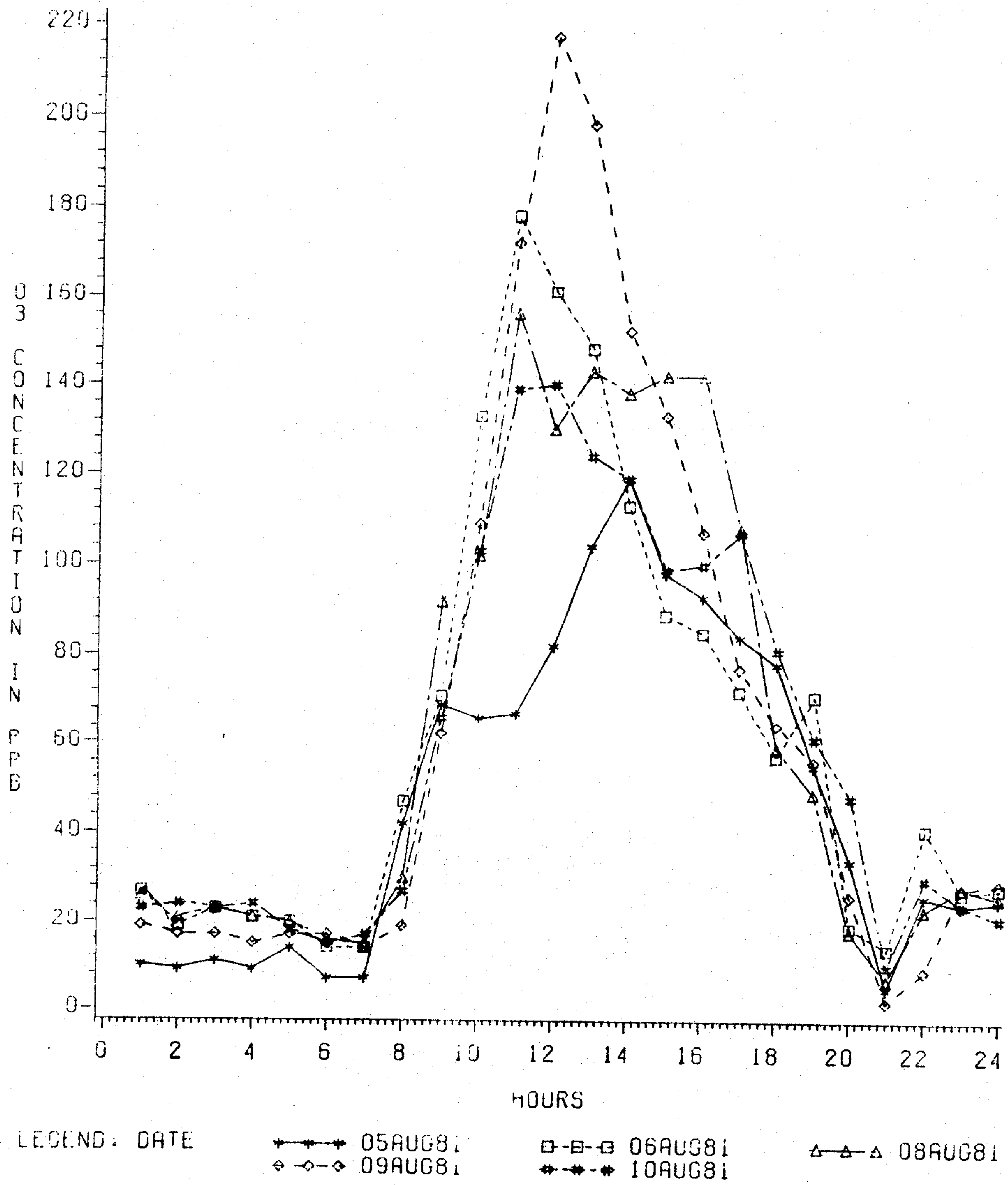


FIGURE 5.5

OZONE CONCENTRATIONS AT STATION T7 ON CONSECUTIVE STATION EPISODE DAYS



5.6 RELATIVE FREQUENCY OF HOUR AT WHICH MAXIMUM OZONE LEVELS OCCUR ON EPISODE DAYS

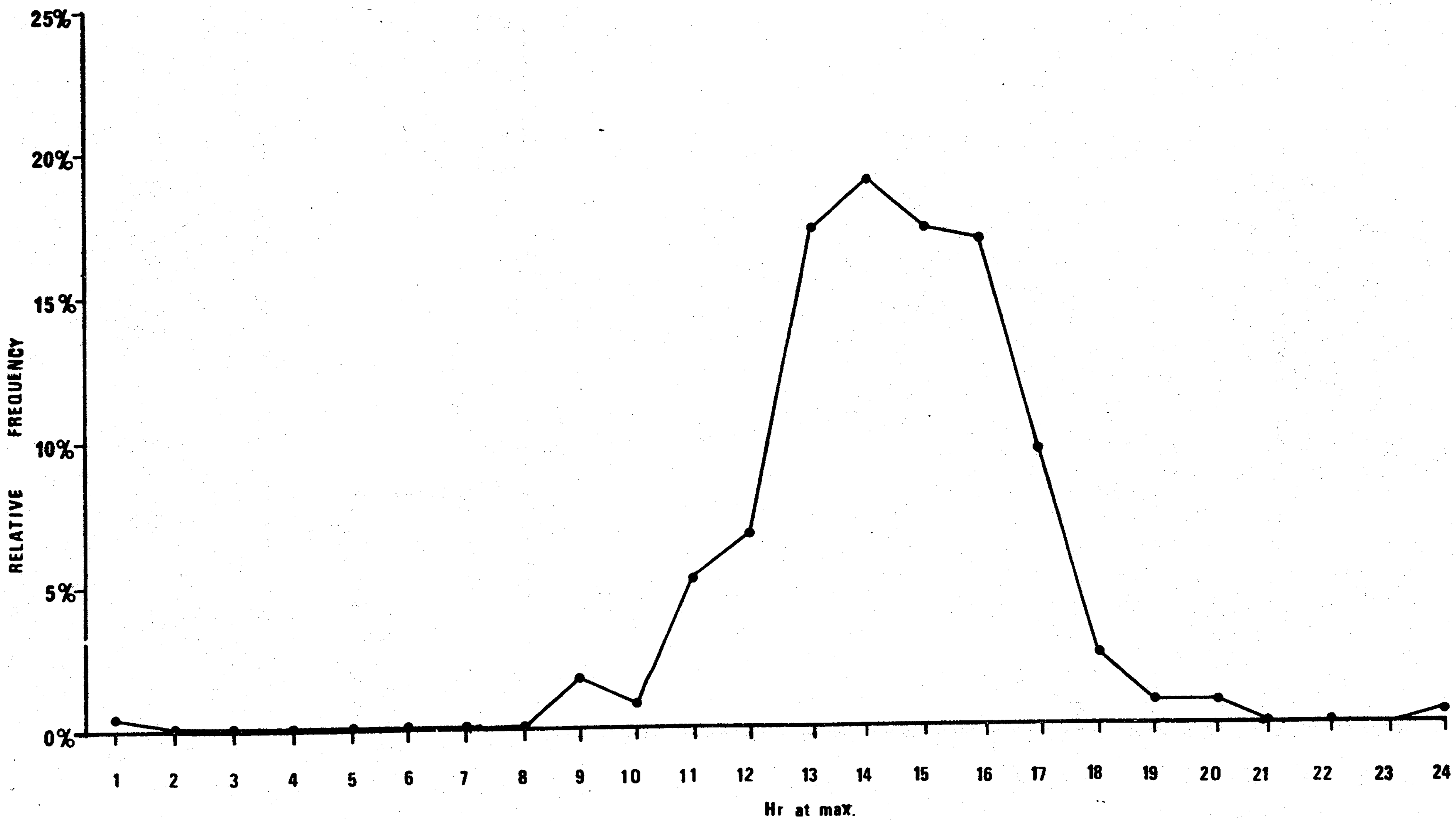


Table 5.4

Ozone Station Episodes With Peculiar Times At Which Maximum Ozone Concentrations Occur

Date	Station	HR Max
3 Jun 1978	T10	2000
4 Jun 1978	T10	1900
22 Jul 1978	T4	0900
23 Jul 1978	T4	0900
3 Aug 1978	T10	1900
13 Oct 1978	T4	0400
10 Jan 1980	T7	0100
11 Jan 1980	T7	2400
19 May 1980	T9	2000
9 Aug 1981	T5	1000
9 Aug 1981	T6	0900
13 Sep 1981	T5	1000
16 Sep 1981	T5	0900

FIGURE 5.7

OZONE DATA
FOR JUNE 3,1978

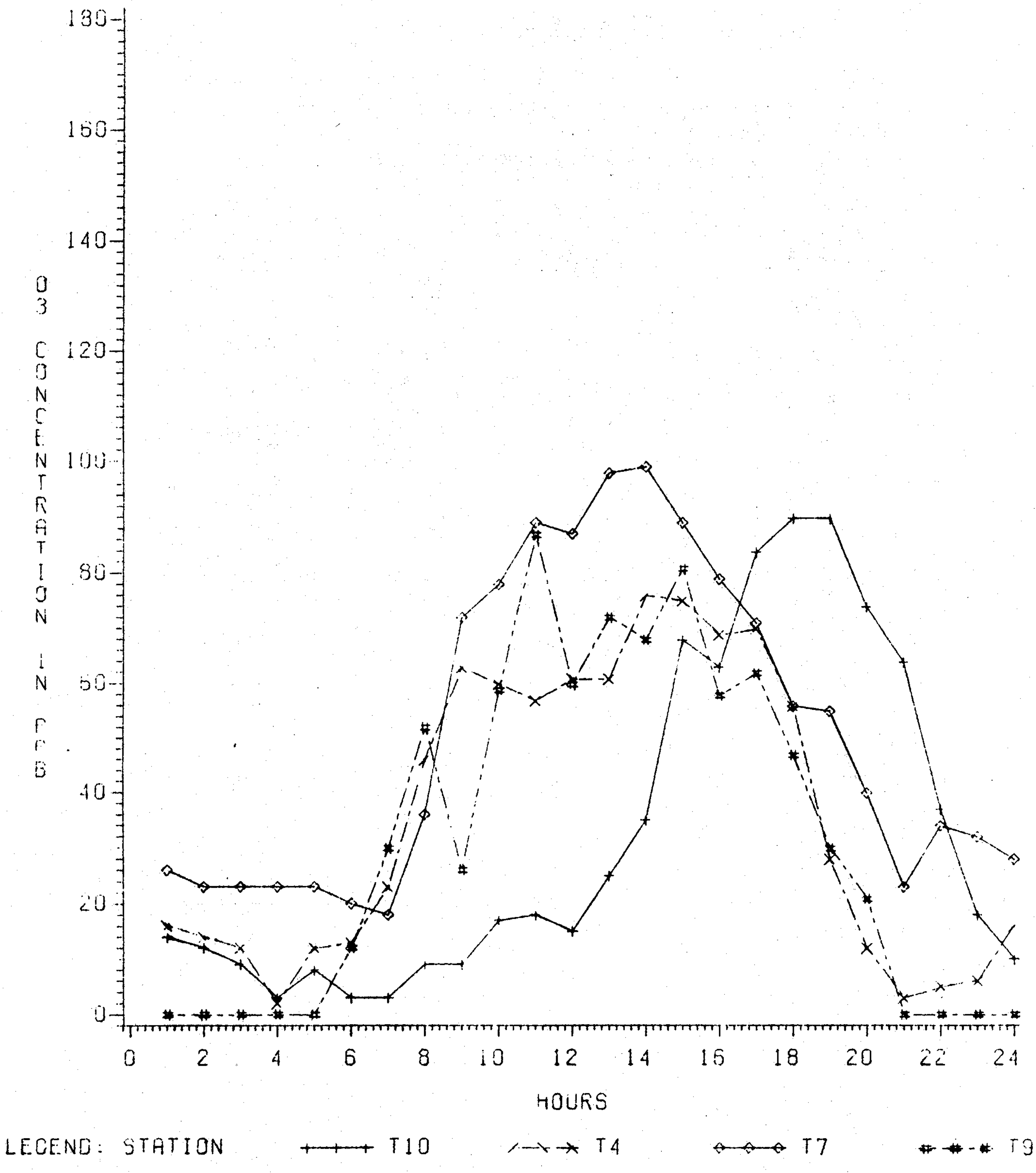
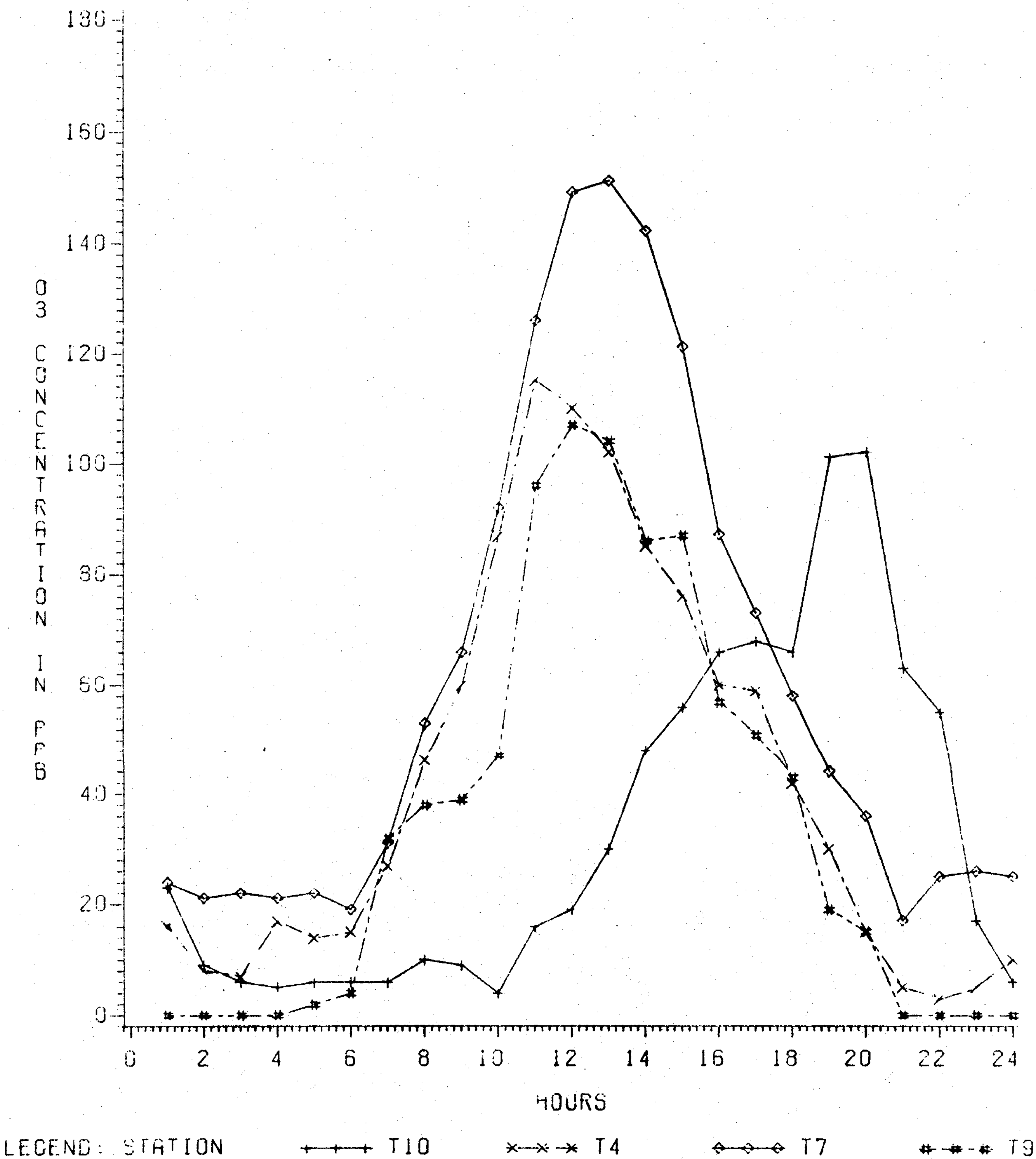


FIGURE 5.8

OZONE DATA
FOR JUNE 4,1978



The ozone maxima for July 22 and 23,1978 occurred at station T5 at 0900. No NO, NO_2 or HC data are available at station T5 for those days. Of both days, at the nearby stations T4 and T6, a similar early peak occurred only at T5 (0800) on July 22, 1978.

For August 3, 1978, the late maximum is also at station T10 and again, no other data for NO, NO_2 or HC are available. The maximum at T11 was also late (1800) but this station is over 40 km east of T10.

For 13 October, 1978, a peculiar maximum in the ozone concentration occurred at 0400 for station T4. Another peak also occurred later in the day at 1200 hours. No data for NO, NO_2 or HC are available and in addition ozone levels at other stations did not show elevated values at that time of morning (between 0200 and 0700 hours). The likely cause is instrument malfunction.

On January 10 and 11, 1980, station T7 showed ozone maxima at 2400 and 0100 respectively. For January 10, somewhat higher than normal ozone levels were also recorded for station T3, T2 and T10. A similar situation on the following day existed where even higher levels at all stations even T8, T1, T2 and T3 were noted between 0100 and 0500 hours. The occurrence of a second maximum in ozone levels at night is common as ozone from upper levels replenishes the depleted lower levels. The occurrence of a second maximum in ozone levels at night is sometimes observed (Kroenig and Ney 1962, Samson, 1978) as ozone above the mixed layer (established in the day) becomes mixed into the lower level at night. The effect of this mixing will of course be less pronounced once the ground level NO concentration is high since NO rapidly reacts with ozone. Another possibility would be the transport of ozone (formed on the previous day) back over the GVRD.

The data for May 19 showed that similar late ozone peaks occurred at station T9 as well as T7 and T10 - two nearby stations - whereas at stations T8, T1, T2 and T3 the behaviour was different in that there were peaks at earlier times.

The pattern of ozone levels on August 9, 1981 is consistent with the NO data in that the ozone peak begins to decrease as soon as NO builds up. The ozone levels at station T5 also peaked relatively early in the day (1000 hrs). Station T4 - a nearby station had the ozone peaking at 1100 hrs while T7 and T10 peaked at 1200 and 1300 hrs respectively. The progressive late peaking of the ozone levels at stations are futher inland is consistent with transport of pollutants. The winds for August 9 were light and variable up to 0900. Thereafter the winds at T8, T6 and T7 were between westerly and southwesterly. Except for T8 where wind speeds were 7 - 12 km/hr up to noon, the wind speeds on that morning were low; 0 - 2 km/hr.

For September 13 and 16, station T5 showed early peaking of ozone levels while other easterly stations peaked later. The stations east of T5, namely T8, T1, T2 and T3 had low ozone levels which peaked between 1200 and 1400 hours.

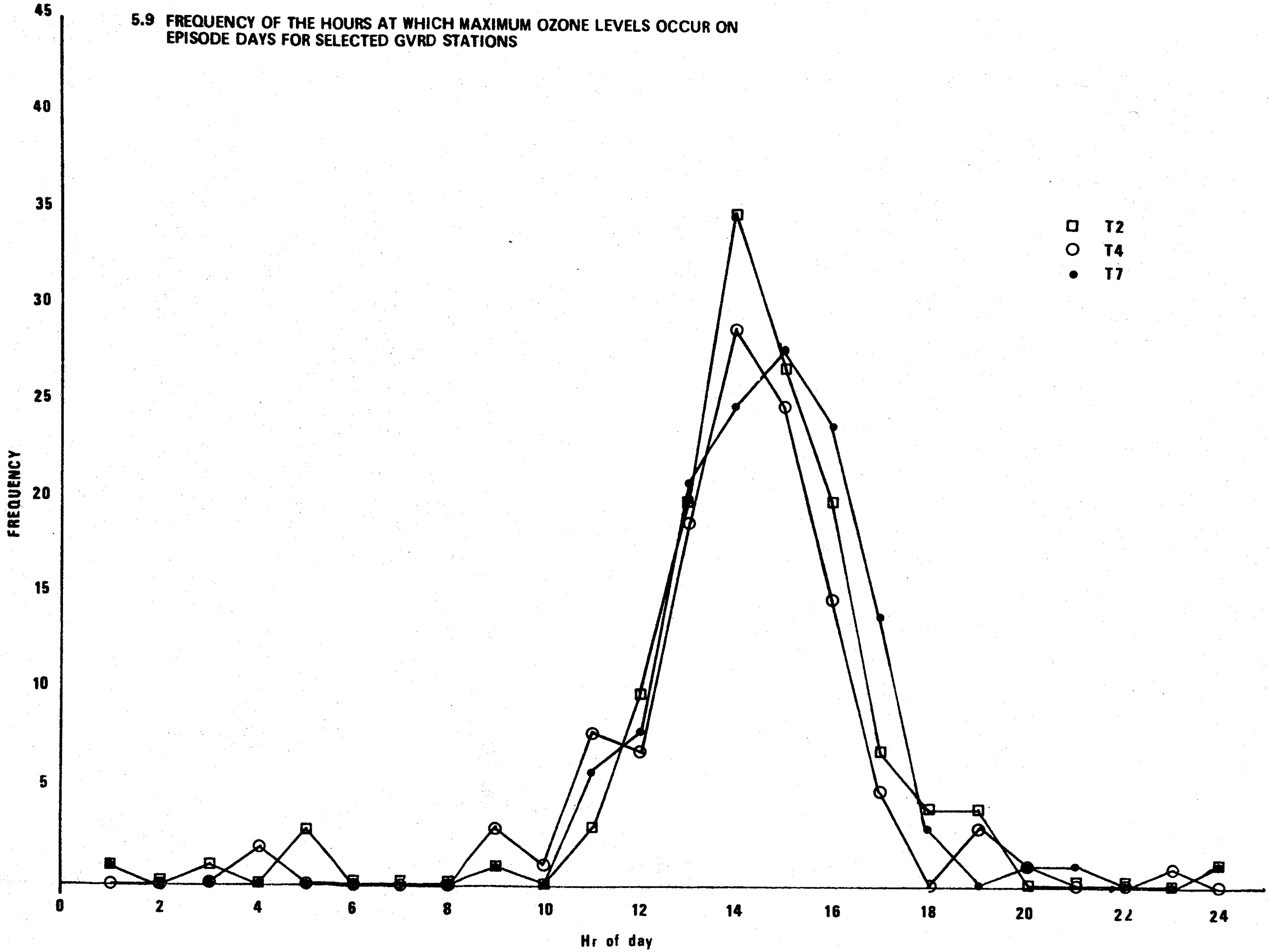
The foregoing analysis of 'unusual' times of day for ozone maxima is consistent with a predominance of only local formation of ozone. The effect of sea breeze transport of the ozone and its precursors can probably account for the cases in which ozone maxima occur at unusual times.

The times at which peak ozone levels occurred at each station were tabulated and the distribution of these times for stations T2, T4 and T7 is shown in Figure 5.9. A similar plot for the most easterly stations T11 and T12 along with Seymour Dam (40) is given in Figure 5.10.

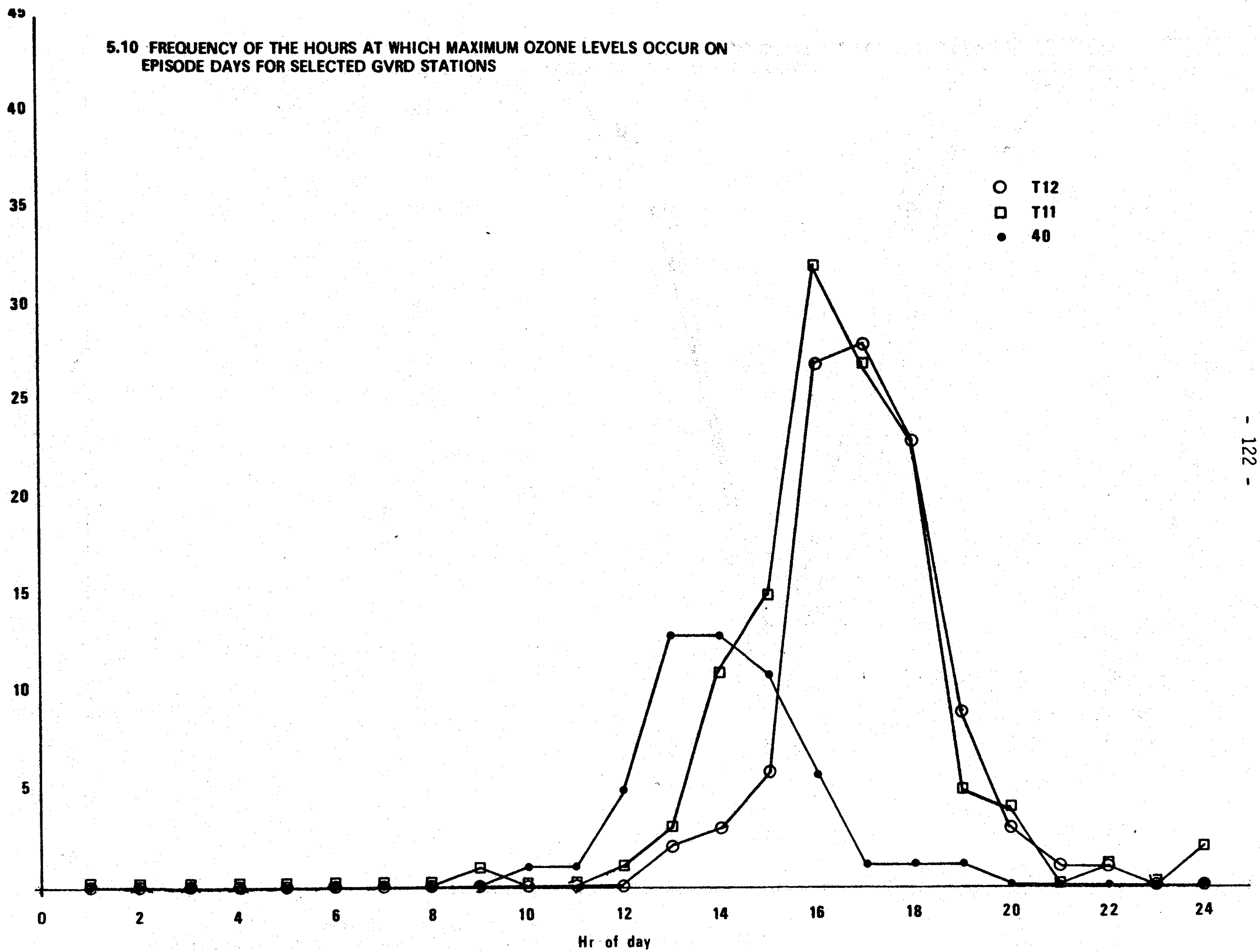
The plots in Figure 5.9 suggest that T7 experiences peak ozone levels slightly later ($\sim$ 1 hour) than stations T2 and T4. There is very conclusive evidence, however, that stations T11 and T12 (Abbotsford and Chilliwack Airports, respectively) experience ozone peaks later in the afternoon (see Figure 5.10) than the more westerly stations (T7, T4, T2, etc.). The transport of pollutants from the GVRD area towards these stations is again suggested. Figure 5.10 also suggests that the ozone peak at Abbotsford (T11) occurs earlier by $\sim$ 1 hour than that at Chilliwack. The distribution of HR (max) for Seymour Dam (40) indicates that the peak ozone levels occur near 1400 hours and suggests that transport of ozone or its precursors to that station from the GVRD is not a factor.

These features again suggest that transport of ozone and its precursors in an easterly direction (with the sea breeze) may be an important ozone episode characteristic. The return flow (land breeze) does not appear to transport significant amounts of ozone (on the basis of Figures 5.9 and

5.9 FREQUENCY OF THE HOURS AT WHICH MAXIMUM OZONE LEVELS OCCUR ON EPISODE DAYS FOR SELECTED GVRD STATIONS



5.10 FREQUENCY OF THE HOURS AT WHICH MAXIMUM OZONE LEVELS OCCUR ON EPISODE DAYS FOR SELECTED GVRD STATIONS



5.10). This could be due to the depletion of ozone later each day by NO emissions. In addition, since the land breeze develops at the shoreline, pollutants which are transported inland enter the land breeze/mountain drainage circulation later and then less completely. See also section 6.6.2 for further discussion.

5.5 Summary

The ozone episode analysis was based on 139 "episode days" (defined in Section 5.1) which occurred almost exclusively in the 6-month period April to September, and with a frequency of about 30 to 40 episode days per year. The highest number of episodes occurred in the Ioco-Anmore-Port Moody area. Precursors generated upwind (west) of this area were probably the cause of the high ozone levels.

The diurnal pattern showed a maximum occurring most frequently between 1300 and 1600 hours. Occasionally, a second maximum occurred during the late night hours. These observations are consistent with the daytime sea breeze circulation and its night-time converse, the land breeze. Alternatively, the secondary maximum could be associated with the mixing downward of ozone from the daytime mixed layer.

6. METEOROLOGICAL ANALYSIS

The meteorological analysis begins with a generalized discussion of the major wind flows - both synoptic and mesoscale - for the region (Section 6.1). Station Episode and Persistent Episode concepts are then reviewed (Section 6.2). Meteorological relationships are then studied, on the basis of persistent episodes, for the synoptic scale (Section 6.3) and the mesoscale (Section 6.4). The overall results of the persistent episode analysis are discussed in Section 6.5, and specifically under the headings of diurnal variation (Section 6.5.1), areal distribution (Section 6.5.2), long range transport (Section 6.5.3) and frequency of persistent episodes (Section 6.5.4). Meteorological relationships for episode days (Section 6.6) are discussed under the headings of temperature (Section 6.6.1) and wind direction (Section 6.6.2). This discussion is, of necessity, limited due to the limited scope of the study. The chapter concludes with a summary (Section 6.7).

6.1 Synoptic and Mesoscale Flows

Synoptic Scale Flow

Mean sea level pressure maps for a thirty year period for the warm season months show a large anticyclone (high pressure) west of Vancouver Island and centred at about 150^{0} W longitude. It is a relatively stationary feature. However, highs do migrate across the continent, usually along an ESE track. The summer highs tend to be weak (Haurwitz and Austin, 1944).

Mesoscale Flow

The major controls on the mesoscale flow are topographic. The land-sea interface coupled with the Lower Fraser Valley topography combine to produce complex wind patterns, some of which are associated with high pollution episodes. The most important circulation is the sea breeze.

Sea Breeze

An onshore flow (sea to land) is established near ground level during the daytime of the warm season when the land temperature is considerably warmer than the sea temperature. The sea breeze circulation consists of a convection cell which can be visualized as follows: Warm air rises over the land reducing the air pressure near the ground. Cool sea air moves in to replace the rising air. A return flow (land to sea) is established at higher levels. The sea breeze begins on a small scale near the shore a few hours after sunrise, and may grow in horizontal extent to penetrate some tens of kilometres inland. It begins to weaken during late afternoon or early evening and is often replaced by the reverse circulation - the land breeze - at night.

The sea breeze circulation occurs on warm, sunny days when the large scale or synoptic flow is light. A discussion of the land/sea breeze as it specifically relates to the Lower Fraser Valley appears in Appendix A.

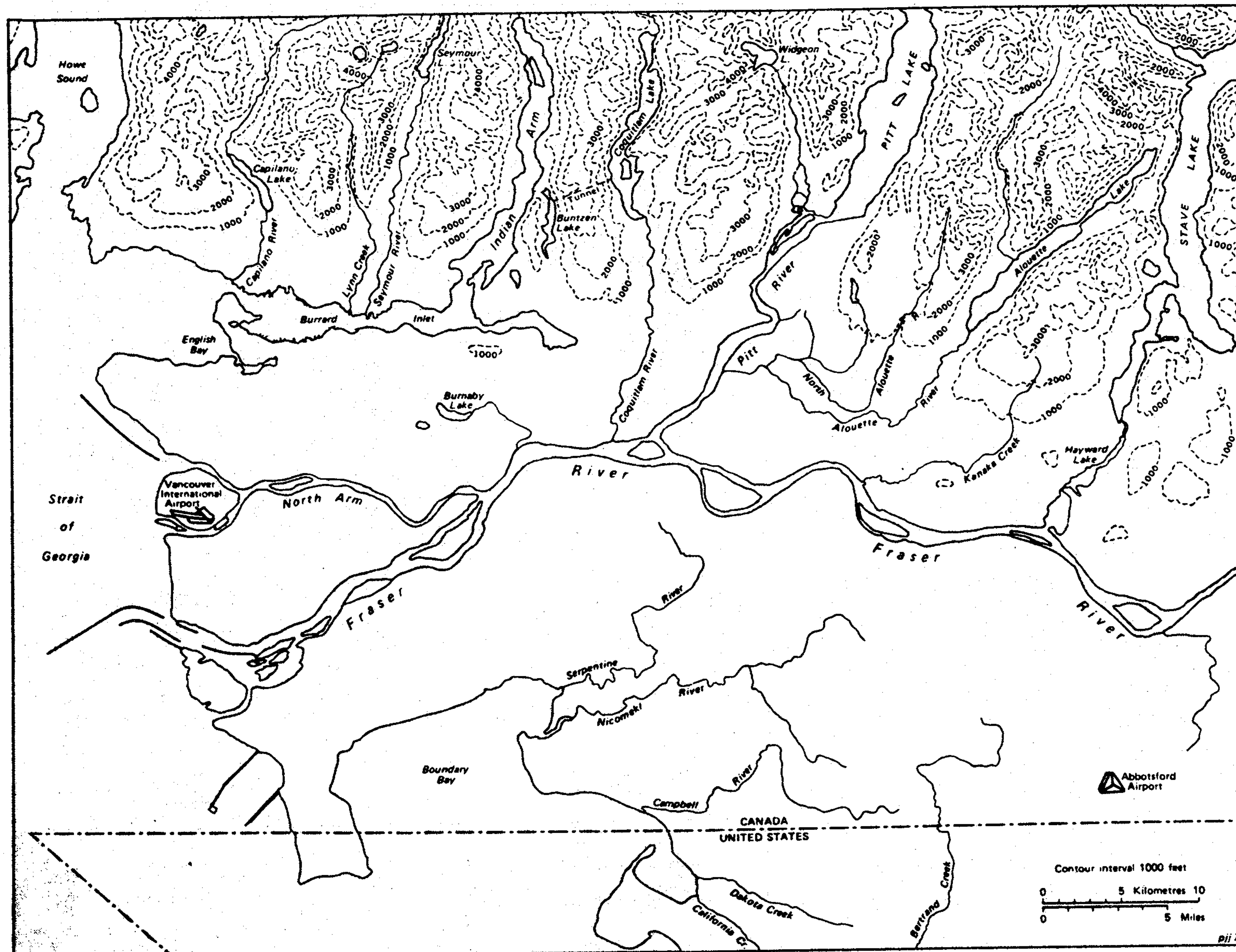
Topography

The land over the Greater Vancouver area (Figure 6.1) slopes gradually upward from south to north. However, the rise becomes very rapid from Burrard Inlet to the top of the ridge of mountains along the North Shore. Lulu and Sea Islands to the south are almost flat and only a few metres above sea level. The city proper slopes gradually from the Fraser River on the south upward to the ridge of land between the Fraser and Burrard Inlet. This height of land varies from about 100 to 150 metres and contains several small crests or peaks, such as Little Mountain and Burnaby Mountain. To the north of Burrard Inlet, the mountain peaks of the North Shore rise to heights in excess of one thousand metres, just a few kilometres from tidewater (Harry and Wright, undated).

6.2 Review of Ozone Episode Criteria

Although it has been described above, the ozone stratification procedure is repeated here to again underline the distinction between station episodes and persistent episodes in the analysis.

1. Station episodes were defined for each station as having at least one hour of ozone > 82 ppb and 10 or more hours of ozone > 20 ppb.



6.1 THE LOWER FRASER VALLEY

2. Areal episodes were defined as occurrences of station episodes at 3 or more stations on the same day.

3. Persistent episodes were defined as areal episodes that persisted for 2 or more consecutive days.

The annual episode statistics appear in the table below.

	1978	1979	1980	1981	Total
No. of station episodes	62	45	55	75	237
No. of days of station episodes (station episode days)	29	30	41	39	139
No. of areal episodes	7	2	3	9	21
No. of persistent episodes	2	1	0	2	5

A study of the station episodes provides a measure of the local ozone situation in the vicinity of a monitor, while the persistent ozone episode analysis is concerned with incidents of considerable duration and areal extent.

6.3 Synoptic Analysis of Persistent Episodes

This section summarizes the synoptic weather for the persistent episode days. Although strictly not a persistent episode, the September 6-7 1981 period is included since it illustrates one situation in which synoptic scale transport may contribute to ozone levels. Another example is found on September 15 and 16, 1981. The ozone levels and winds at 1400 hours on these days are indicated on maps for each day (see Figures 6.2 - 6.22 and are discussed in Section 6.4.

1. 3 - 5 June 1978

500 mb	High centred over central B.C. from 31 May became a NE-SW ridge over southern B.C. on the 4th; rotated to N-S on the 5th; weakened and moved eastward by the 7th.
850 mb	NW-SE ridge lay central B.C. to midwest U.S. from 2 June to 5 June; on 6 June it was penetrated by cool air from the NE which effectively split the ridge into 2 Highs.
Surface	Elongated warm anticyclone NW-SE through central B.C. extended into midwest U.S. until the 4th; on June 6 it was pushed southward and replaced by cooler, drier air.
Comments	Hot, humid airmass; light pressure gradient at all levels, sea breeze at surface. June 6 - moderate westerly flow developing aloft.

2. 21 - 22 July 1978

500 mb	High over Pacific with NE-SW ridge over northern B.C. on the 20th persisted through the 21st and weakened on the 22nd.
850 mb	High over the Pacific with NE-SW ridge through northern B.C. on the 20th through the 22nd kept flow light over GVRD; ridge weakened and was replaced by weak N-S trough on the 23rd.
Surface	High over B.C. and Alberta on the 19th elongated on the 20th into W-E ridge from southern B.C. to Lake Superior; persisted to the 21st and was replaced by a N-S trough along the Pacific coast on the 22nd.
Comments	Very light pressure gradient; sea breeze; end of episode accompanied by moderate westerly flow aloft (23rd).

3. 1 - 2 June 1979

500 mb	N-S ridge off Pacific coast for several days moved over the coastal region on the 1st, over the Alberta border on the 2nd, thence flattened out.

850 mb — NE-SW ridge through central B.C. on the 31st became very broad high pressure region covering western Canada and U.S. on the 1st and most of the U.S. by the 2nd.

Surface — High over Vancouver Island on the 30th stretched into a broad high pressure system covering western Canada on the 31st, then slid down into the U.S. midwest by the 2nd.

Comments — Light pressure gradient at surface; end of episode signalled by end of sea breeze circulation accompanied by moderate westerly flow aloft.

4. 5-6, 8-10 August, 1981

500 mb — Low just south of Alaska; ridging over southern B.C. on the 5th; ridging intensified and broadened to cover the Prairies on the 6th and 7th; persisted to the 11th when it weakened.

850 mb — Low south of Alaska; NE-SW ridging over southern B.C. on the 4th drifted northwestward to allow large high to form over B.C., Alberta and north west U.S. By the 7th it became a broad NW-SE ridge and by the 11th it had weakened and flattened out.

Surface NE-SW synoptic scale ridge over Vancouver Island on the 4th swung to a NW-SE orientation over central B.C. extending down to the Gulf of Mexico on the 6th; squeezed by a developing California low on the 10th.

Comments Light pressure gradient; sea breeze; end of episode signalled by weakening ridge moving eastward and failure of sea breeze to develop.

5. 6 - 7 September 1981

500 mb Ridging along Pacific coast on the 5th intensified on the 6th with a high off the California coast; moved to Alberta border on the 7th putting B.C. into a moderate SW flow.

850 mb Broad ridge NE-SW over southern B.C. became high centred over Utah on the 7th putting GVRD into light S flow.

Surface High pressure dominated W. Canada with GVRD in a light return flow.

Comments A "back of the high" incident with trajectory from the SE and associated with sea breeze; end of episode as approaching low to the NW brought moderate SW winds.

The synoptic analysis has related ozone episodes to 2 meteorological phenomena on different scales: i) to the anticyclone on the synoptic scale and ii) to the sea breeze on the mesoscale. In the next section, we look at some mesoscale features of wind and ozone concentrations.

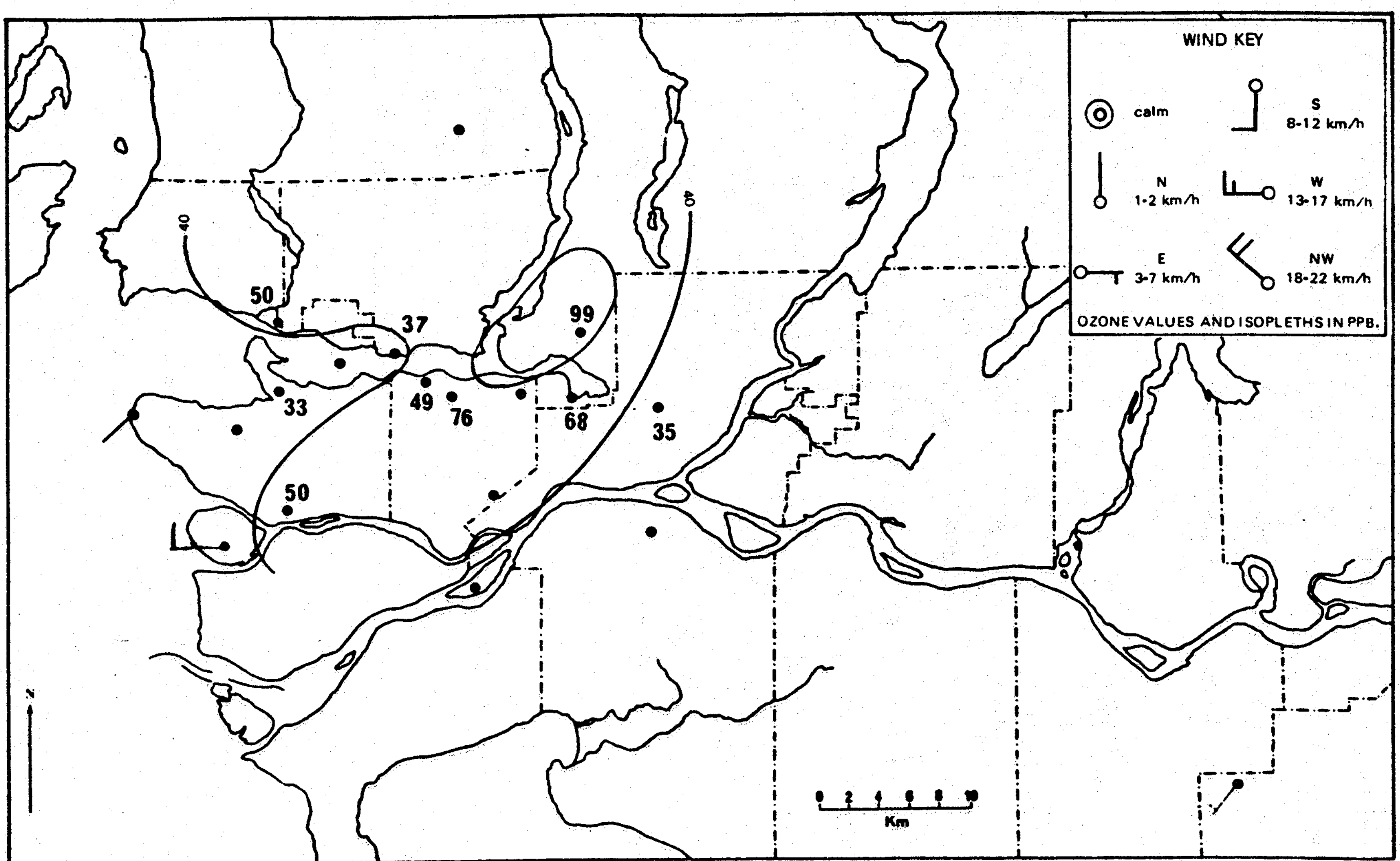
6.4 Mesoscale Analysis

The mesoscale was studied by using large scale (1:400,000) maps and plotting all available ozone concentration and wind observation data at particular times of interest. Specifically, this was done for 1400 Pacific Std. Time (corresponding to the peak of the diurnal concentration plots - see, for example, Figure 5.6) for each of the persistent episode days as well as for some other days of interest. Figures 6.2 - 6.22 show these maps. The isopleths are largely speculative due to the paucity of data, and are drawn only to allow some inferencc regarding the qualitative shape of affected areas. Concentration units are ppb.

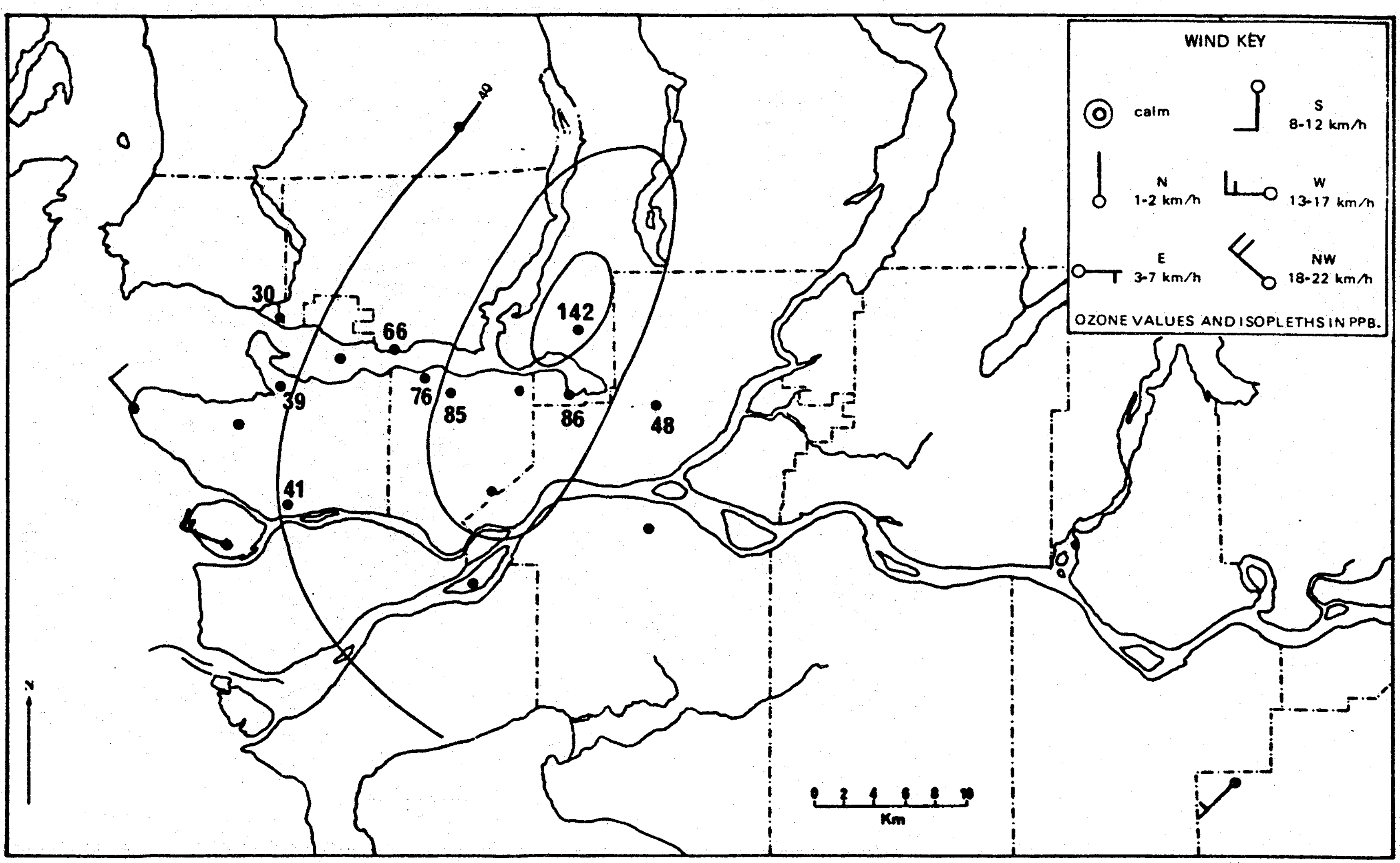
The persistent ozone episode maps will be discussed below. The additional maps are included to illustrate specific points. Figure 6.8 for the day following an episode, shows that when the sea breeze failed to develop, the affected area shrank and concentrations rapidly dropped.

Figure 6.21 shows that a slow moving high pressure system does not guarantee an ozone episode. On October 3, an elongated High stagnated over southern B.C. The 850 mb map showed a NW-SE ridge over the area and

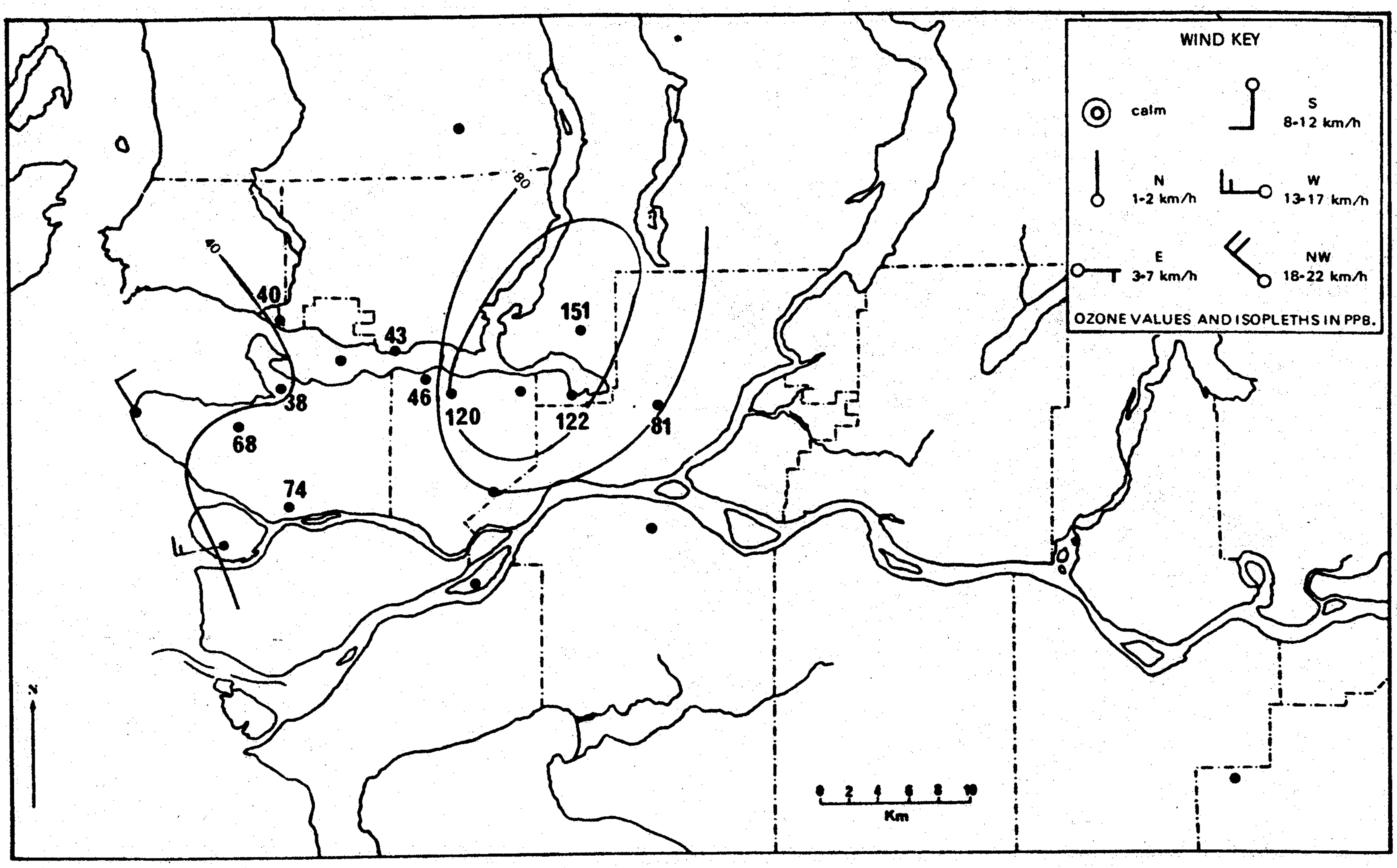
6.2 OZONE AND WIND DATA AT 1400 HOURS JUNE 3, 1978



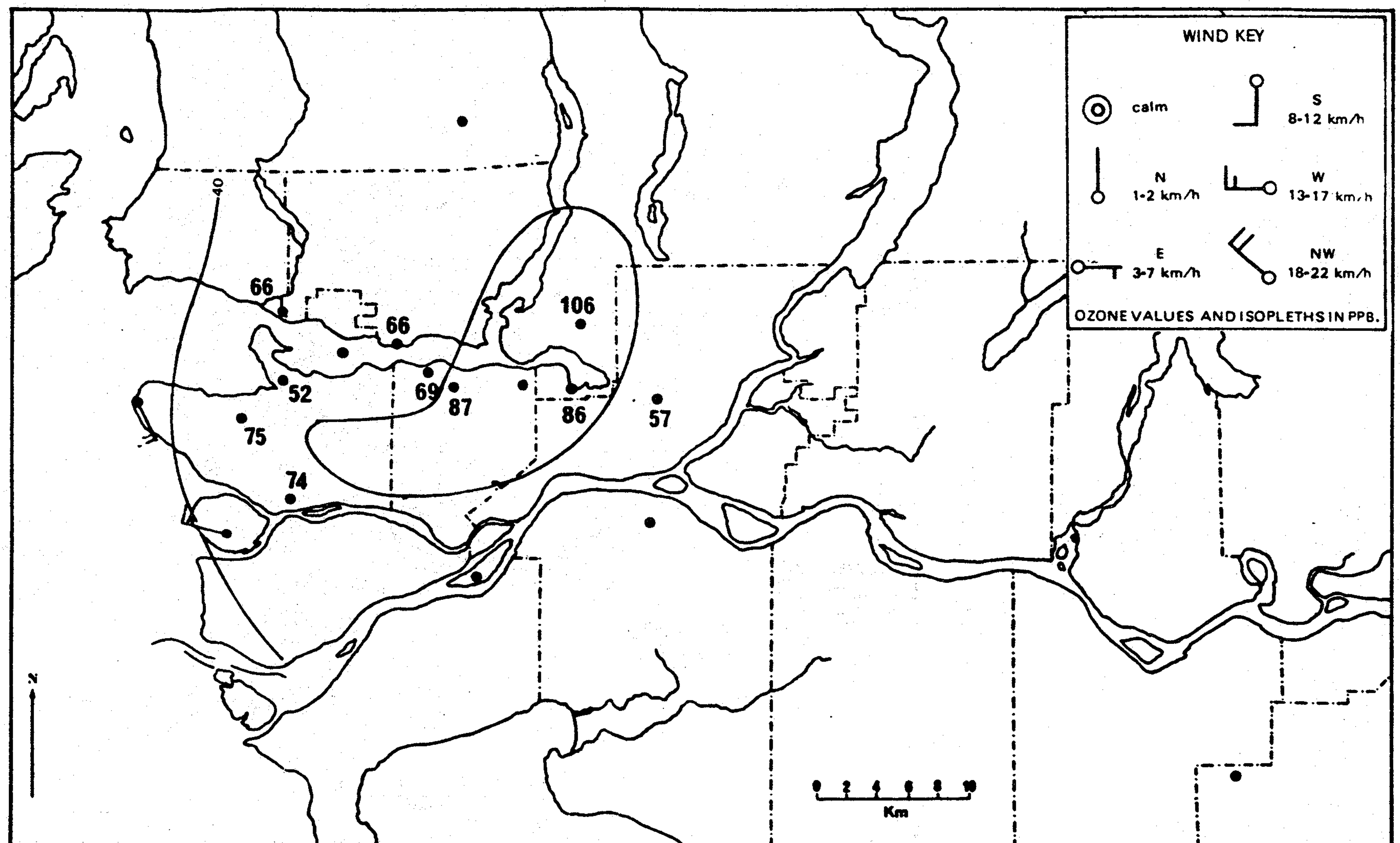
6.3 OZONE AND WIND DATA AT 1400 HOURS JUNE 4, 1978



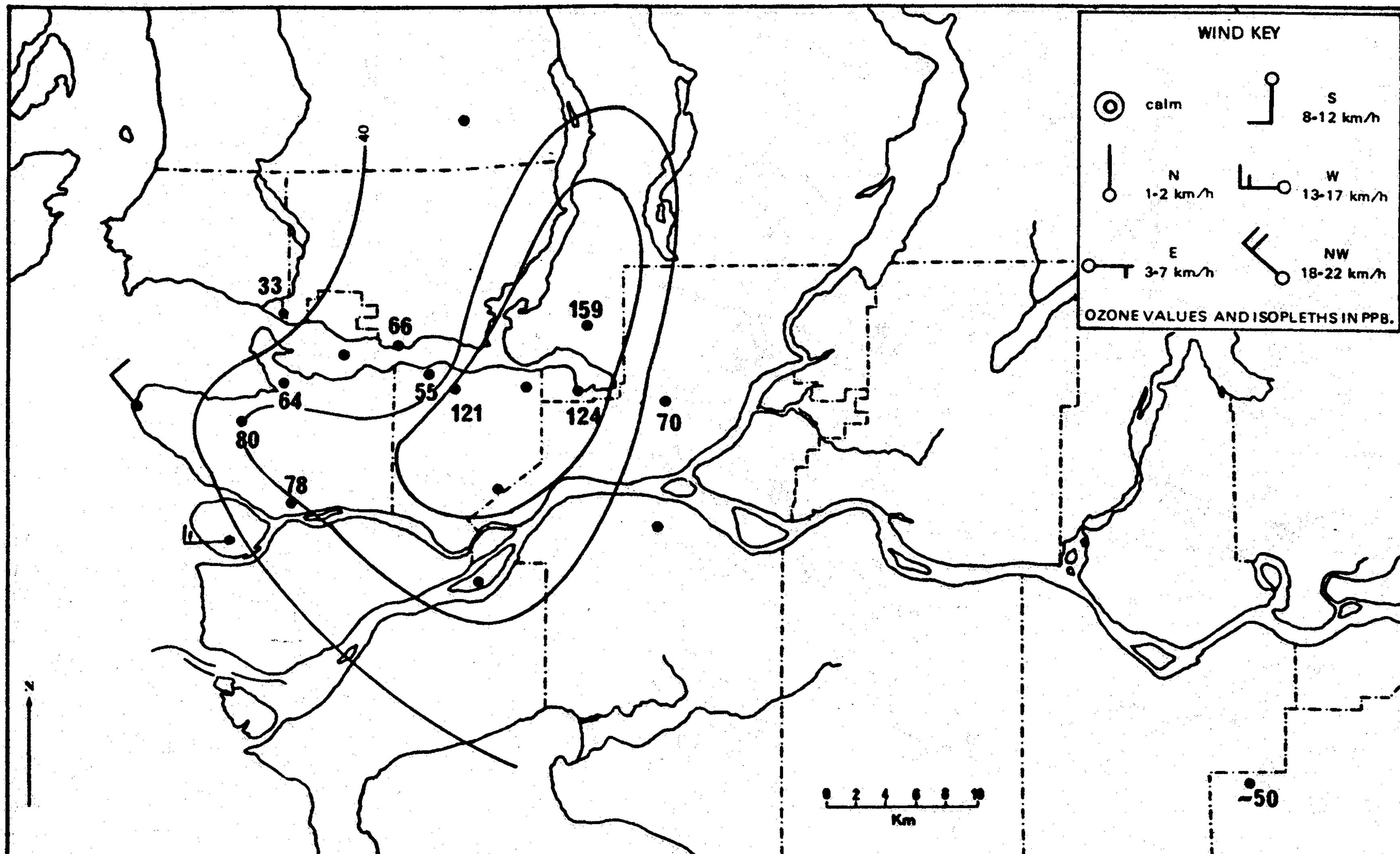
6.4 OZONE AND WIND DATA AT 1400 HOURS JUNE 5, 1978



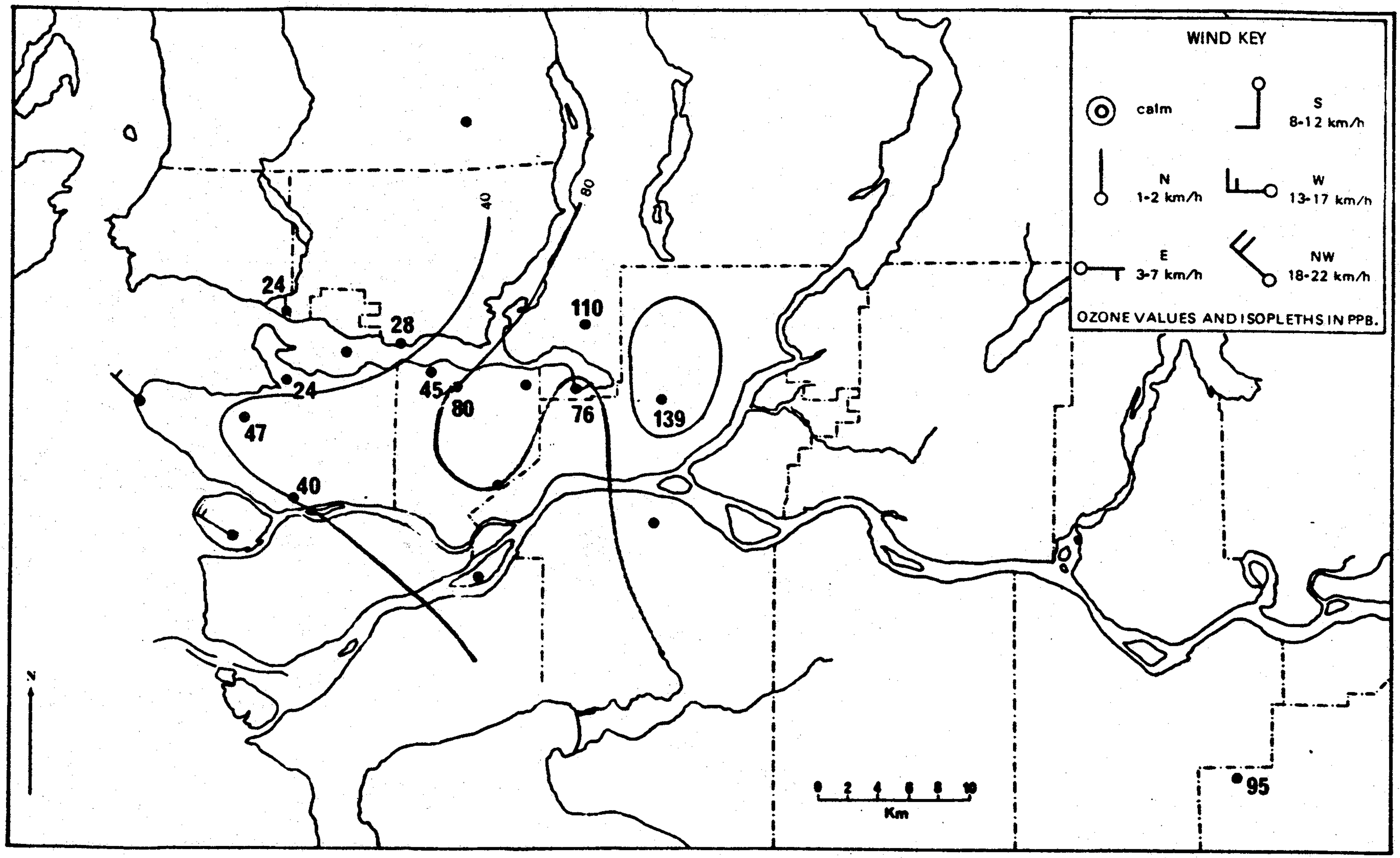
6.5 OZONE AND WIND DATA AT 1400 HOURS JUNE 6, 1978



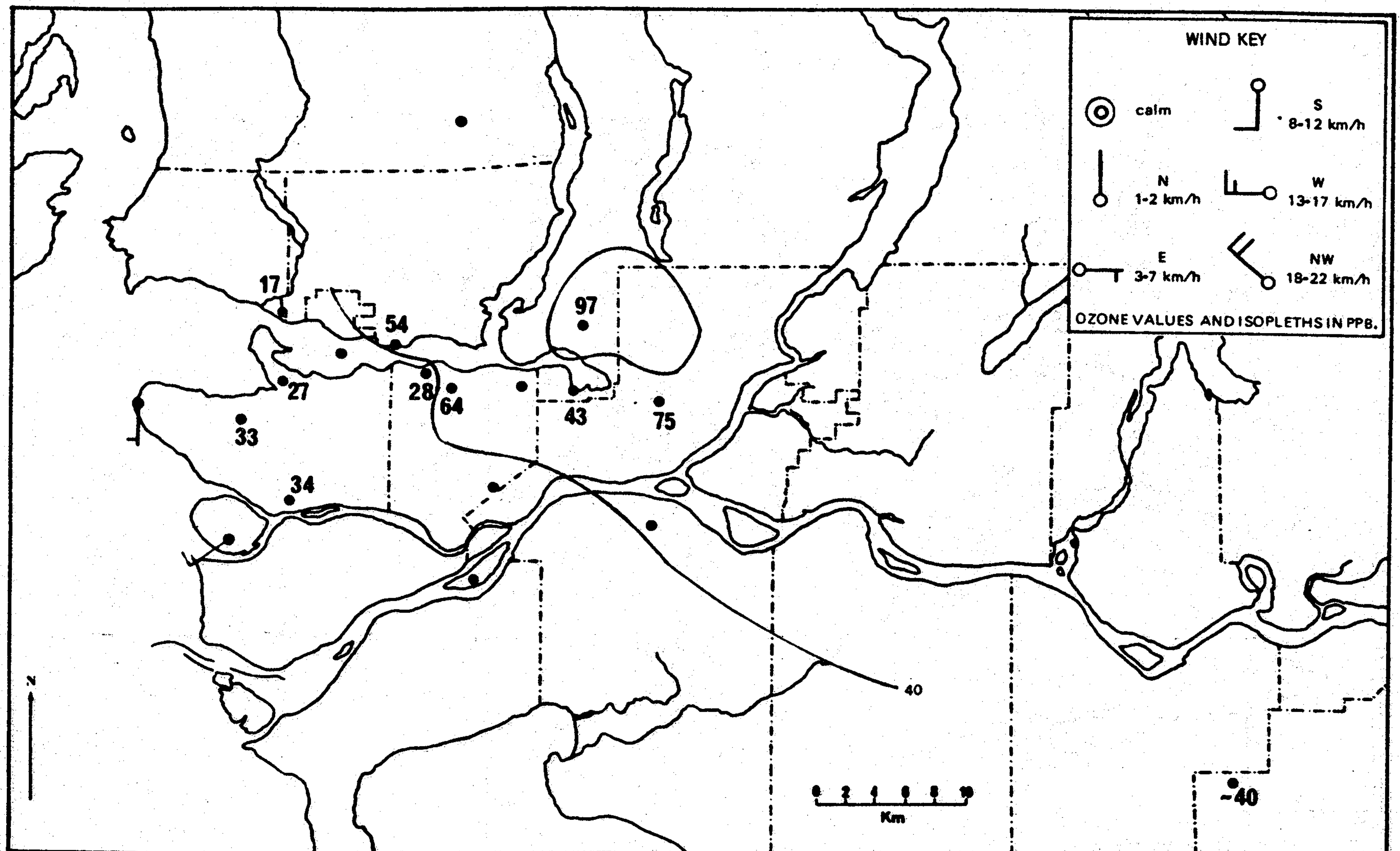
6.6 OZONE AND WIND DATA AT 1400 HOURS JULY 21, 1978



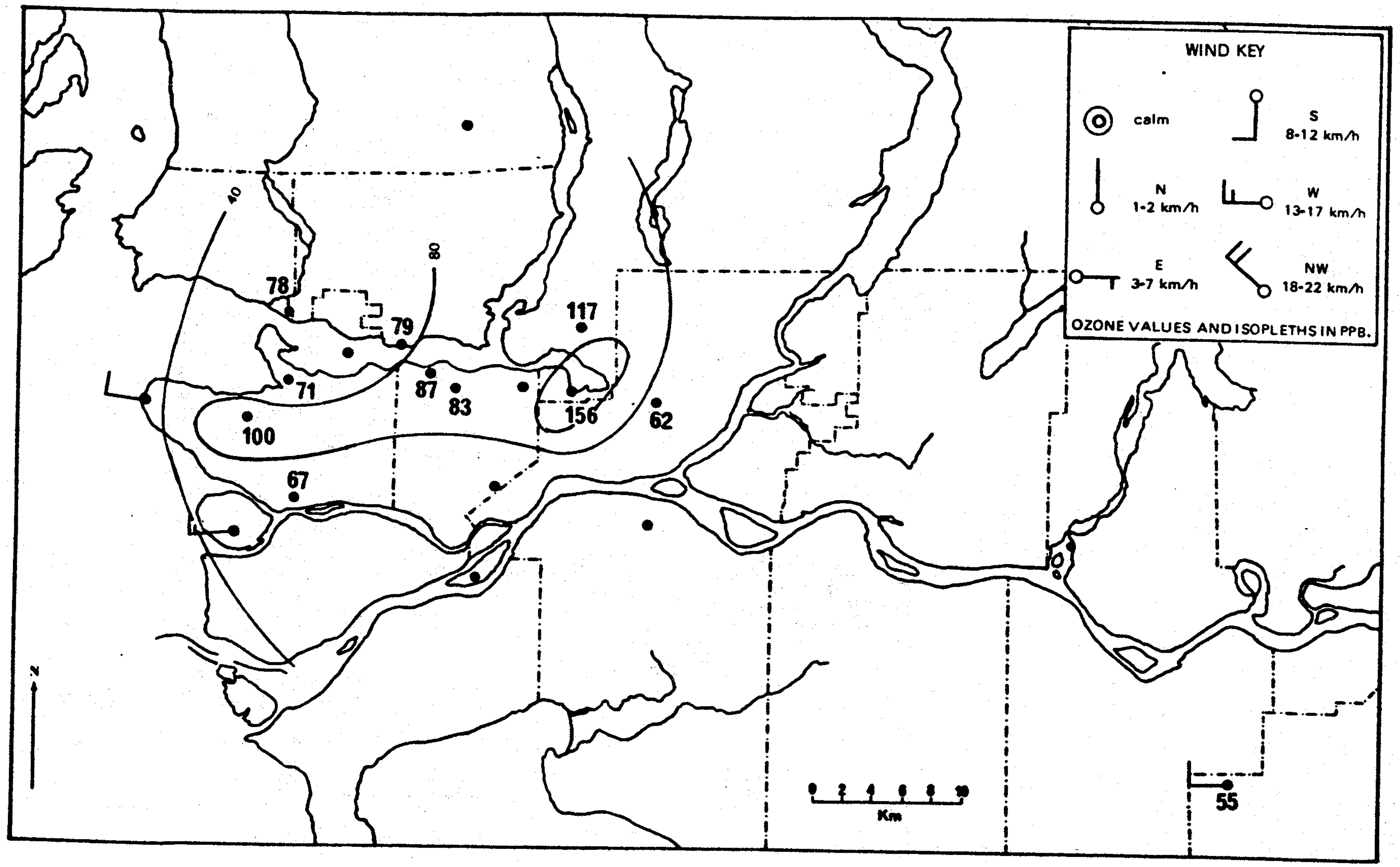
6.7 OZONE AND WIND DATA AT 1400 HOURS JULY 22, 1978



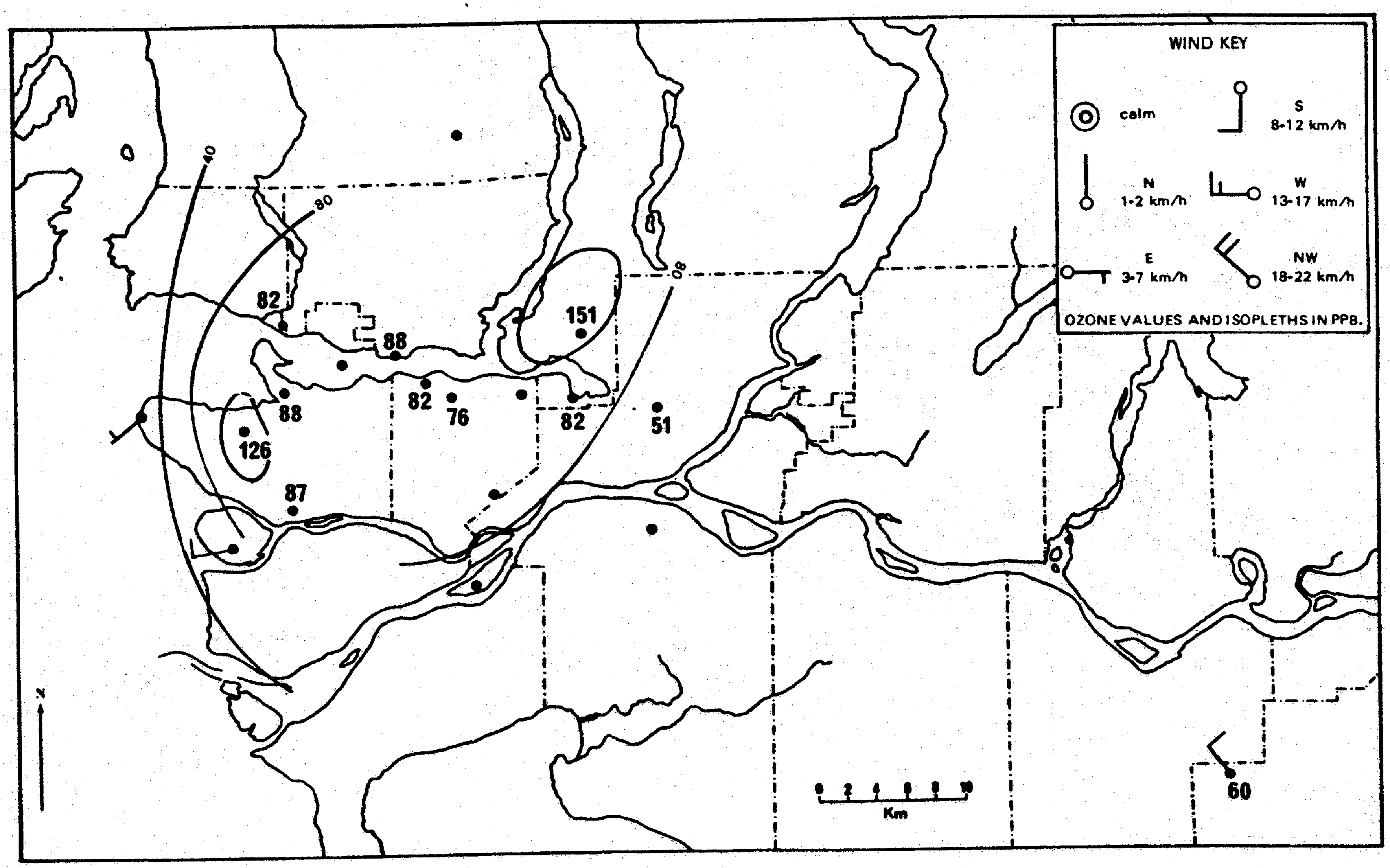
6.8 OZONE AND WIND DATA AT 1400 HOURS JULY 23, 1978



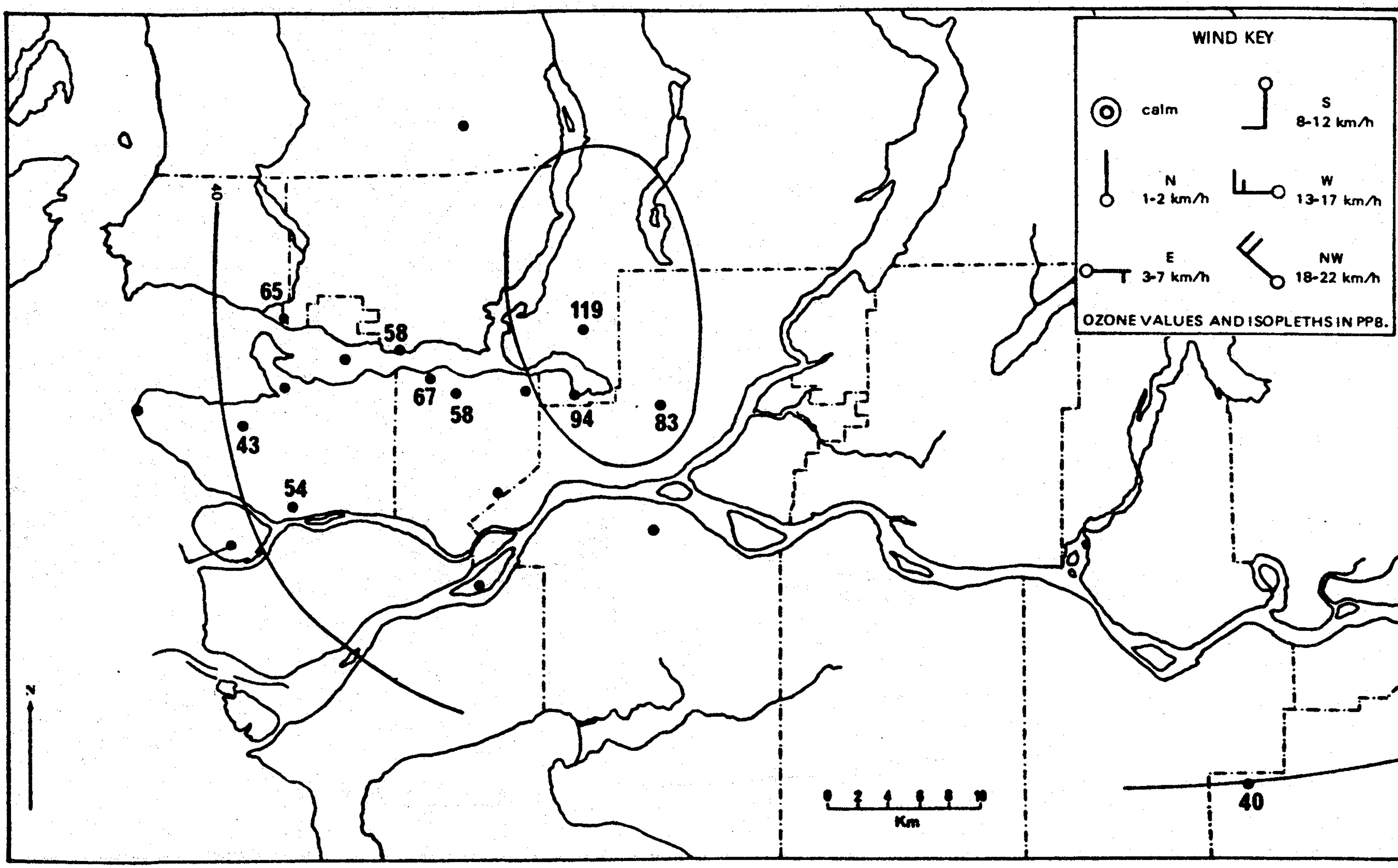
6.9 OZONE AND WIND DATA AT 1400 HOURS JUNE 1, 1979



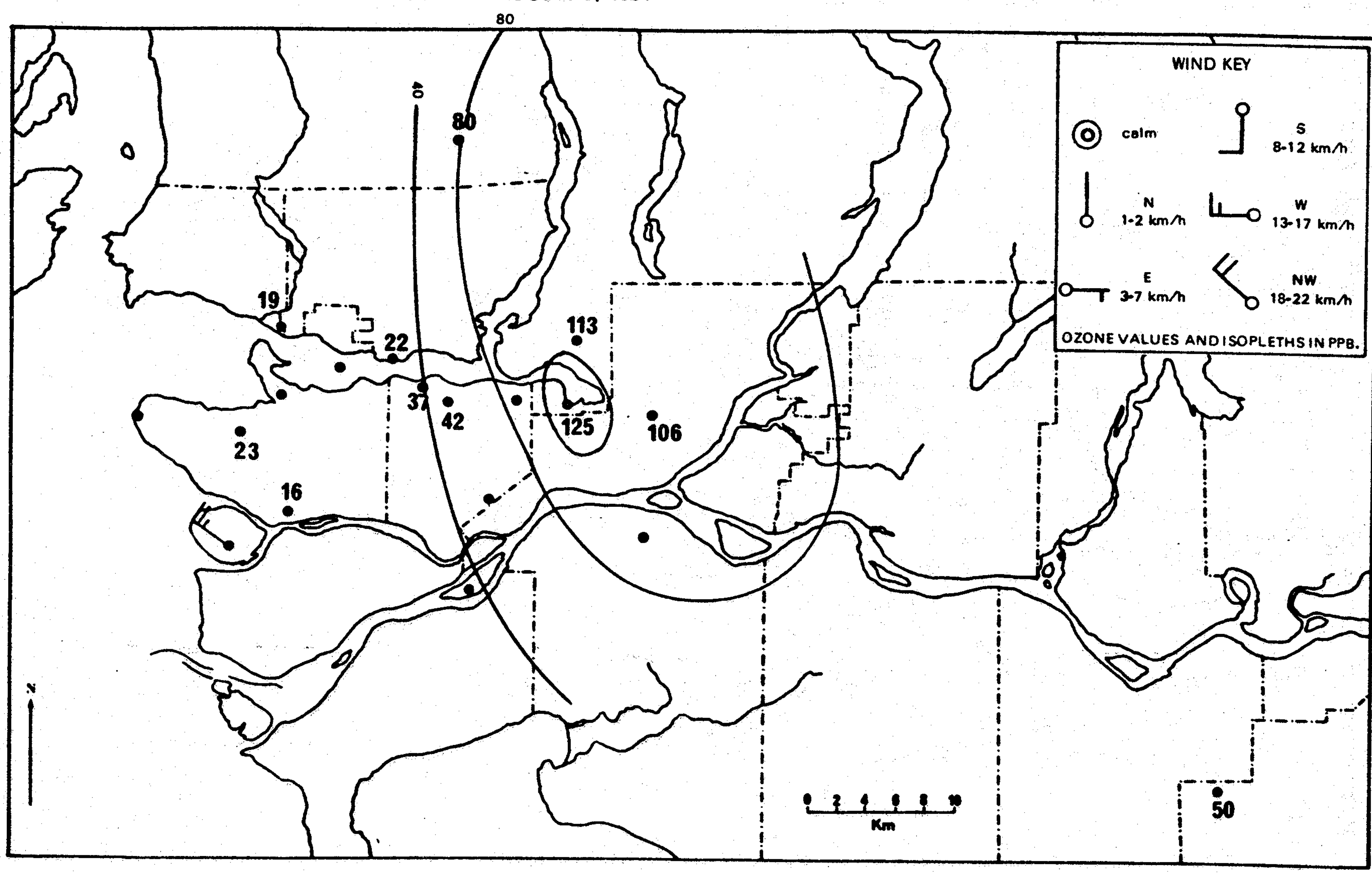
6.10 OZONE AND WIND DATA AT 1400 HOURS JUNE 2, 1979



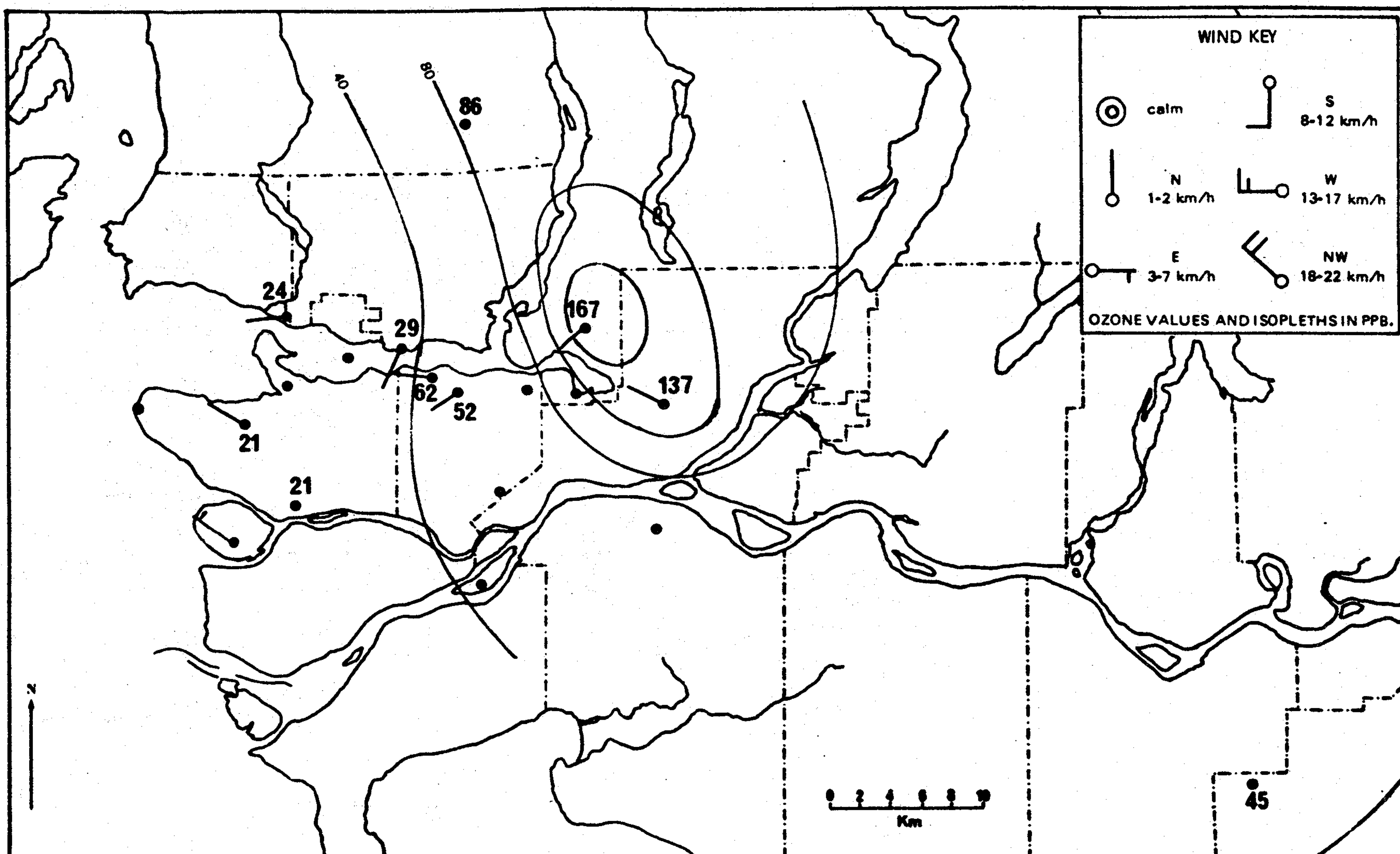
6.11 OZONE AND WIND DATA AT 1400 HOURS AUGUST 5, 1981



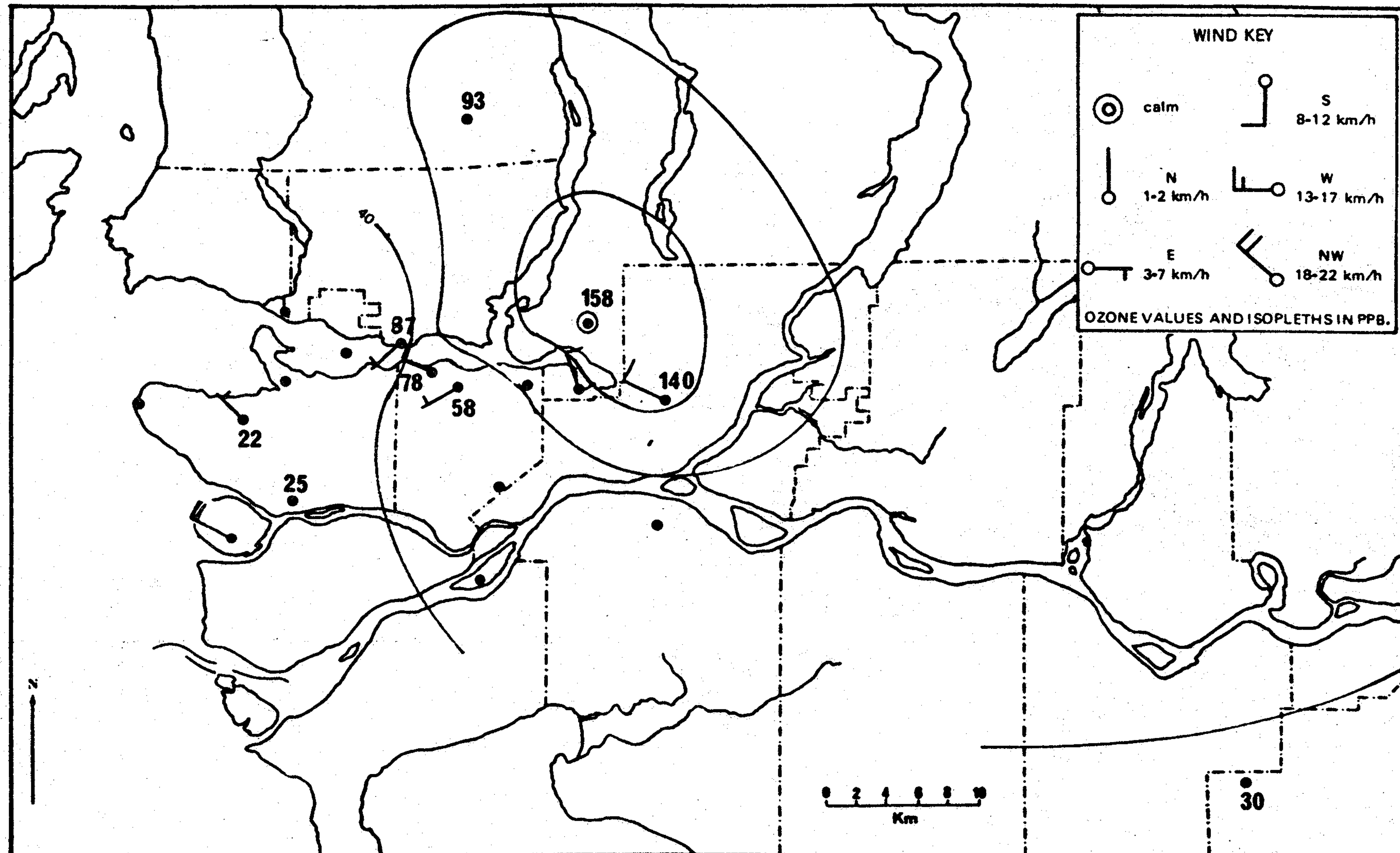
6.12 OZONE AND WIND DATA AT 1400 HOURS AUGUST 6, 1981



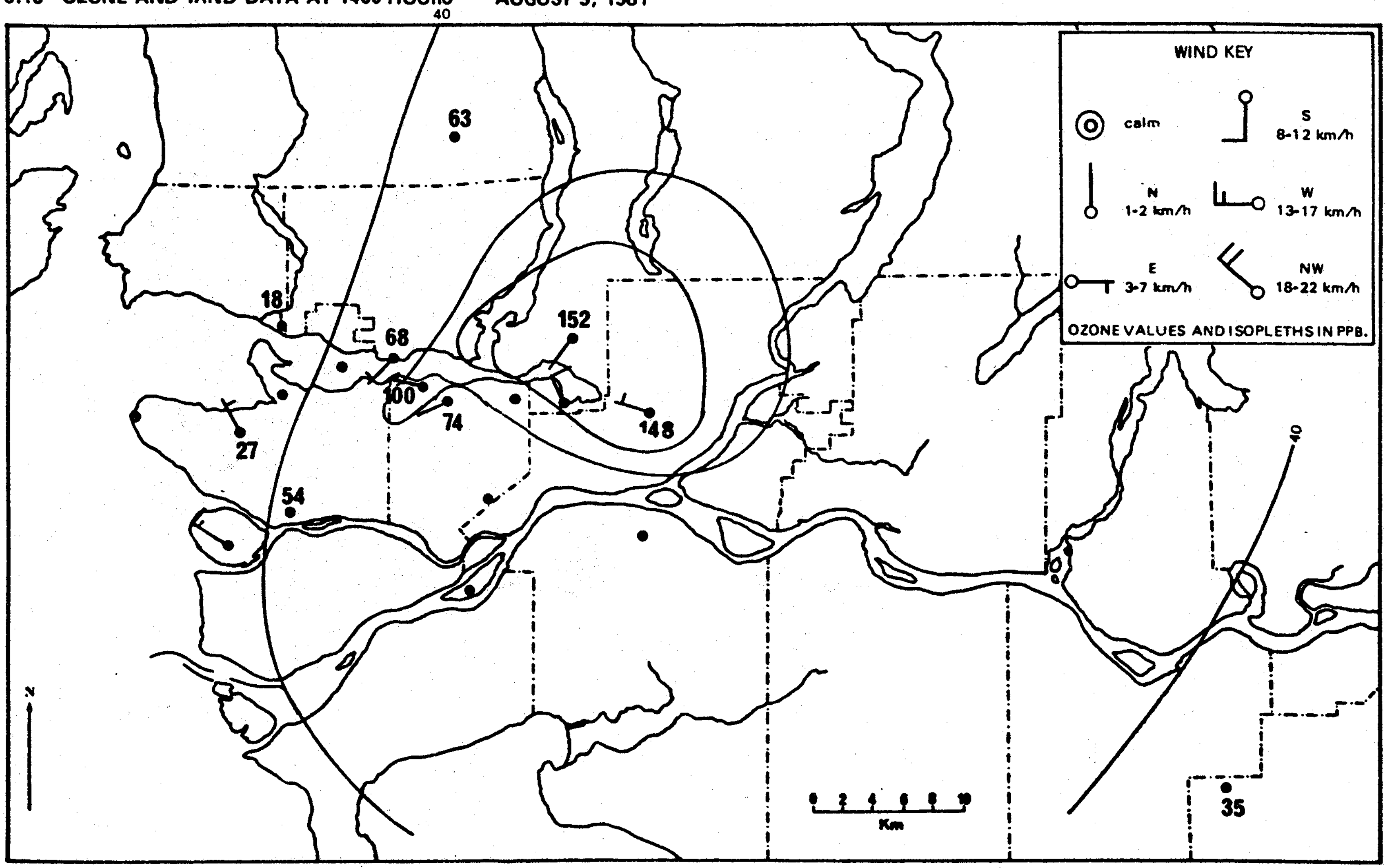
6.13 OZONE AND WIND DATA AT 1400 HOURS AUGUST 7, 1981



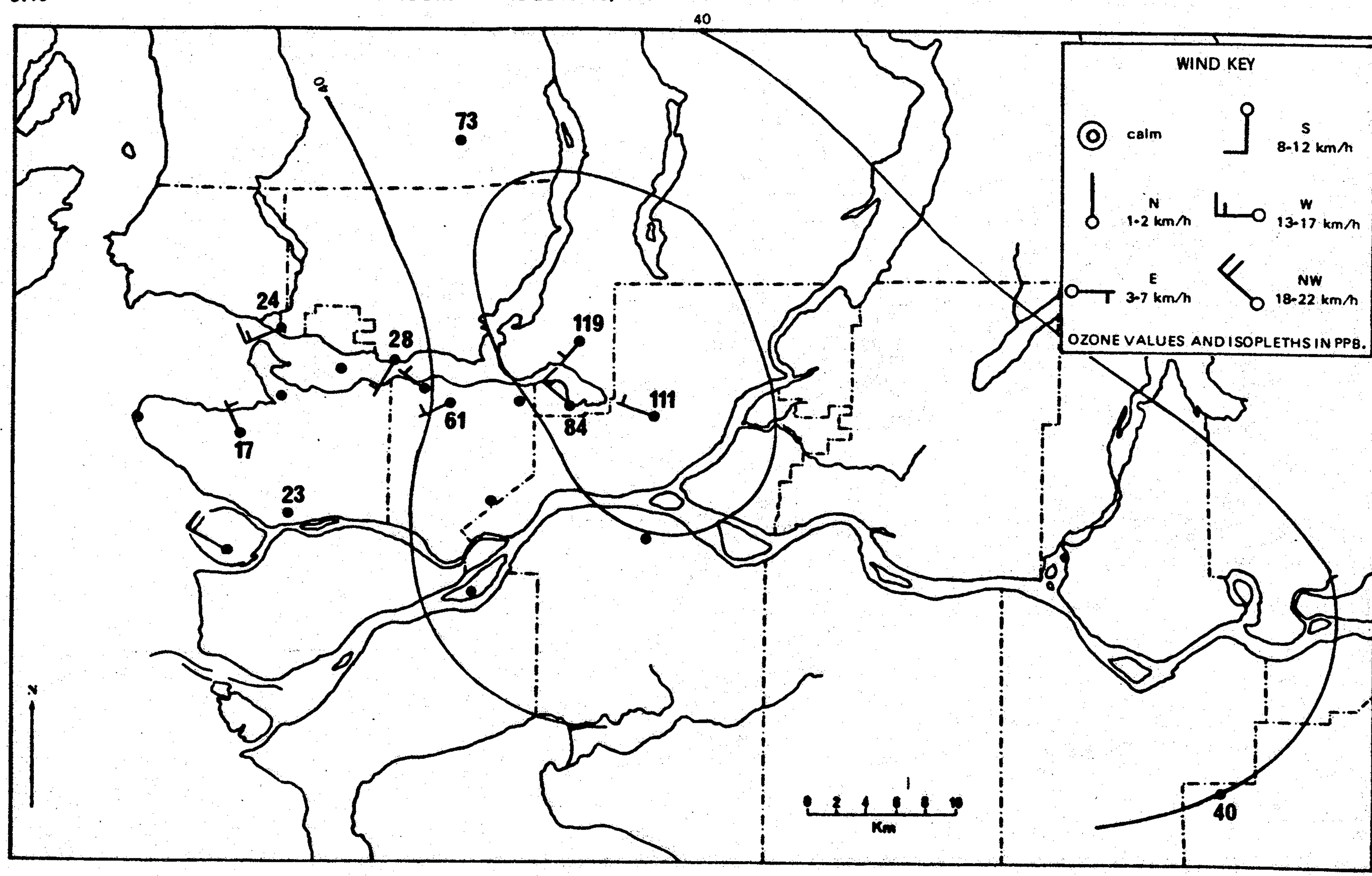
6.14 OZONE AND WIND DATA AT 1400 HOURS AUGUST 8, 1981



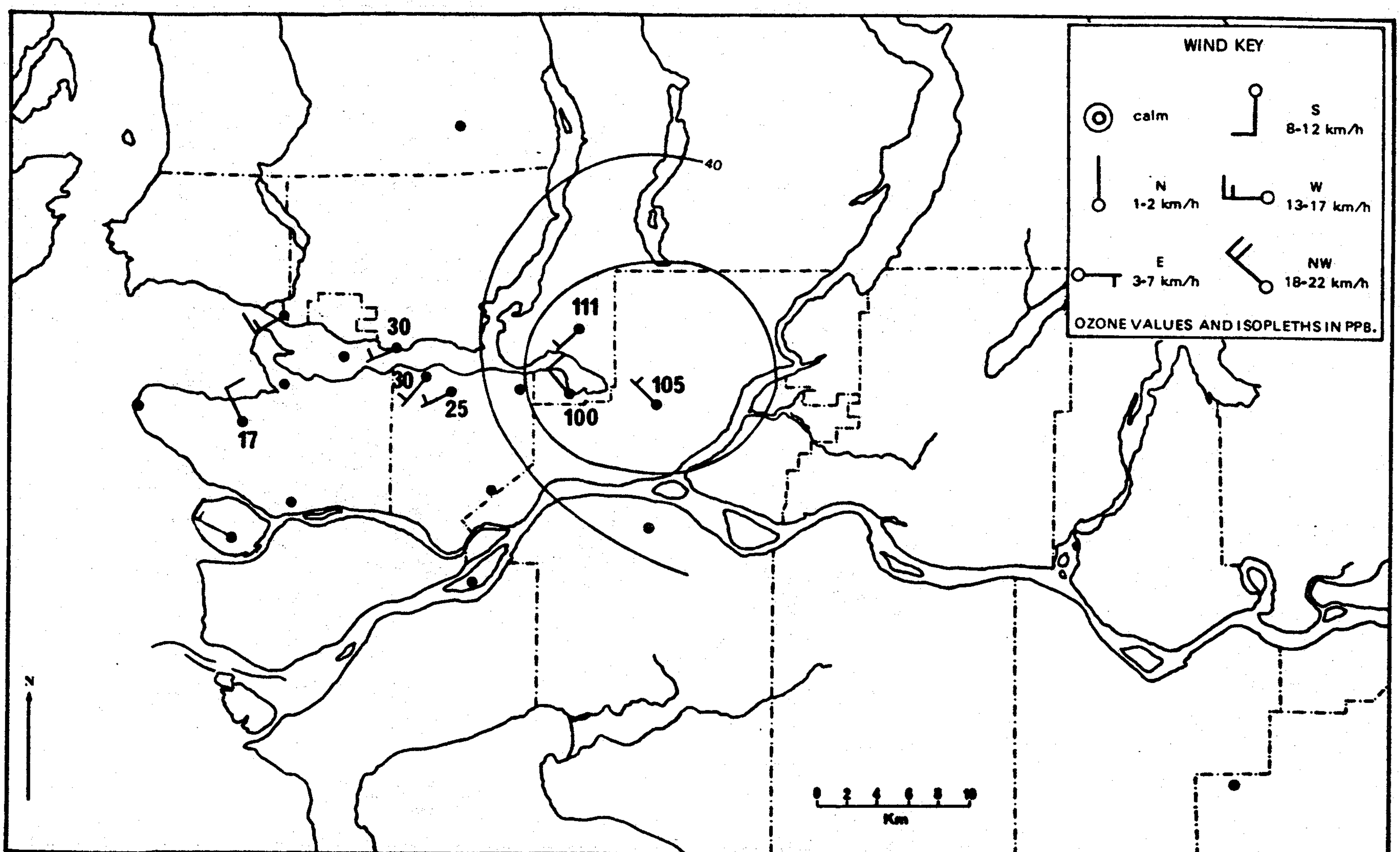
6.15 OZONE AND WIND DATA AT 1400 HOURS AUGUST 9, 1981



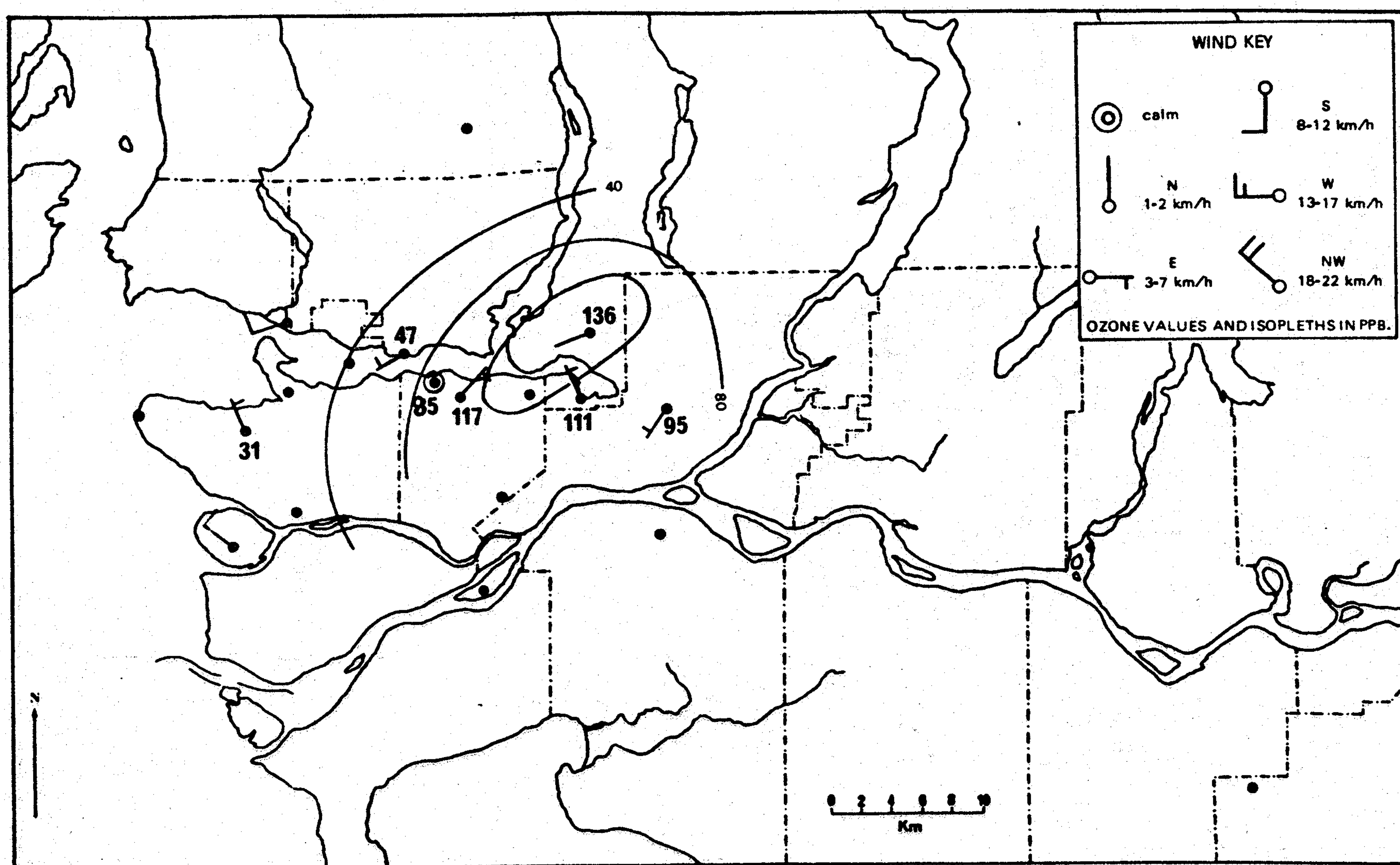
6.16 OZONE AND WIND DATA AT 1400 HOURS AUGUST 10, 1981



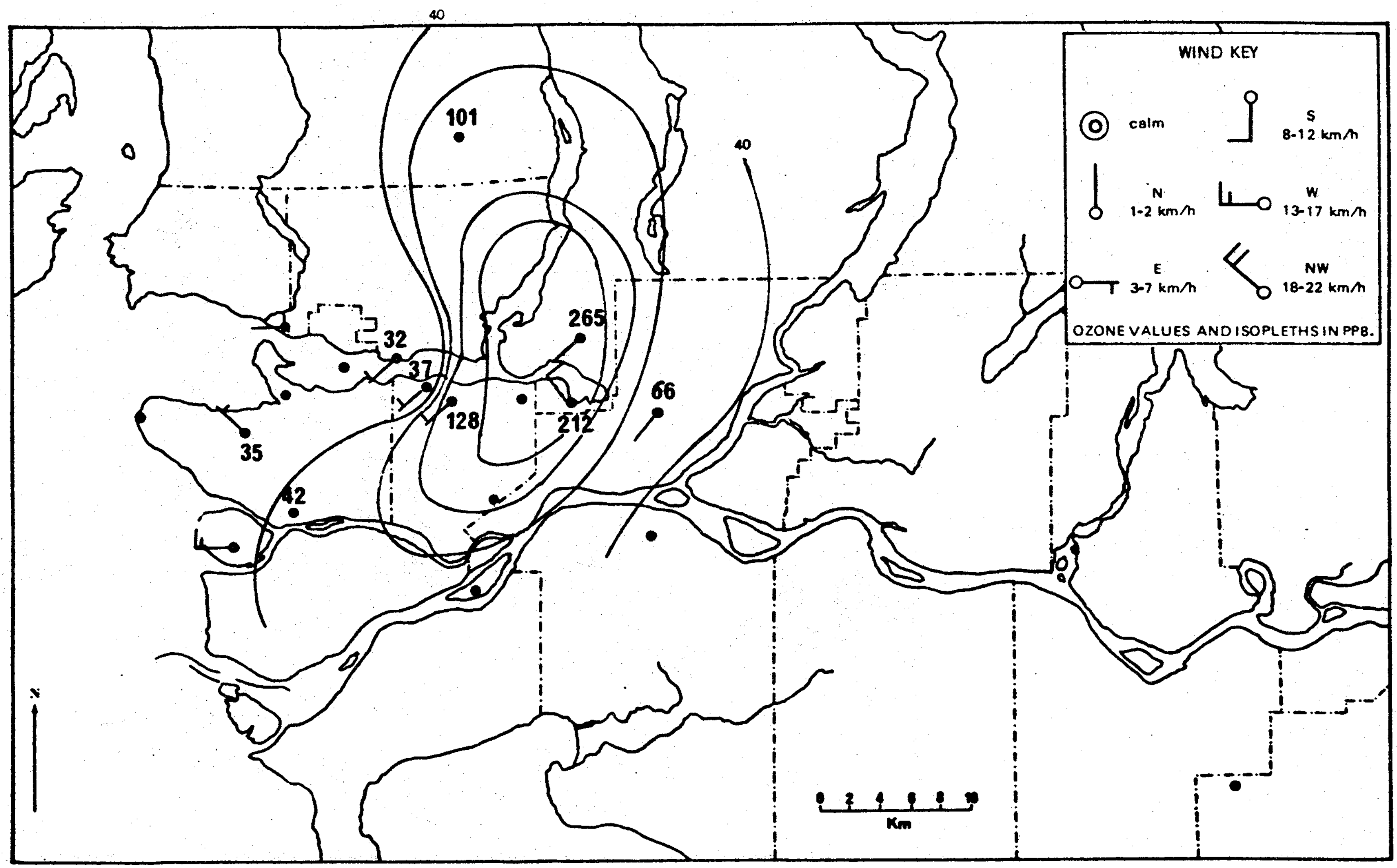
6.17 OZONE AND WIND DATA AT 1400 HOURS SEPTEMBER 6, 1981



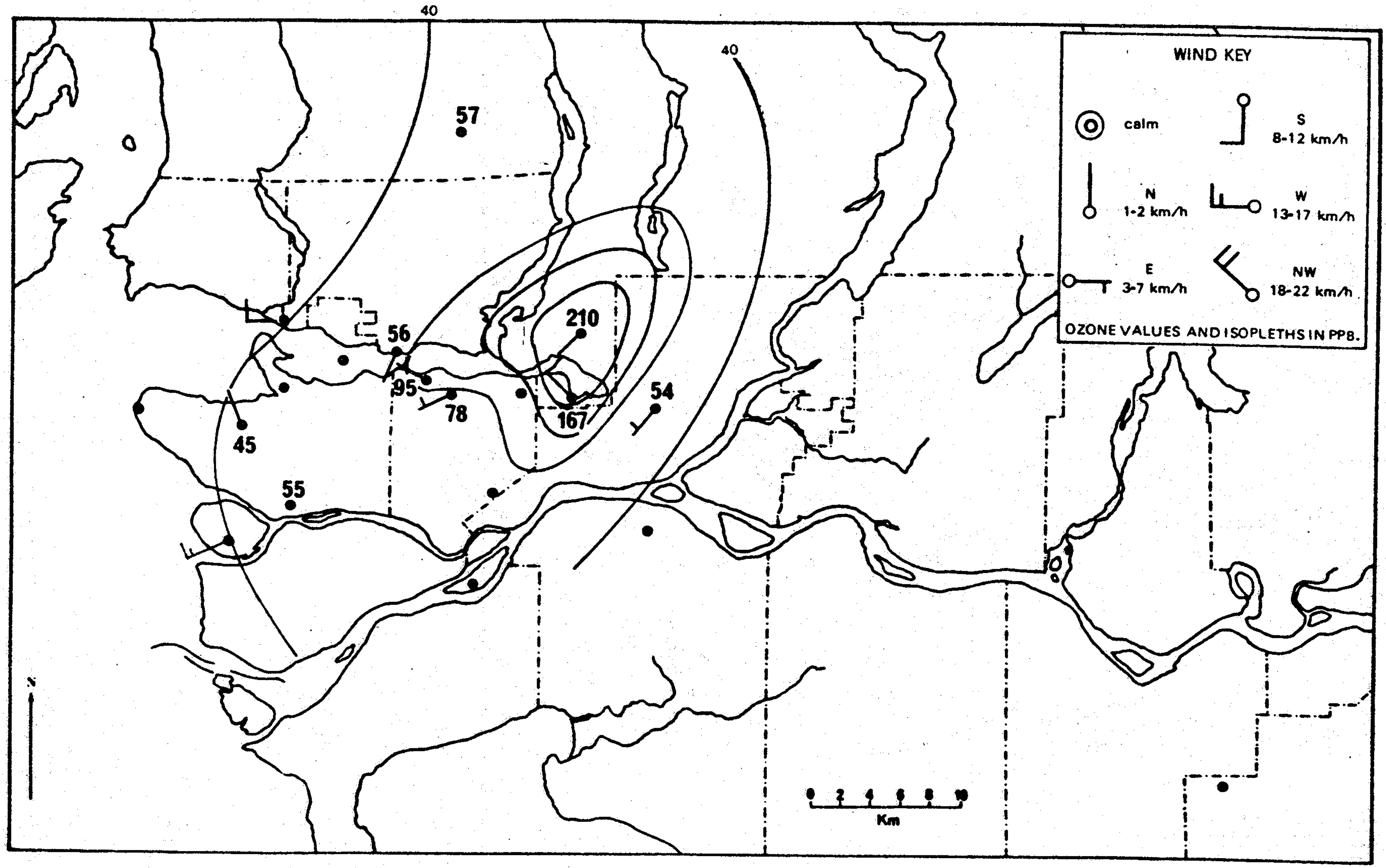
6.18 OZONE AND WIND DATA AT 1400 HOURS SEPTEMBER 7, 1981



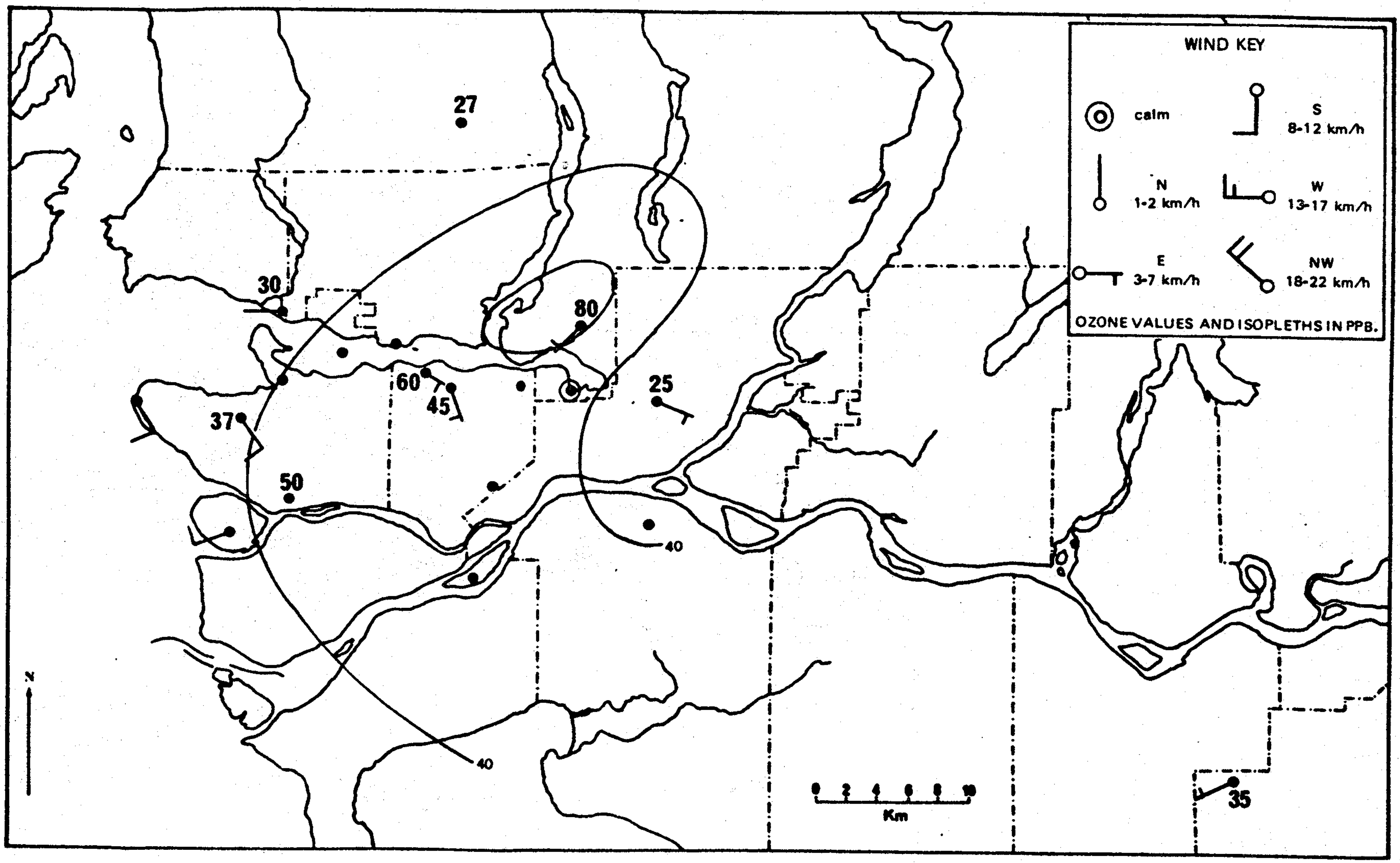
6.19 OZONE AND WIND DATA AT 1400 HOURS SEPTEMBER 15, 1981



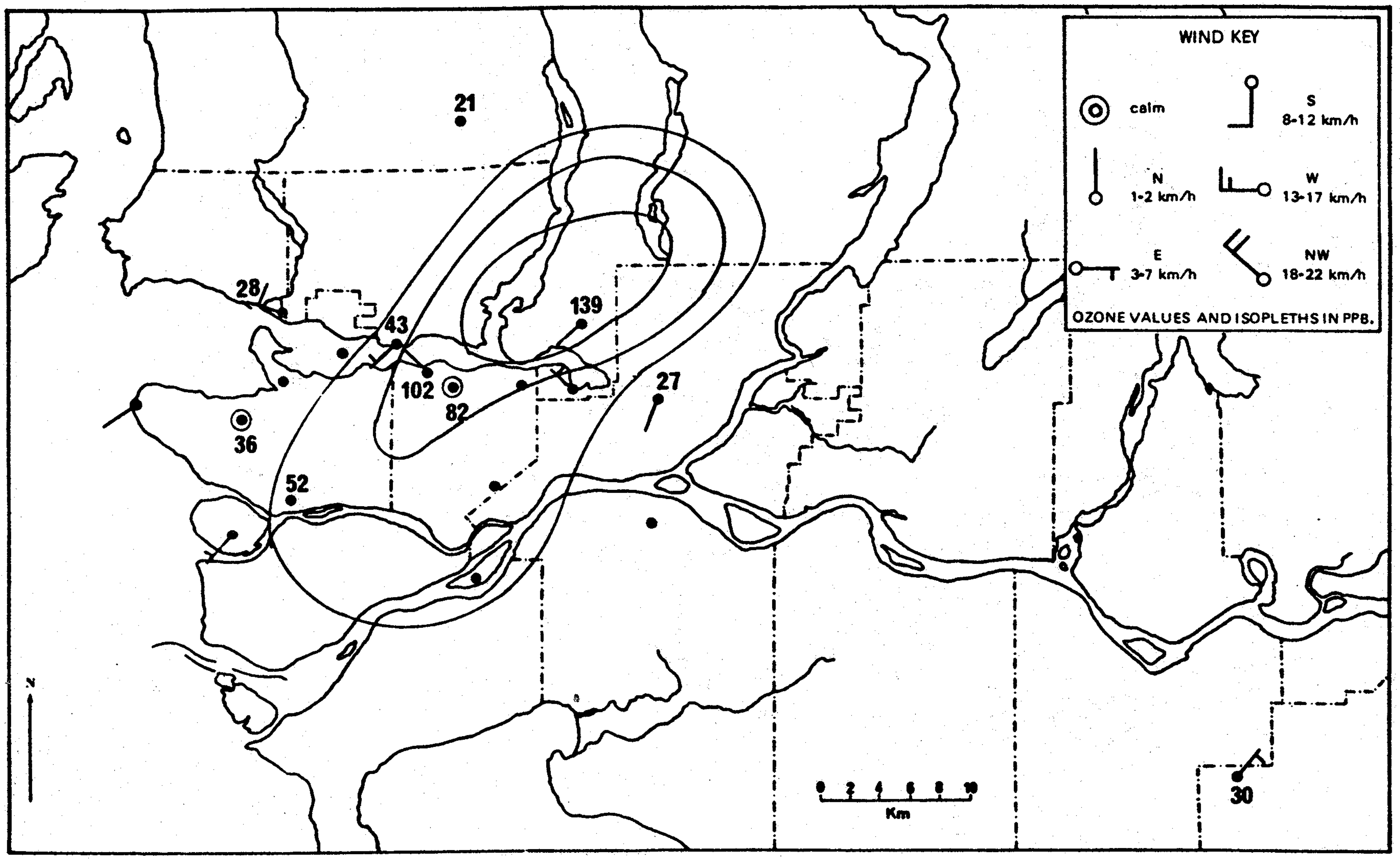
6.20 OZONE AND WIND DATA AT 1400 HOURS SEPTEMBER 16, 1981



6.21 OZONE AND WIND DATA AT 1400 HOURS OCTOBER 3, 1980



6.22 OZONE AND WIND DATA AT 1400 HOURS OCTOBER 5, 1980



the 500 mb map indicated a high over northern California with ridging north to B.C.; but it was not until the 5th that a sea breeze could develop. October 5 was consequently a station episode day (see Figure 6.22).

It appears that the ability to predict ozone episodes is contingent upon a proper understanding and successful prediction of sea breezes.

6.5 Results of Persistent Episode Analysis

A study of the persistent ozone episodes indicates their close relationship to the sea breeze phenomenon. The typical episode occurs under the influence of a slow moving system of high pressure manifest not only at ground level but at the 850 mb and 500 mb surfaces as well (see Section 6.3). The inland maximum temperature (Abbotsford Airport) generally reaches at least 30^{0}C during the episode (see Table 6.1) and the daytime onshore winds are generally perpendicular to the major coastline (Figures 6.2 - 6.22).

The episode generally ends with a drop in temperature, often associated with cloud, as the High weakens or drifts east-southeastward, winds pick up in speed and the sea breeze circulation is destroyed. The end of the episode is often signalled by the establishment of a moderate westerly flow aloft (500 mb).

Table 6.1

Maximum Daily Temperatures During and After Persistent Ozone Episodes

			T max		ΔT*
1978	June	3	30		
		4	29		
		5	28		
		6	26		
		7	22	←	-4
	July	21	32		
		22	34		
		23	29	←	-5
1979	June	1	26		
		2	27		
		3	23	←	-4
1981	Aug	5	26		
		6	31		
		7	34		
		8	34		
		9	36		
		10	34		
		11	33	←	-1
	Sept	6	27		
		7	32		
		8	27	←	-5
		15	31		
		16	30		
		17	20	←	-10

*ΔT indicates the drop in temperature associated with the end of the episode.

6.5.1 Diurnal Variations of Ozone Concentration

The typical diurnal variation is illustrated in Tables 6.2 and 6.3 for Station T7 during and immediately following the persistent episodes of June 1978 (Figures 6.2 - 6.5) and August 1981 (Figures 6.11 - 6.16) respectively. These tables demonstrate some features of a persistent episode.

1. Ozone concentrations follow a diurnal cycle with the maximum normally occurring within a few hours of noon and the minimum in the early morning hours.

2. During a persistent episode, the daily mean first increases, then drops as the episode wanes.

3. During a persistent episode the number of hourly exceedances of the one hour maximum acceptable level of 82 ppb is normally 9 or less.

6.5.2 Areal Distribution of Ozone Concentrations

Attempts were made to contour ozone concentrations (at 40 ppb intervals) for the ozone episode days of Figures 6.2 - 6.22. The affected area often appears elongated in a northeast-southwest direction almost perpendicular to the Pacific coastline. Maximum concentrations almost invariably occur in the Ioco-Anmore-Port Moody area, about 20 km downwind of the downtown area during a sea breeze flow.

Table 6.2

Some Parameters Associated with a Persistent Ozone Episode in June 1978 for Station T7

		Time	O_3 (ppb)	Daily Mean	EPN*	t max#
1978	June 3	0100	26			
		0700	18			
		1300	98	50	5	1400
		1900	55			
	June 4	0100	24			
		0700	31			
		1300	151	59	7	1300
		1900	44			
	June 5	0100	28			
		0700	22			
		1300	133	53	5	1500
		1900	38			
	June 6	0100	17			
		0700	33			
		1300	97	48	6	1400
		1900	48			
	June 7	0100	20			
		0700	28			
		1300	42	31	0	1700
		1900	43			

*EPN is no. of hours with $[O_3] \geq 82$ ppb

#t max is the time of the maximum concentration

Table 6.3

Some Parameters Associated with a Persistent Ozone Episode in August 1981 for Station T7

		Time	O_3 (ppb)	Daily Mean	EPN*	t max#
1981	Aug 5	0100	10			
		0700	7			
		1300	104	47	6	1400
		1900	55			
	Aug 6	0100	27			
		0700	14			
		1300	148	62	7	1100
		1900	71			
	Aug 7	0100	25			
		0700	15			
		1300	166	67	8	1200
		1900	81			
	Aug 8	0100	26			
		0700	15			
		1300	143	64	9	1100
		1900	49			
	Aug 9	0100	19			
		0700	14			
		1300	198	66	7	1200
		1900	56			
	Aug 10	0100	23			
		0700	17			
		1300	124	60	8	1200
		1900	61			
	Aug 11	0100	30			
		0700	17			
		1300	64	38	0	1400
		1900	25			

* EPN is no. of hours with $[O_3] \geq 82$ ppb

t max is the time of the maximum concentration

The location of the maximum may relate to the following factors:

1. The highest precursor emissions are west of this location.

2. The topography (see Figure 6.1) acts to contain and entrap the heavily polluted air south of the Coastal Mountains.

Typically, as an episode proceeds, daily ozone concentrations rise and the affected area (>80 ppb) expands as far, on occasion, as T11 or Abbotsford (e.g. 95 ppb on July 22, 1978 - see Figure 5.17). Towards the end of the episode, as the anticyclone weakens or drifts eastward, the contours shrink. The episode eventually dies out where it had begun, in the Ioco-Anmore-Port Moody area.

6.5.3 Long Range Transport

From this preliminary study, it appears that long range transport of ozone and ozone precursors from outside the Lower Fraser Valley is not a contributing factor to ozone episodes in GVRD. Synoptic scale transport is generally not important as the episodes are contemporaneous with stagnating high pressure systems implying little or no large scale motion of air.

As stated above, however, south-east trajectories (from western U.S.) are <u>occasionally</u> associated with episode days as on September 6-7 1981 (Figures 6.17 - 6.18) and September 15-16, 1981 (Figures 6.19 - 6.20).

These cases are associated with "back of the high" (centre of the High east or south-east of Vancouver).

6.5.4 Frequency of Persistent Ozone Episodes

Lynch and Emslie (1972) have estimated that the sea breeze - land breeze cycle occurs on as many as 50-60% of the days of the warm season. Most of these occurrences do not coincide with a persistent ozone episode as consecutive days of the cycle, typical of a stagnating high pressure situation, are required. The number of stagnating anticyclones is highly variable from year to year but appears to lie in the range 1 - 3 per year for the persistent ozone episode period - June to September (based on an examination of synoptic maps for 1977 - 1981). This range may also reflect an expected frequency of persistent episodes but wide fluctuations from year to year should also be anticipated. The range is consistent with the number of observed persistent episodes in the period 1978 - 1981 (1.5 per year) but is probably conservative since, as has been noted in Section 6.4, a slow-moving High does not guarantee an ozone episode.

6.6 Meteorological Relationships for Episode Days

The meteorological relationships discussed above have been gleaned from a study of the persistent ozone episodes. These relationships are now partially generalized to the episode days during the period of study (1978 - 1981). The analysis is of necessity not comprehensive due to the limited scope of this study.

6.6.1 Temperature

The importance of high temperature can be seen by noting that 85% of the hours with inland (Abbotsford Airport) temperatures greater than 30^{o}C during the study period occurred on episode days.

Although most episode days had higher than normal tempratures, 6% of episode days (in winter and early spring) occurred with temperatures below 15^{o}C.

Generally, the more severe episodes, both in terms of ozone concentration and duration, corresponded to higher temperatures. The end of persistent episodes was often accompanied by a significant temperature drop (see Table 6.1).

August 1981 had an unusually high number of hours with temperatures exceeding 30^{o}C (see, for example, Table 6.1) compared to a normal value (based on 1957 - 1966) of 12 hours. This was reflected in an unusual situation in which 5 of 6 consecutive days had areal episode conditions.

6.6.2 Wind Direction

The wind directional frequencies shown in Table 6.4 for daylight hours and Table 6.5 for night-time hours are based on the station episode days (for definition, see Section 6.2) for the period 1978-81. The Tables reflect the local day (sea breeze) and night (land breeze) wind regimes.

The sea breeze flow is apparent in the wind directions of Table 6.4. Over 40% of the daylight hours at Station T2 had winds in the 30^{o} sector centred on 330^{o}.

For the UBC station (See Figure 4.1), the sea breeze is reflected in a wider range of wind directions due to the peninsular nature of its location. Fifty-five percent of the daylight hours recorded winds in the 60^{o} sector centred on 270^{o}.

The wind patterns are more complex at stations further inland. At Station T7, 24% of the winds during station episode days were calm, while another 42% lay in the 30^{o} sector centred on 230^{o}. At Station T4, 16% of the winds were calm and 23% lay in the 40^{o} sector centred on 255^{o}. (Over 40% of the winds were in the sector 180^{o} to 270^{o}). The most frequent daytime wind directions for station episode days provide information on the most probable orientation of the sea breeze front.

The offshore (land to sea) breeze will be seen in the high frequency of easterly winds at Stations T2 and UBC in Table 6.5. A 5.2% occurrence of 290^{o} winds at UBC likely reflects some cases of particularly well organized sea breeze circulations which persisted into the evening hours.

The night-time winds at Stations T4 and T7 are controlled by a drainage flow of air from higher to lower elevations (see Figure 6.1). At Station T4, this flow is primarily north-northeasterly while at Station T7 is mainly northeasterly.

Table 6.4

Wind Directions Associated with Station Episode Days - Daytime Hours

This table displays wind directional frequencies in excess of 5%.
Days consist of the hours 06-18. Based on data from 1978-1981.

Days

Station	Direction (o)	Frequency (%)	Total (%)
T 2	340	12.8	40.9
	330	12.4	
	320	5.7	
T 4	calm	16.4	39.0
	240	7.2	
	250	6.0	
	270	5.2	
	(260	4.2)	
T 7	calm	23.5	65.5
	230	23.0	
	240	10.3	
	220	8.7	
UBC	290	10.9	59.7
	280	10.2	
	300	7.8	
	250	7.2	
	240	7.0	
	260	6.0	
	270	5.6	
	calm	5.0	

Table 6.5

Wind Directions Associated with Station Episode Nights

This table displays wind directional frequencies in excess of 5%. Nights consist of the hours 18-06. Based on data from 1978-1981.

Nights

Station	Direction (o)	Frequency (%)	Total (%)
T2	calm	12.5	48.6
	090	11.6	
	080	10.4	
	100	7.5	
	110	6.6	
T4	calm	42.5	63.0
	010	7.8	
	020	7.7	
	200	5.0	
T7	calm	36.7	81.6
	050	20.0	
	040	13.4	
	060	11.5	
UBC	calm	16.4	47.5
	100	10.3	
	090	9.7	
	110	5.9	
	290	5.2	

There is a high frequncy of calm winds at night, particularly at the stations further inland (T4 and T7).

6.7 Summary

The meteorological analysis has determined that slow moving anticyclones and sea breeze circulations are intimately connected to the occurrence of persistent ozone episodes. However, the occurrence of a slow moving High does not guarantee a persistent episode, and the ability to accurately predict persistent episodes is contingent on an increased understanding of the GVRD sea breeze circulation.

The diurnal variation and areal distribution of concentrations confirm the sea breeze connection.

From a trajectory study, long range transport does not appear to be a factor in persistent episodes, which require stagnation conditions, but may occasionally be associated with the less severe episode days.

Based on the measured air quality in the period 1977-1981, and on the estimated frequency of occurrence of the meteorological controls, a persistent episode can be expected, on the average, once or twice per year.

The set of episode days had higher than normal maximum daily temperatures and frequent onshore daytime surface winds. The nights following episode days had a high frequency of offshore winds. These findings are consistent with the seabreeze/orzone episode link.

7. ATMOSPHERIC CHEMISTRY OF OZONE AND REVIEW OF MODELS

7.1 Atmospheric Chemistry of Ozone

The chemical transformations taking place in the polluted urban atmosphere leading to the production of ozone have been extensively discussed in the literature (see, for example, Derwent and Hov, 1980). They may be briefly summarized as follows.

The major route for production of ozone in the troposphere is via the photolysis of NO_2

$$NO_2 + h\nu \xrightarrow{k_1} NO + O\,(^3P) \qquad (1)$$

followed by

$$O\,(^3P) + O_2 + M \xrightarrow{k_2} O_3 + M \qquad (2)$$

where M will generally be N_2 or O_2.

The oxides of nitrogen are also involved in the major removal pathway for O_3, which is

$$NO + O_3 \xrightarrow{k_3} NO_2 + O_2 \qquad (3)$$

It is often possible for a stationary state to be reached in ozone concentration i.e. the concentration does not change appreciably with time. If this is the case, it can be shown that

$$[O_3] = \frac{k_1 \, [NO_2]}{k_3 \, [NO]} \tag{4}$$

where the rate constant k_1, depends on the solar intensity, and k_3 is a function of temperature.

The limits of applicability of equation 4 remain to be explored (Calvert, 1976), but even under conditions where it is not quantitatively correct, it will remain true that an increase in the ratio of NO_2 to NO will result in enhanced levels of ozone.

Oxides of nitrogen are emitted by a number of sources, both stationary and mobile. The predominant form is nitric oxide, NO. This is rapidly (1-2 hours) oxidized to nitrogen dioxide, NO_2, by ozone (O_3), the hydroperoxy radical (HO_2) and various alkylperoxy radicals (RO_2), all of which are present in polluted air.

Atmospheric species which are capable of accelerating the oxidation of NO to NO_2 are thus of importance in determining the production of ozone. Most important among these species are the free radicals HO_2 (hydroperoxy) and RO_2 (alkyrperoxy, e.g. CH_3O_2 etc.). Their importance is magnified by their ability to take part in chain reactions, in which relatively low concentrations of the free radical will bring about the conversion of large amounts of NO. For example

$$NO + NO_2 \longrightarrow NO_2 + OH \qquad (5)$$

$$OH + CO \longrightarrow CO_2 + H \qquad (6)$$

$$H + O_2 + M \longrightarrow HO_2 + M \qquad (7)$$

where all three reactions are rapid, and the net effect is oxidation of one molecule of NO, with regeneration of the hydroperoxy radical. Similar chains occur for RO_2.

The peroxy radicals are readily formed in an atmosphere containing reactive hydrocargons, particularly from alkenes. Aldehydes are even more rapidly converted to peroxy radicals, as these reactions all have a photochemical basis. Thus elevated ozone levels are expected to result when there are elevated levels of NO_2, reactive hydrocarbons and sunlight.

In the absence of reactive hydrocarbon species, one molecule of ozone will oxidize one molecule of nitric oxide, and the resulting molecule of nitrogen dioxide may photolyse to recreate one molecule of ozone. In other words, very little happens.

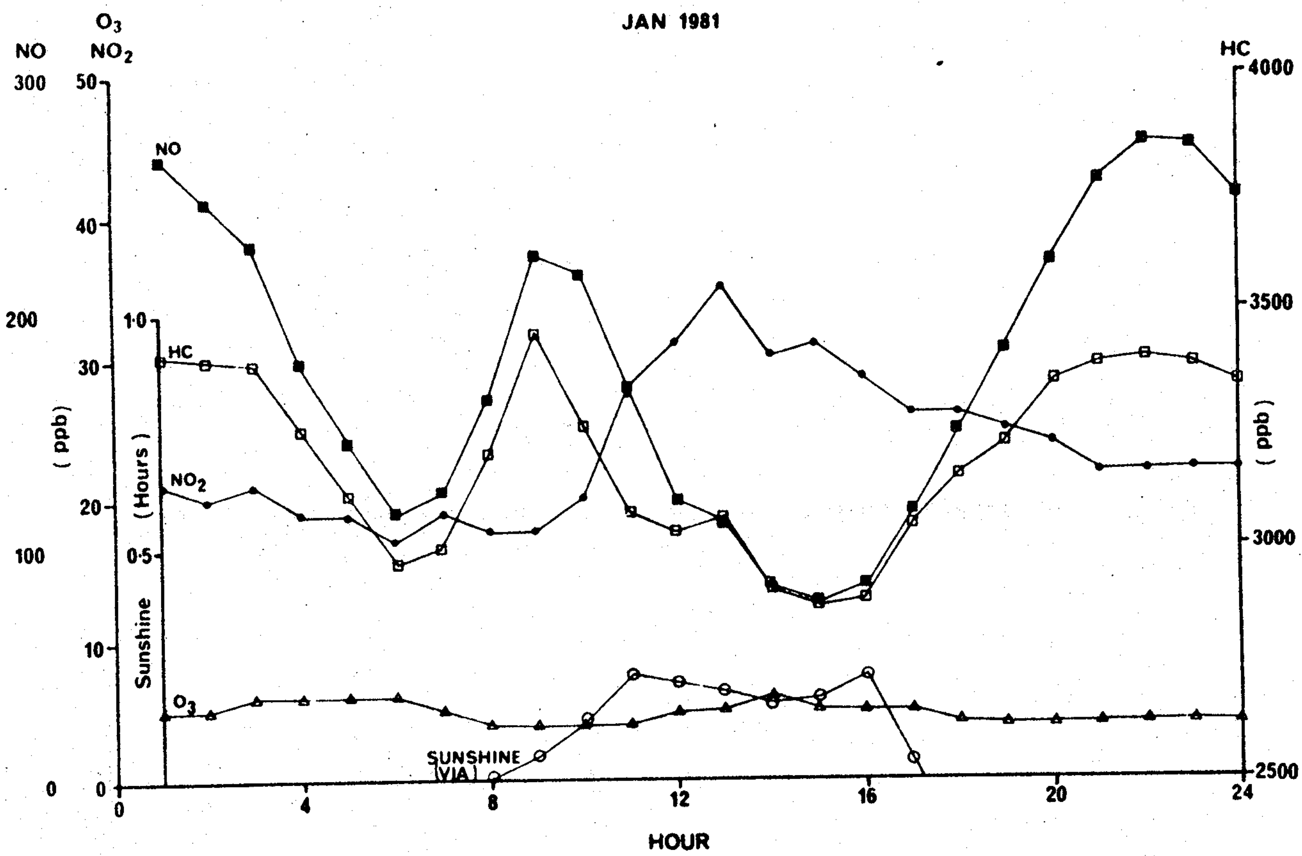
The addition of reactive hydrocarbons makes a dramatic difference, however, since these will react, particularly with ozone and hydroxyl radicals which are always present, albeit possibly in very small amounts. The products of reaction are HO_2 and RO_2, each of which can lead to the production of a large number (typically ~ 500 - Stedman, 1982) of NO_2 molecules, and thus O_3 molecules.

As was dicussed in Section 3 the reactvity of hydrocarbon species varies very widely. The relative constancy of the ambient hydrocarbon levels in Vancouver suggests that a relatively large proportion of the atmospheric hydrocarbons there is non-reactive. If this were not so the large diurnal variation of NO_x and O_3 would result in relatively large variation in hydrocarbon levels. Information on the temporal and spatial variability of emissions and measurments of ambient reactive hydrocarbons would allow for more detailed discussion.

The diurnal variation of ozone and its precursors NO, NO_2 and total hydrocarbons are presented in Figures 7.1, 7.2 and 7.3 in order to illustrate the ozone-precursor relationships and to rationalize the air quality at selected stations. Sunshine data for Vancouver International Airport (VIA) are also plotted.

The two months selected are those which had the largest (August 1981) and smallest number of episodes (January 1981 being one example). The station with the highest incidence of episodes was T7 and the other two stations selected for which there are total hydrocarbons data, T4 and T2 are locations that may represent the central and western areas of the Burrard Inlet.

FIGURE 7.1 DIURNAL VARIATION OF MEAN O_3, NO, NO_2 AND TOTAL HYDROCARBON LEVELS AT STATION T2, JANUARY AND AUGUST 1981.



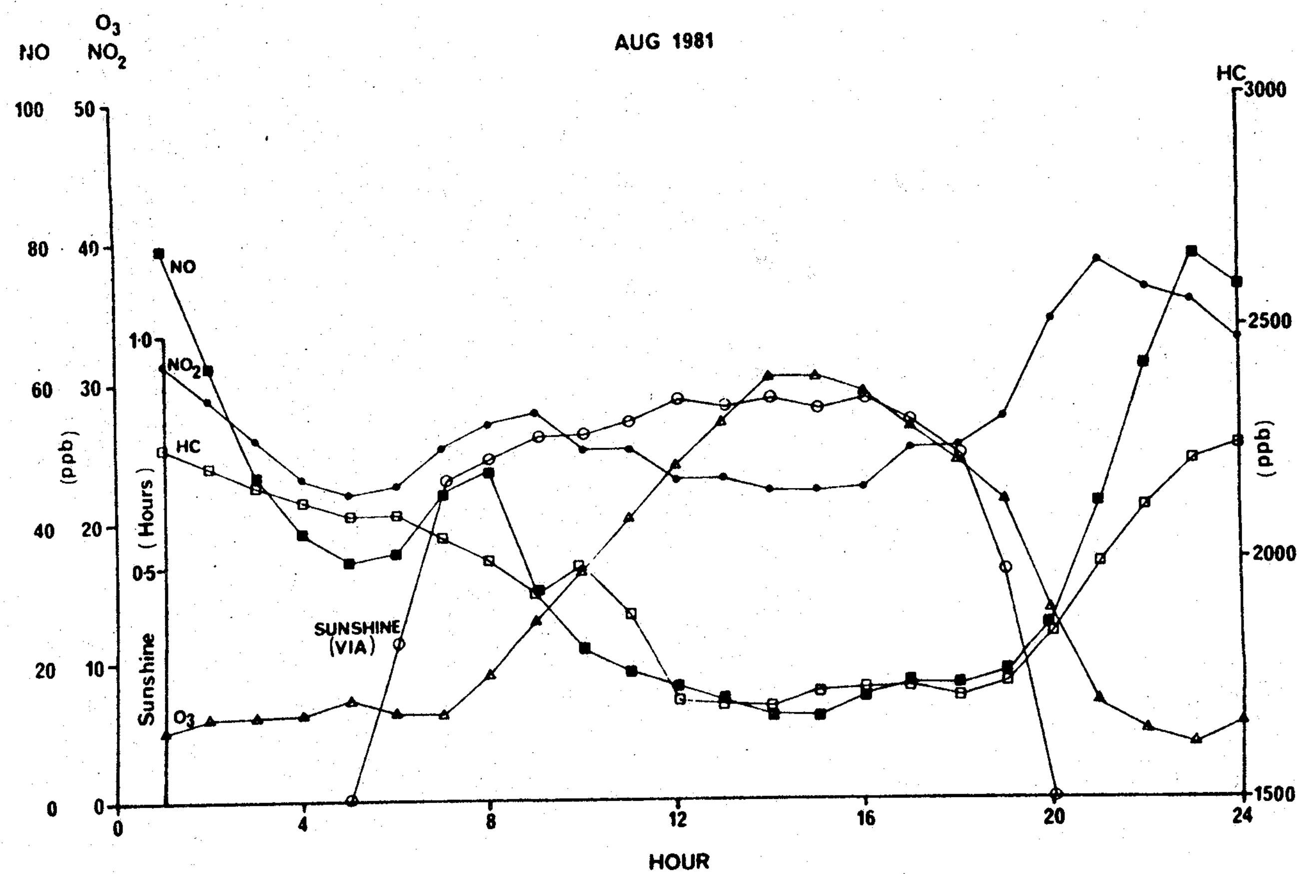
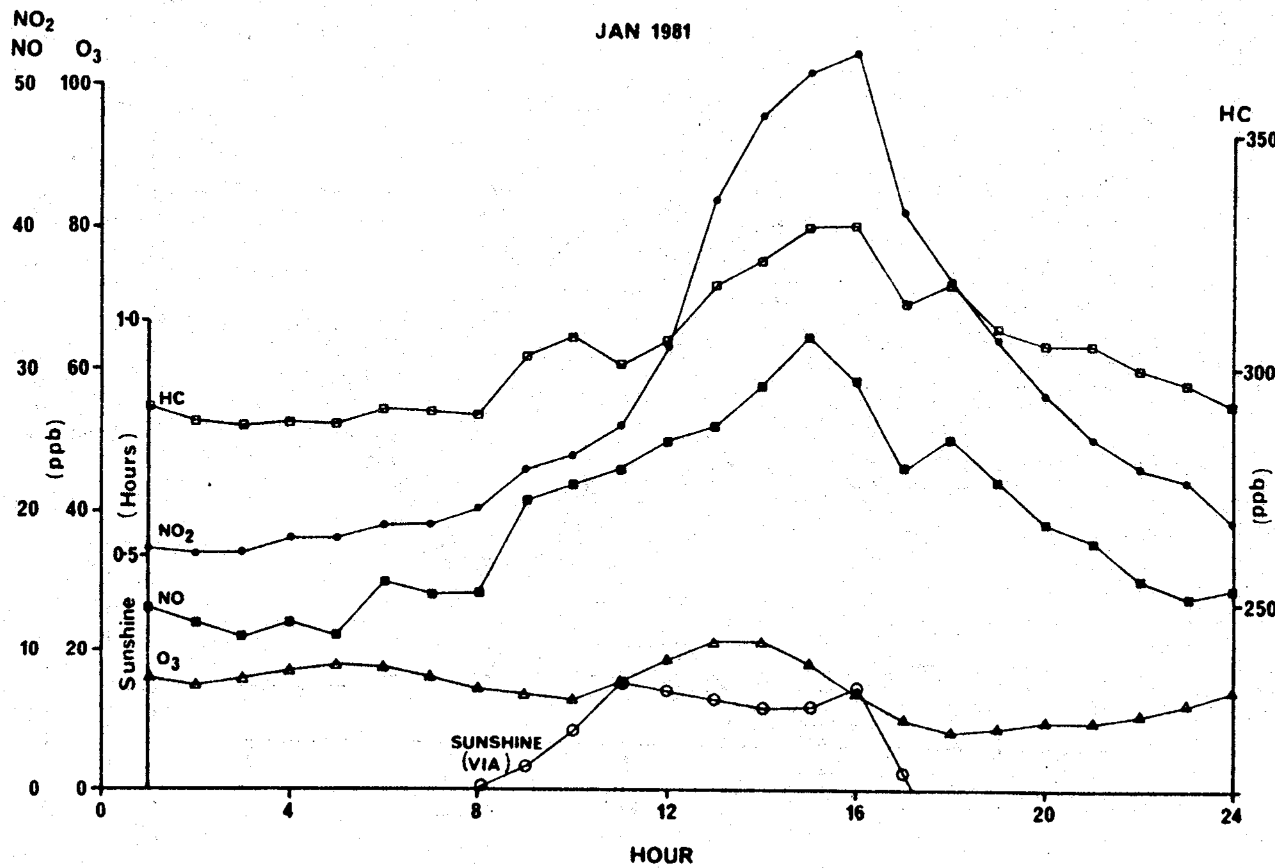


FIGURE 7.3 DIURNAL VARIATION OF MEAN O_3, NO, NO_2 AND TOTAL HYDROCARBON LEVELS AT STATION T7, JANUARY AND AUGUST 1981.



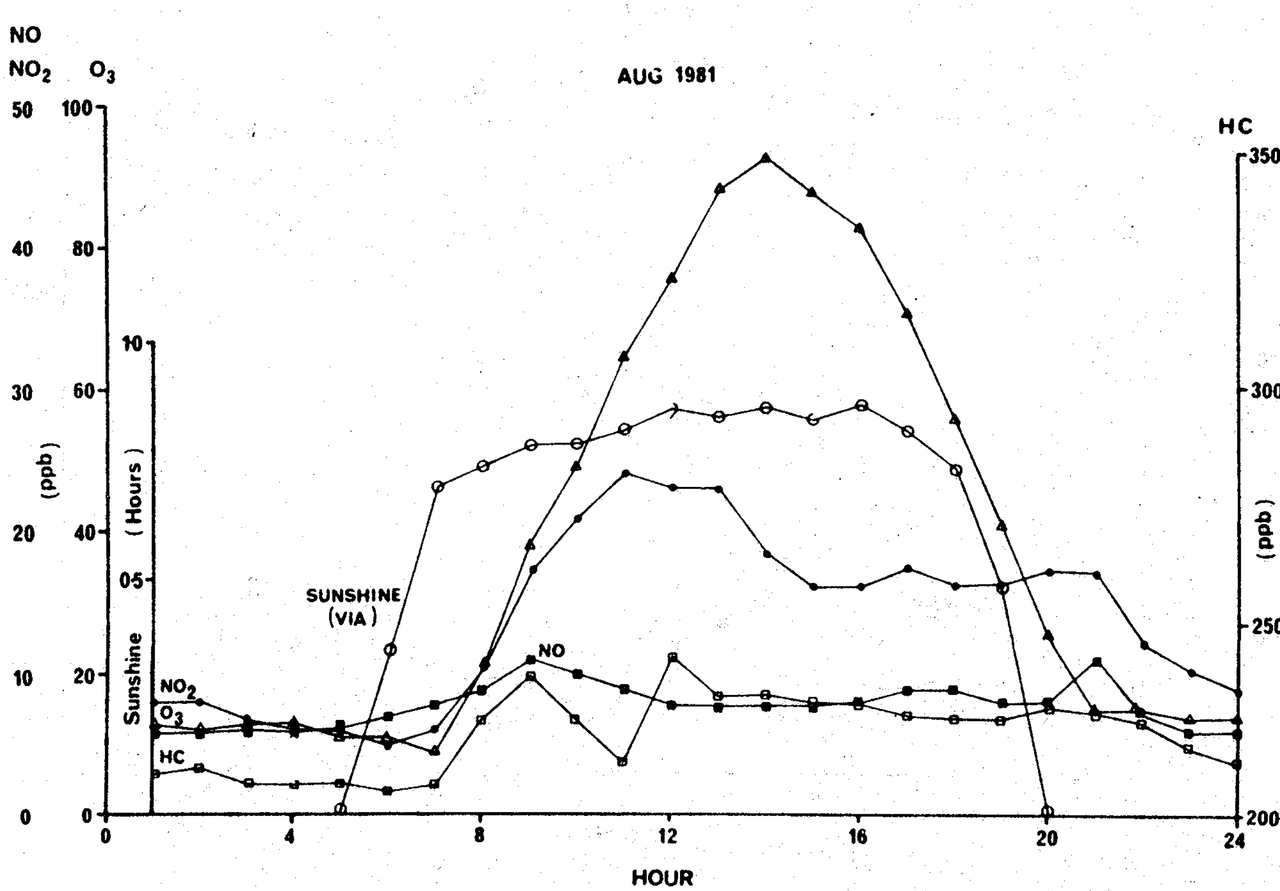
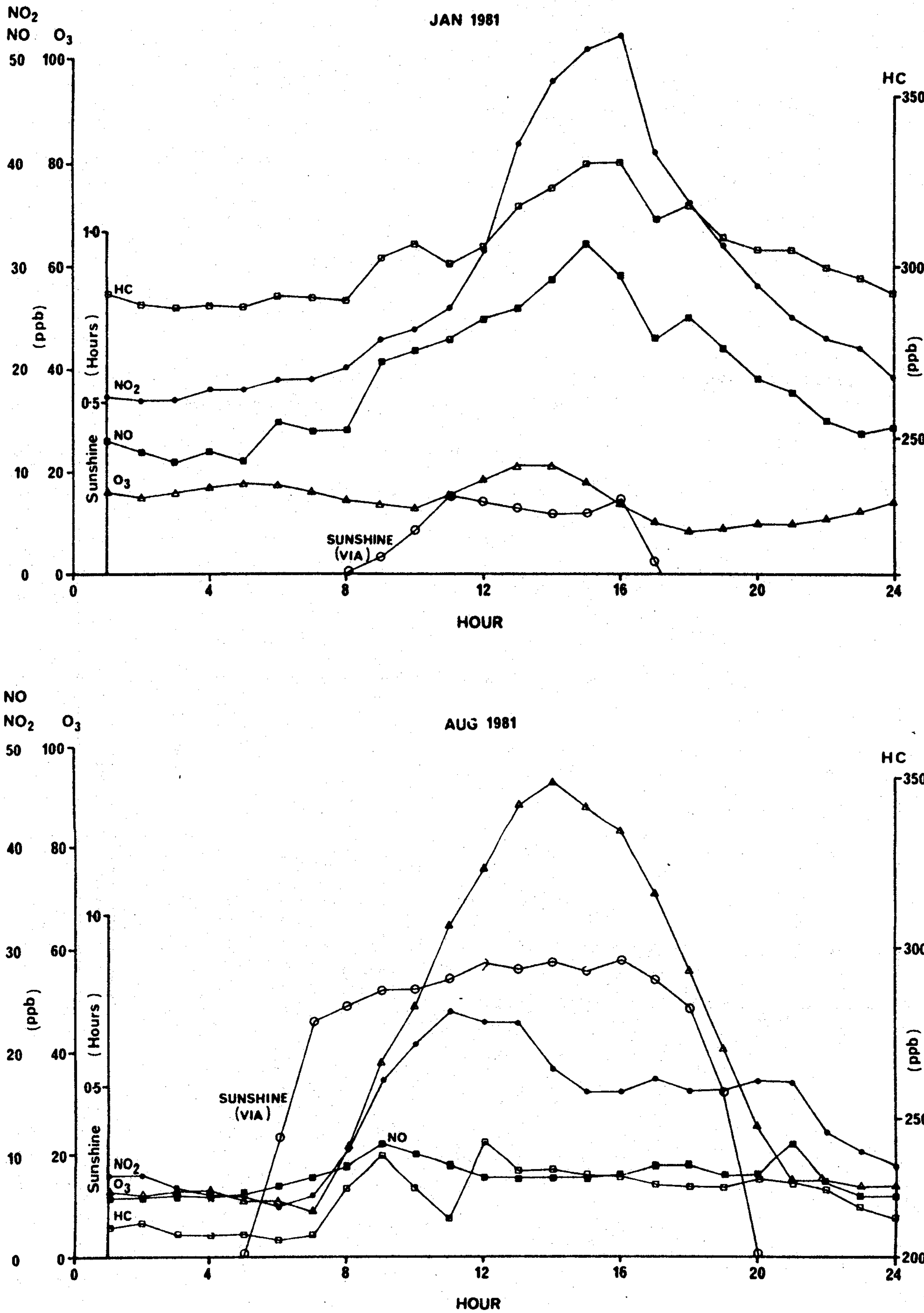


FIGURE 7.3 DIURNAL VARIATION OF MEAN O_3, NO, NO_2 AND TOTAL HYDROCARBON LEVELS AT STATION T7, JANUARY AND AUGUST 1981.



The ozone levels are consistently lower in January than in August for each station (See Table 7.1). The hours of sunshine are also less. In contrast the NO and HC levels are higher in January than in August. The NO_2 levels show similar monthly mean levels at T2 and T4 while at T7 the NO_2 level is higher in January than in August 1981. The monthly variation of these parameters were discussed in section 4.

The diurnal variation of NO, NO_2, HC and O_3 follow the classical pattern for photochemical smog production (Stern 1968). The NO and HC levels peak in the morning hours at times consistent with mobile sources for these pollutants. The NO_2 peak occurs later, consistent with the time needed for oxidation of NO. As this oxidation occurs NO is depleted and NO_2 increases. The NO_2 also is depeleted as other reactions between NO_2, NO and other species occur (forming species such as peroxyalkylnitrates, nitric acid etc.). Ozone of course increases as the photolysis of NO_2 together with reactions in equations 2 and 3 take place.

The build up of NO and HC in the late evening again occurs since sources generate these emissions and also because the photolysis of NO_2 and subsequent ozone formation does not occur. Therefore, the depletion of NO by O_3 is less effective. This general pattern is clearly shown in August 1981 (Figures 7.1, 7.2, 7.3).

In case of January 1981 for stations T2 and T4 the pattern for NO and HC is similar except that the levels are higher. Station T7 shows

Table 7.1

Diurnal variation of selected parameters for

January and August 1981

Monthly mean (ppb)

Paramter	Month	January 1981		August 1981		
	Station T2	T4	T7	T2	T4	T7
O_3	4.93	1.85	14.51	14.05	16.66	37.61
NO	177.4	84.79	18.72	36.25	17.94	7.73
NO_2	23.9	28.17	27.75	26.97	26.47	13.54
HC	3209	3633	3030	1981	2782	2296

somewhat different behaviour in that though there is an increase in NO and HC levels in the morning 0800-1000 and also a lag in the rise of NO_2, the peaks for all these species occur later in the day. One explanation for this may be that since photochemical activity is low, the depletion of NO and NO_2 does not occur as extensively and also the transport of these species (NO, NO_2, HC) from upwind sites contributes significantly to the levels at T7.

Another feature of Figures 7.1-7.3 is the relative variation in HC levels. The diurnal variation is superimposed on a relatively high background level that must essentially consist of accumulated non-reactive species. The diurnal variation is therefore in part due to emissions, the reaction of reactive hydrocarbon species and of course dispersion.

The patterns of diurnal variation of NO and HC are very similar. (See Figures 7.1, 7.2 and 7.3) The behaviour of NO_x also follows the pattern. The similarity in the diurnal variation of NO, NO_x and HC is also illustrated from plots of data for February 1980 (Figures 4.14, 4.19 and 4.24) May 1980 (Figures 4.15, 4.20 and 4.25) and November 1980 (Figures 4.17, 4.22 and 4.27). Strong support for concluding that these species come from a common source comes from examination of the emissions inventory data which shows that mobile sources contribute the greatest fractions of VOC and also NO_x emissions.

The foregoing analysis adequately demonstrates the relationships between ozone and its precursors, and is consistent with the limited information on emissions. More detailed information on the spatial, temporal and chemical resolution (into reactive and nonreactive hydrocarbons) of the emission data would allow for more detailed analysis. The superimposition of the meteorological factors that are important in ensuring the development of episodes (see Section 6) will therefore characterize the occurrence of ozone episodes in the study area.

7.2 Review of Models

7.2.1 Introduction

Once it has been established that unacceptable oxidant levels can occur in an area, it is desirable to understand the conditions that give rise to such occurrences. The development of suitable models for forecasting or predictive purposes is necessary for rational determination of likely adverse air quality conditions, for formulating control strategies and to estimate the likely effectiveness of these strategies.

Oxidant control strategies which have been formulated have been based on models that have allowed the prediction of ambient ozone levels from precursor emission levels, meteorological parameters and from topographical considerations. A variety of models have been formulated in Europe and North America (Hov and Derwent, 1981; de Mandel, et al., 1979) The models vary greatly in complexity, validity and cost. The complexity is determined by the extent to which atmsopheric chemical reaction kinetics and the spatial and temporal resolution of air quality and meteorological parameters are included.

An assessment of the suitability and applicability of a particular model to the GVRD is premature and beyond the scope of this project. A thorough review of potentially useful models is required. Such a review should be cognizant of the available Air Quality, Meteorological and Emissions inventory data as well as the likelihood and cost effectiveness of acquiring additional data for model inputs.

The following discourse on photochemical models is clearly not meant to be a comprehensive review of models but will merely highlight the features of <u>two</u> models that are based on different methodologies or approaches. The examples will illustrate some of the necessary model inputs and will indicate the level of complexity and effort needed to test these models.

It is possible to approach the modelling of urban air quality from two completely different points of view: -

i) Empirically, employing regression techniques on historical data to relate the concentration of the required species to an appropriate set of parameters.

ii) By setting up a more or less detailed mathematical model, incorporating treatment of the various physical and chemical processes affecting the air mass involved.

Both methods have been employed in a number of situations, and some examples are discussed below.

7.2.2 Empirical Modelling

This corresponds to modelling in the sense used by statisticians. It should be noted that setting up a model based on a reasonable set of parameters, which is capable of responding to a wide range of conditions, requires detailed knowledge of the chemistry and physics of the situation.

Prior et al (1981) adopted a statistical approach in predicting the maximum daily ozone concentration in St. Louis. The data base consisted of hourly average ozone concentrations, averaged spatially over 11 monitoring sites covering a 400 square kilometre area. This data base was large enough that the model could be derived using half of the data, then verified against the other half.

The parameters chosen as possible predictors for the maximum ozone concentration were

- 6 to 9 a.m. average wind speed
- predicted daily maximum temperature
- 9 a.m. ozone concentration
- 6 to 9 a.m. NO_x concentration
- 9 a.m. solar intensity

Because the ultimate aim of their work was to achieve a predictive capability, all parameter values were chosen to be available at 9 a.m. or earlier, thus explaining the choice of predicted, rather than measured, maximum temperature. In practice it was found that use of the measured temperature made no significant change to the model.

The first two parameters (wind speed and temperature) were chosen to provide a measure of the meteorology of the situation, e.g. atmospheric turbulence and mixing, mixing height, etc. The third parameter (9 a.m. ozone concentration) allows for the occurence of multi-day episodes, with high ozone levels from one day persisting to the next, while the last two (NO_x concentration and solar intensity) reflect the known photochemical basis for ozone production.

A multiple linear regression was performed between daily maximum ozone concentration as the dependent variable and the five parameters listed above. It was found that the 9 a.m. ozone concentration was the best single predictor, while the predicted maximum temperature was second best. Surprising at first was the observation that the addition of 6 to 9 a.m. NO_x concentration and 9 a.m. solar intensity to the multiple regression did not improve the prediction. This feature arises because the 9 a.m. ozone concentration incorporates the effect of these two parameters, as was confirmed by the strong correlation between 9 a.m. ozone concentration and 6 to 9 a.m. NO_x concentration and 9 a.m. solar intensity. The latter two parameters were therefore dropped from the model.

Analysis of the residuals (measured minus predicted maximum ozone concentration) revealed that there was no significant dependence on surface wind direction, but that there was an effect due to long range transport. This occurs when a high pressure area exists capable of feeding in polluted air from the industrial areas of the eastern United States, or when a prolonged period of stagnation (ten days or more) allows accumulation of pollutants in any area.

When these effects were included, and the model tuned by inclusion of squared terms in each of the three predictors, it was found that the standard deviation of the fit between the model and the data was approximately 11 ppb, approaching that of the measurements. Further, the 6 days from the data set on which the U.S. National Ambient Air Quality Standard of 120 ppb was exceeded were correctly predicted, with no misses and no false alarms.

A somewhat different approach to developing a predictor set was used by Aron (1981). He described two models applicable to the Los Angeles basin. Model I is based on data available prior to 7 a.m., while model II requires data available prior to noon (all times are Pacific Standard Time).

Model I relates the maximum ozone concentration in the Los Angeles basin to the temperature measured at the International Airport at 5:30 a.m. at various levels (1000, 900 and 850 mb) and also to the inversion base temperature measured at the same time and location. Additive, cyclically varying terms for day of week (highest on Friday and Saturday) and month of year (highest in March and April) account respectively for temporal variation of such factors as emissions and photochemical activity.

Model II includes similar terms for day and month, and for temperatures at different levels (950 mb at 5:30 a.m. and noon, 850 mb at noon) and has extra terms in the maximum ozone concentration measured on the previous day, and various pressure gradients between Los Angeles International Airport, Las Vegas, San Diego, San Bernadino, Victorville and

Dagget. The latter terms account for transport effects within the L.A. basin.

The estimated standard deviations are 49 and 36 ppb for models I and II respectively. These values are approximately four times as large as those found by Prior et al (1981) for the St. Louis area. However, the maximum ozone levels in the area are also approximately four times as large, so the performance of the two sets of models is approximately equivalent. It should be noted that the Los Angeles Basin models are used predictively. Model I provides an initial prediction of the daily maximum ozone concentration, while Model II is used to provide subsequent confirmation or revision.

The two sets of models described above are typical examples of the empirical approach to air quality model. Although they appear to be based on different sets of predictors, they actually relate to the same underlying physics and chemistry.

Neither piece of work attempts to provide spatial resolution within the area being modelled. Indeed, there is considerable justification for the point of view that elevated ozone concentration is an area wide phenomenon. For example, Cox and Clark (1981), applying factor analysis to ozone data for the eastern United States, deduced that there were essentially four areas, within each of which ozone concentrations tended to vary in concert.

The basic advantages and disadvantages of the empirical approach are essentially independent of the particular application. The principal advantage is that this type of model is simple and cheap to use. Indeed, once the model coefficients have been derived using historical data, it can readily be run on a hand calculator.

The chief disadvantage is that there is no way to guarantee the validity of the model outside the range of the data used in its derivation. In particular, this drastically limits the applicability of empirical models in assessing control strategies, since these, of necessity, involve estimating the effect of reducing some emissions below current levels.

7.2.3 Numerical Simulation

Computer based numerical simulation of air quality requires, in principle at least, that the following processes be treated

- emission of pollutant species, notably SO_2, NO_x and hydrocarbons
- advection and dispersion of these species
- chemical transformation
- deposition

Widely varying levels of sophistication have been brought to bear on the treatment of these processes.

At the simplest end of the scale, the air parcel over the region of interest is assumed to be contained in a box, within which the emitted pollutants are uniformly and instantaneously mixed. This approach, which eliminates the need for specifying advection and dispersion and which requires only a knowledge of emission rates with no spatial resolution, has been followed by Derwent & Hov (1980). They modelled air quality in London under a number of emission scenarios.

The simplifications achieved by assuming a well-mixed box generally carry the price that day to day variations due to meteorological effects are not considered, so that the temporal resolution is low. Obviously there is no spatial resolution within the box. Such models are thus most useful for determining long term average concentrations.

Increasing the number of boxes within the area of interest allows improvement in the spatial resolution, while it is also possible for advection of a set of boxes to be followed.

The result is a trajectory model, which would typically be applied in assessing air quality downwind of point or area sources. Such a model would thus be applicable to the study of the effects of Vancouver emissions on the Fraser River Valley. A typical example of such a model is given by Lurman et al (1982). This model, known as PLMSTAR, features a moving "wall of cells", thus providing lateral and vertical resolution. The wall of cells remains of constant size while undergoing advection by the mean wind. Diffusion between cells allows for plume expansion, while chemical reaction is treated within the cells. This model appears to combine the best features of several reactive plume models, and incorporates refinements in several areas. It has apparently not yet been applied in modelling an actual source, or group of sources.

Further increases in the number of boxes result in Eulerian or grid models. Two examples of this type will be considered.

Swan and Lee (1980) applied a two dimensional gridded model in the San Francisco Bay area. They used a 60 x 60 grid, with grid dimensions corresponding to 1 arcmin (approximately 1.5 x 1.75 km). Each "square" was assumed to support a column of air, equal in height to the boundary layer height, within which mixing was uniform.

The meteorological boundary conditions for the model were obtained by a double nesting procedure. The model was run first with a grid square dimension of 20 arcmin, thus covering the whole of California and Nevada. The results from this run were saved on the appropriate interior area, and used as boundary conditions for a run with grid square dimension of 5 arcmin. Results from the second run were similarly applied as boundary conditions for the final run.

It is currently recognised that consideration of the vertical structure of the atmosphere is important (see, for example, Lamb, 1982). An example of a three-dimensional gridded model is IMPACT (Sklarew et al, 1977; Sklarew and Mirabella, 1979; Sklarew and Henderson, 1979). This model is composed of five submodels, which treat the important processes i.e. wind field development, pollutant transport, diffusivity field development, plume rise calculation and chemical transformation. Typical grid dimensions used in the model range from 100 m horizontally and 50 m vertically to 2 km horizontally and 100 m vertically.

Common to all of the numerical models discussed above, regardless of the degree of simplification of advection and dispersion, is a module simulating complex photochemistry. Thus Derwent and Hov (1980) considered some 280 reactions of 85 species, Swan and Lee (1980) included 35 reactions of 25 species, and IMPACT allows a range of options, featuring up to 60 reactions of 20 species. Clearly, sophistication of the atmospheric physics is accomplished at the cost of some simplification of the chemistry, otherwise the computational costs rapidly become unmanageable. It is currently suggested that integration of the chemical rate equations occupies 80% or more of the computer time required by large Eulerian models (Lamb, 1982).

The need for complex chemical rate components in numerical models arises because of the highly non-linear relationships between nitrogen oxides, ozone, hydrocarbons and the various reactive intermediates produced as a result of photochemical action on these species. The situation is aggravated by the wide range of hydrocarbons typically emitted into the urban environment, and is discussed in more detail below.

From a mathematical point of view, the result is a large set of coupled differential equations, featuring widely varying time constants.

Such sets of equations are computationally expensive to solve. Consequently active research is currently aimed at the development of improved numerical methods, and at simplifying and rationalising the chemical mechanisms without causing loss of accuracy.

8. SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

8.1 Summary and Conclusions

The foregoing analysis of the air quality, meteorological and emissions inventory data for the GVRD has allowed several conclusions to be drawn. The analysis has addressed most aspects of the air quality and meteorology related to ozone episodes in the GVRD and Lower Fraser Valley. Those areas that require more in-depth analysis will be indicated and recommendations for pursuing additional aspects of the oxidants study in the GVRD and Lower Fraser Valley are given in Section 8.2. The major conclusions of this study are summarized below.

8.1.1 Data Base

The designated air quality and meteorological data for the GVRD have been archived and magnetic tapes containing the archive have been provided. The documentation (Code Book) for the Archive has been included in this report. The archive will allow any additional data analysis required to be done efficiently Recommendations for the continued updating of the Archive have been made (see Section 8.2).

Analysis of the emissions inventory, air quality and meteorological data, along with synoptic weather maps for the area and other climatological information, have allowed the identification and characterization of ozone episodes.

8.1.2 Emissions Inventory

The available emissions inventory data for the GVRD have been summarized. Gasoline powered vehicles constitute the major sources of volatile organic carbon and nitrogen oxides emissions (historically and for 1985 projections). Projections for 1985 emissions levels were prepared. These projections are subject to considerable uncertainty but suggest that by 1985 there would be a decrease of 16% (compared to 1976 levels) of volatile organic carbon (VOC) emissions but an increase of 25% in total nitrogen oxides (NO_x) emissions. This leads to the continued decrease in the VOC/NO_x ratio. The relative amounts of reactive hydrocarbons and nitrogen oxides can significantly affect the formation of ozone and other secondary pollutants (Dimitriades 1977). Before inferring the likely impact that the change in the relative amounts of VOC and NO_x may have on ozone levels in the GVRD, it would be prudent to obtain more reliable estimates of these emissions, together with spatial, temporal and chemical resolution of the emissions inventory data. The VOC emissions were classified into seven reactivity classifications including non reactive methane and unidentified compounds (or those with unknown reactivity). The 1976 data indicate that methane and the non reactive VOC and the unidentified classes constitute ≈ 27% of the emissions and therefore suggests that the reactive VOC are the predominant type in VOC emissions.

The large uncertainties in accuracy, the lack of spatial and temporal resolution of the emissions inventory as well as the absence of information on the actual levels of reactive classes of hydrocarbons are deficiencies of the emissions inventory information and the air quality data base. The extent to which these deficiencies should be redressed should be determined with due consideration of oxidant control modelling requirements.

8.1.3 Data Analysis

Air Quality

Air quality data (O_3, NO, NO_2, NO_x and HC) for the four year period 1978 - 1981 were analyzed. There were indications of an increase in ozone levels at some monitoring stations over this period. No conclusive trends in the other parameters were discernible.

Ozone levels at several stations in the GVRD frequently exceed the National Maximum Acceptable 1 hour level of 82 ppb. The objective for the annual mean ozone concentration is also exceeded at some stations. For NO_2, only one exceedance of the 1 hour maximum acceptable level was recorded in the four year period 1978 - 1981.

The precursor pollutants NO, NO_2 and Hydrocarbons are generated locally and under favourable meteorological conditions, contribute to very high ozone levels.

Ozone levels were higher in the spring and summer months than in the winter fall months. The converse is true for the nitrogen oxides (NO, NO_2 or NO_x). Total hydrocarbons levels were generally high throughout the year but superimposed on these high levels were seasonal variations - higher in winter and fall months than in spring and summer.

The diurnal variations of ozone and its precursors are similar to those found elsewhere. Peak ozone levels occur most often at about 1400 hours for most stations except at Abbotsford and Chilliwack where peak levels occur 2 - 3 hours later. Total hydrocarbons levels remain high throughout the day but a relatively small diurnal variation (indicative of morning and evening peak emissions) is superimposed on this. The diurnal patterns for NO and total hydrocarbons are similar and indicate a common source, namely mobile combustion sources. This conclusion is supported by emissions inventory data, which show that gasoline powered vehicles are the major source of VOC and NO_x.

Ozone Episodes

Criteria for defining ozone episodes were developed. These criteria allowed the identification of station episodes, area episodes and persistent area episodes.

Episode conditions as defined occurred between April and September each year with most episodes occurring in July and August.

Persistent episode conditions were always associated with a stagnant anticyclone system over the region.

There is no indication that long range transport of ozone or its precursors is a contributing factor to ozone episodes in the GVRD.

Persistent episodes were associated with the land/sea breeze circulation which determines the mesoscale transport of ozone and its precursors. The analysis of the frequencies of the wind directions for episode daylight and night hours, the tendency for episodes to occur when inland temperatures are higher than normal and the spatial distribution of ozone levels and wind data , all support the importance of the sea/land breeze phenomenon in ozone episodes.

In the single instance (July 21/22, 1978) where a persistent episode coincided with the availability of more detailed meteorological data (minisonde studies), some detail of sea breeze structure were derived. The attendant conditions of a low mixed layer depth and low wind speeds favoured the buildup of ozone levels.

The mesoscale transport by the sea breeze front results in down-wind areas being affected by ozone and other secondary pollutants generated in the GVRD. The occurrence of peak ozone concentrations at T11 and T12 (Abbotsford and Chilliwack) suggests that these stations show the effects of the sea breeze transport. More detailed analysis of the sea breeze dynamics is needed to determine the extent to which these stations and other Lower Fraser Valley areas are affected by mesoscale transport.

The effects of the return flow (land breezes) on the transport of ozone back over the GVRD have not been strongly evident. It is likely that the high levels of nitric oxide together with inefficient reentrainment of the polluted air mass in drainage flows and land breeze at night are sufficient to mask the observation of elevated ozone levels later in the evenings.

8.1.4 Review of Photochemical Models

A brief examination of two types of approaches to modelling for predictive purposes was made. One specific application of each type of approach was presented to indicate the range of model inputs which are needed. A more thorough review of modelling requirements for eventually determining oxidant control strategies is needed.

8.2 Recommendations

The conclusions detailed in the previous section clearly indicate that ozone episodes (as defined) in the GVRD occur frequently and are likely to continue. In addition, transport of polluted air towards the Fraser Valley is a matter of concern. The ultimate objective should be to determine the nature and extent of oxidant control strategies that will allow acceptable (in economic and environmental terms) oxidant levels to be established in the GVRD as well as in the potentially susceptible downwind receptor area in the Fraser Valley. The following recommendations will address these objectives.

The analysis of the data as it relates to ozone episodes was limited and the following types of additional data analysis may be done to obtain more detailed understanding of the factors affecting ozone formation:

1. Examine empirical relationships between ozone and parameters including NO, NO_2, hydrocarbons, wind speed, wind direction, solar radiation, previous day's precursor concentrations, temperature and mixed layer depth.

2. More detailed analysis of the wind data to determine local and regional wind fields and to allow the selection of suitable sites for short term intensive meteorological studies.

We recommend the conduct of short term detailed meteorological studies in conditions that have been shown in this study to be conducive to ozone episode occurrence. These studies should include the spatial three dimensional and time dependency of circulation systems, the speed and structure of local fronts, and the interaction of the regional flow with slope and tributary winds. The dynamics and variability of the mixed layer depth should, of course, be included.

During such intensive studies, the routine air quality monitoring should be augmented by aircraft and mobile ground sampling to obtain three dimensional pollutant data.

In order to obtain a better assessment of the spatial distribution of ozone levels in the GVRD and to better characterize the mesoscale transport of pollutants, additional stations are recommended. These additional stations should be sited in the following areas:

1. Delta District Municipality
2. Cloverdale (East Surrey)
3. Aldergove (East Langley)
4. Mission City
5. Websters Corners
6. Sheridan Hill area

Stations in the Cloverdale, Aldergrove and Mission City areas would supplement the existing stations at Abbotsford and Chilliwack in better characterizing the transport of pollutants towards the Fraser Valley.

These additional stations may be established by relocating at least two existing stations. For example station T10 may be moved to the Sheridan Hill area, station T5 (or T4) and possibly T8 might also be deployed elsewhere. However, the siting of the stations in the Burrard Inlet may have been intended to obtain information on specific point sources in the area. Information on point sources and an assessment of air quality in relation to specific point sources were not within the scope of work for this project. The requirements for site-specific coverage would need to be considered in deciding whether or not relocation of stations is desirable. It should be stressed that the establishment of the additional stations should be undertaken as one component of an overall rationalization of all air quality (and meteorological) monitoring objectives.

General recommendations for continually updating and if desirable extending the Archive were outlined in Chapter 2. The continued updating of the GVRD Archive will allow efficient air quality assessment studies to be made as required from time to time. Since data originate from different networks, the comparability and uniformity of the data, in terms of the station siting requirements, quality assurance, quality control and data validation procedures, should be an immediate objective.

The emissions inventory information for the GVRD lacks spatial, temporal and chemical resolution. In addition, the accuracy of the existing information could be improved to provide more precise estimates of existing data. Before more detailed emissions inventory data are acquired, a thorough assessment of the model inputs (of which emissions inventories may be one) for control strategies should be undertaken.

An in-depth review of control strategies and the modelling requirements for these strategies should be undertaken to determine which approach will best serve the peculiar needs of the GVRD given the complex topography and existing data. This study would represent the key element in determining the future courses of action.

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APPENDIX A

LAND/SEA BREEZE CIRCULATION OF THE LOWER FRASER VALLEY OF B.C.

A1. MESOSCALE CONTROLS

A1.1 Relation to macro- and synoptic events

Ideally a land/sea breeze circulation can occur on any day of the year but necessary conditions include (Lyons, 1975):

- very light gradient winds (usually a high pressure system)
- strong solar radiation (usually <60% middle and high cloud cover)
- daytime air temperatures inland greater than water surface value.

These requirements clearly favour the warmer portion of the year in Vancouver and this is verified in the analysis of diurnal wind shifts produced by Emslie (1968) using data from the Lion's Gate Bridge for the period 1961-67 (Table 1):

Table A1. Percentage frequency of diurnal wind shift by months (Emslie, 1968).

Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
21	36	54	50	65	63	62	59	58	34	21	9

Although these data point to an easily recognizable and reasonable intra-annual cycle it should be noted that the synoptic conditions of any one year will cause significant deviations from such a pattern. Similarly changes on even longer time scales may be important. Fukaishi (1979) has shown that long-term changes in the frequency of synoptic weather regimes (especially anticyclonic) can account for observed trends in fog frequency in Vancouver. There may well be an impact on land-sea breeze frequencies.

A1.2 Spatial local controls

The land/sea breeze circulation in the Lower Fraser Valley is complicated by the presence of mountain/valley topography and the urbanized area of Greater Vancouver. Both topography and urbanized land use can modify existing airflow characteristics and generate their own local breeze systems under the same conditions which favour land/sea winds.

A1.2.1 Topography - normally it is expected that sea breezes are aligned normal to the coastline early in the day, later they come increasingly under the influence of the Coriolis force and end up flowing more parallel to the coast. There is little evidence of this in Vancouver because of the channelling influence of the Fraser Valley on the near surface airflow. The general argument regarding the interaction between the mountain/valley and anabatic/katabatic winds of the valley with the land/sea breeze has been outlined by Hay and Oke (1976). Intuition further suggests that the tributary valleys off the main Fraser Valley must also provide secondary channelways to and from the main system (e.g. Capilano, Lynn and Seymour Rivers, Indian Arm, Coquitlam, Stave, Pitt and Harrison Lakes). In general such topographic wind systems act in concert rather than oppose the land/sea breeze tendencies. The most obvious augmentation is provided by cold air outflows at night and on a larger scale in winter (Hoos and Packman, 1974). The bottleneck shape of the valley as it opens onto the delta may also be important. This will presumably lead to convergence and uplift in the sea breeze and divergence and subsidence in the land breeze.

A1.2.2 Urbanization - the presence of Greater Vancouver must modify certain characteristics of the land/sea breeze system. For example the greater surface roughness of the city is likely to produce additional frictional retardation of the near-surface winds and may disrupt the passage of land/use breeze fronts as has been observed in New York (Bornstein and Johnson, 1977 and Bornstein et al. 1978). The increased turbulence also appears to mask evidence of sea breeze frontal passage (Kalanda et al. 1980; Oke et al. 1982). The heat island of the city also provides a complication due to the development of thermal internal boundary layers in the sea inflow, and land outflow, layers as illustrated in Fig. 4. Conversely it should be noted that the strength of the wind system is an important control on the depth of the urban mixed layer (heat island) via its ability to advect heat downwind (Steyn and Oke, 1982). The interaction between the land/sea breeze strength and the depth of the mixed layer is very significant to the build-up of pollutants since together they define the crucial 'ventilation factor' used in air pollution box models (Pasquill, 1974). Finally it is important to recognize the existence of an urban/country breeze system due to the horizontal pressure field generated by the heat island. Recent work in St. Louis suggests the urban circulation is best developed by day because although the heat island is smaller static stability favours circulatory motion more than at night (Shreffler, 1978). If such winds exist in Vancouver they will add a vector component to the existing flow travelling from the upwind edge of the city to the centre but will oppose flow out of the city downwind of the centre.

A2. SURFACE NETWORK INFORMATION

A2.1 Background

Although the land/sea breeze circulation of the Vancouver-Lower Fraser Valley region is well recognized and is allowed for in weather forecasting for the region, detailed information regarding its characteristics is sparse so that recent reviews of the climate of the area by Hoos and Packman (1974) and Hay and Oke (1976) draw from a very limited number of studies. The most quoted studies are those by Emslie (1968, 1971) based on 6 years of data from the Lion's Gate Bridge and Emslie (1973) based on a 1½ year record from Vanier Park. There is little or no information in published form regarding the spatial and temporal nature of the land/sea breeze system for stations away from the coast. In relation to air pollution transport the lack of data concerning the speed and location of the sea breeze front is particularly unfortunate.

A2.2 Statistical characteristics

The available information suggests the land/sea breeze circulation to be a frequent occurrence at the coast (Table A1, Fig.A1 and A2). The typical pattern involves onset at the coast at about 0900 PST in the summer (later in the spring and fall). The westerly flow strengthens into the afternoon reaching maximum values of 16-24 km h^{-1} (Hoos and Packman, 1974). The duration of the sea breeze is greatest in the summer lasting 10-12 h on the coast. The easterly land breeze replaces the daytime flow at about sunset in all seasons (around 2000 PST in June - August). Nocturnal flows is typically about 5-13 km h^{-1}. The highest frequency of calm periods are found in the morning before the wind shift and in the evening just after it (Fig.A3). General experience holds that the sea breeze commonly reaches Abbotsford in the afternoon and indirect evidence suggests it may penetrate at least as far as Chilliwack (Sagert and Tennis, 1975) which is about 60 km from the nearest coast and 80 km from Vancouver.

Wind roses for stations in Greater Vancouver readily confirm the effect of the topography in channelling flow (Hay and Oke, 1976). The published data however do not reveal any information specifically of help in land/sea breeze considerations except to show that certain locations are capable of providing marked shelter (especially the Port Moody Basin).

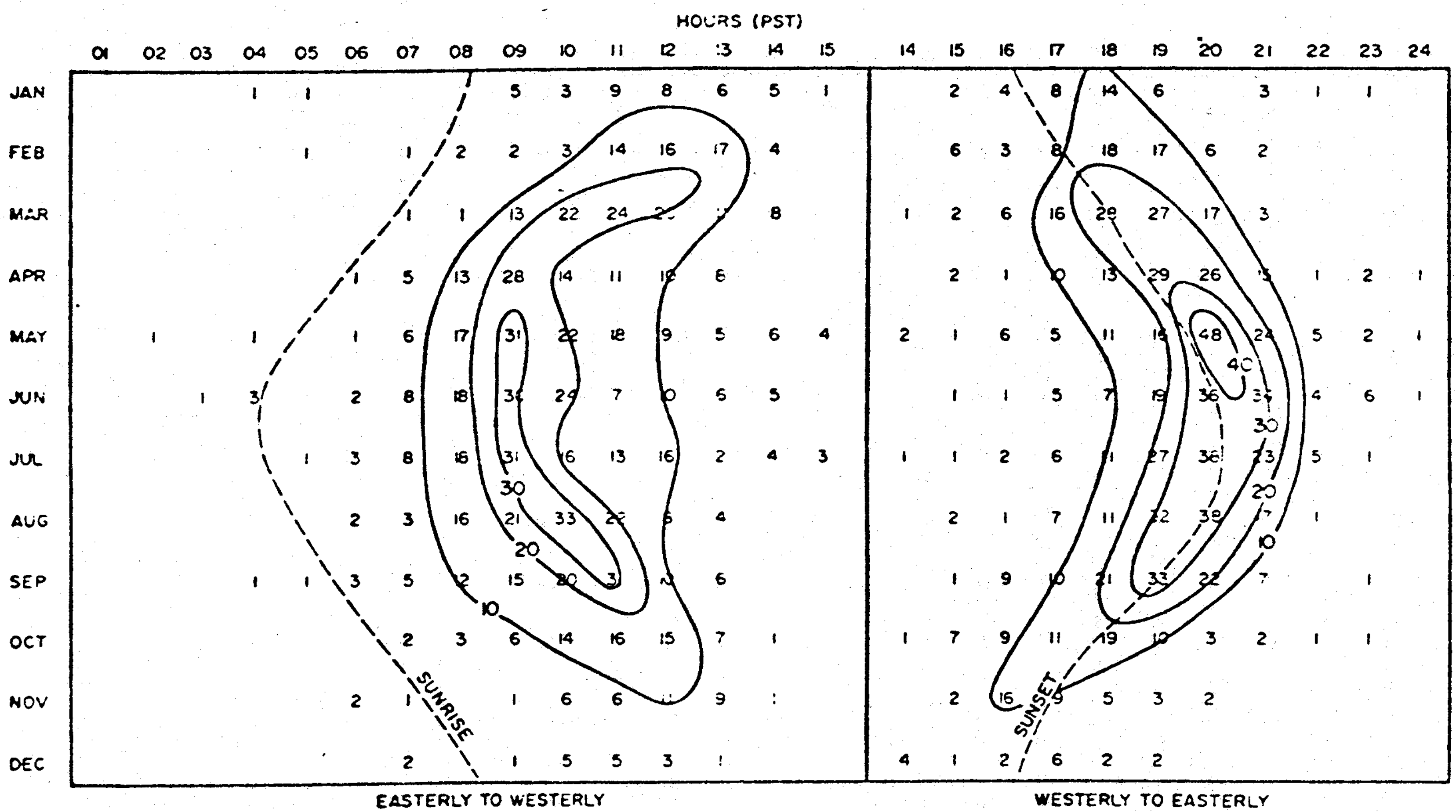

Figure A1. Frequency of Occurrence of Diurnal Wind Shift at the Lion's Gate Bridge by Hour and Month (After Emslie 1968).

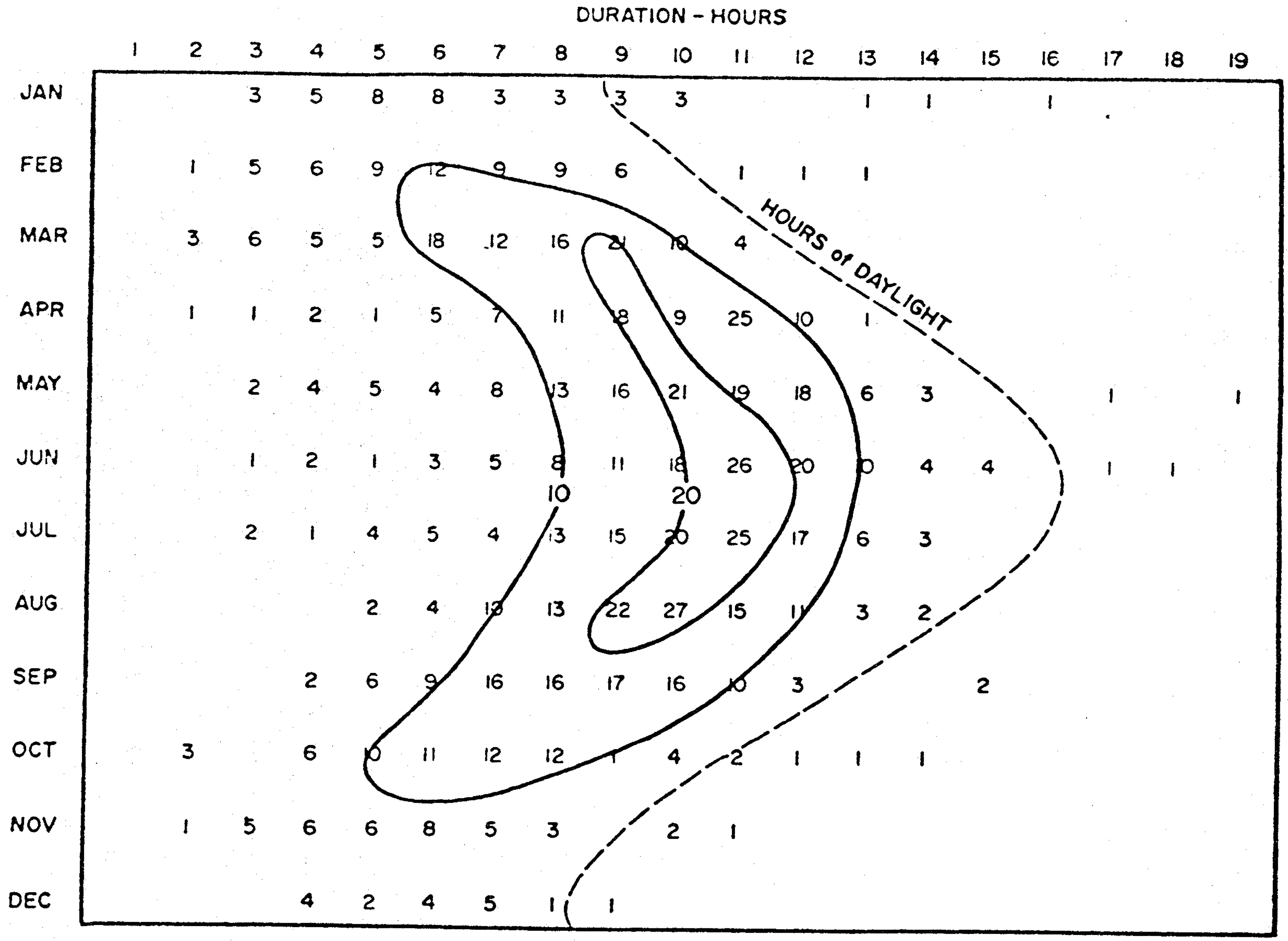

Figure A2. Frequency of Duration of Westerly Air Flow in Burrard Inlet (After Emslie 1968).

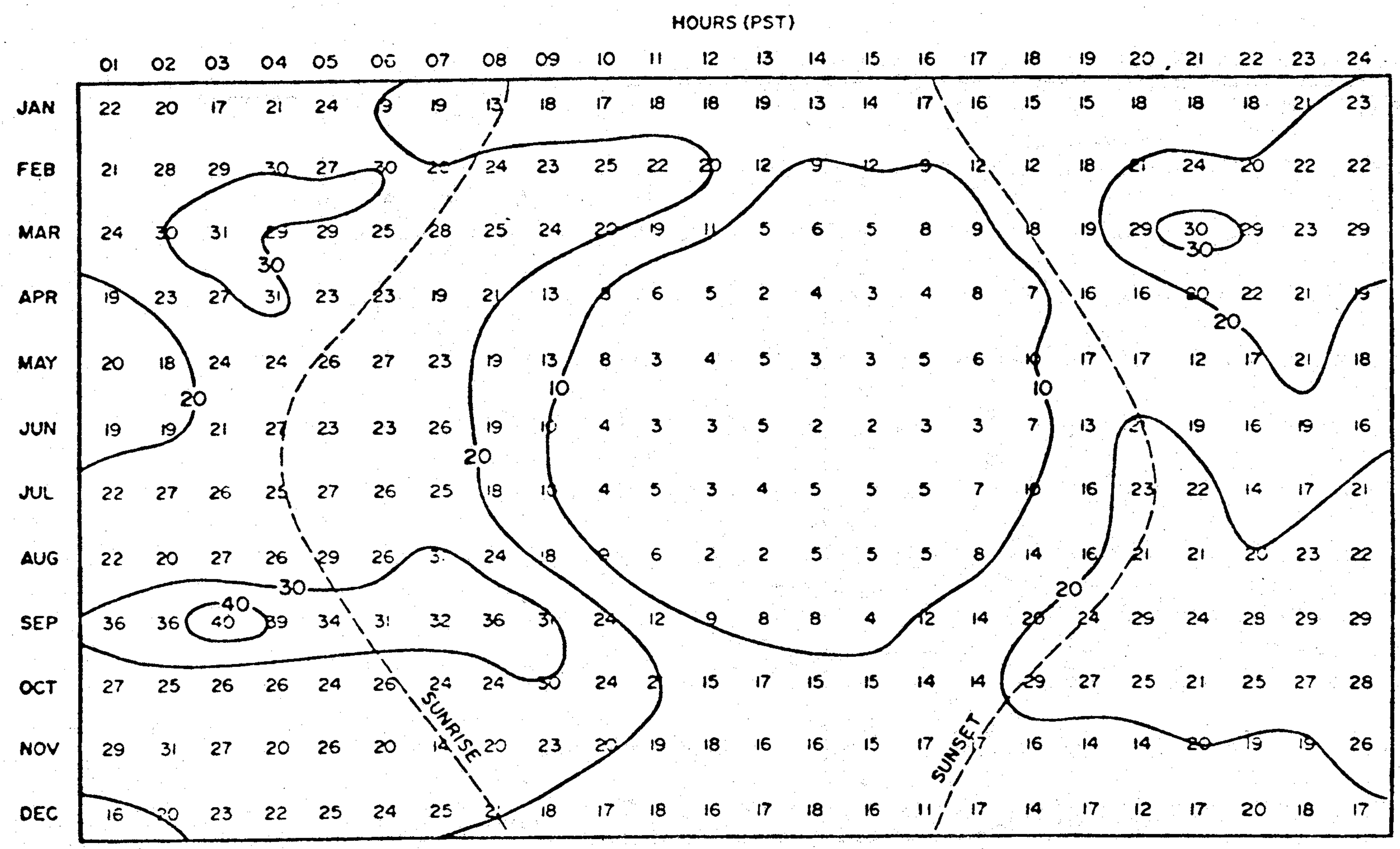

Figure A3. Frequency of Calm Winds (Percent) by Hour and Month in Burrard Inlet (After Emslie 1968).

A3. VERTICAL PROFILE INFORMATION

A3.1 Background

Surface information can represent only a small part of the nature of a three-dimensional system such as a land/sea breeze circulation. However the vertical probing necessary to fill in the picture is not a part of most observation networks. In Vancouver some information might be gleaned from the airport pilot balloon soundings but nothing has been published. Apart from some occasional minisonde balloon flights by AES and BC Hydro personnel the only available study is that by the UBC Geography Department as part of an urban meteorology project in July - August 1978. The details of the methods and instrumentation are given in Steyn and Oke (1982). Despite the shortness of record and restriction to a single site these data are used here to characterize some aspects of the vertical structure of the Vancouver land/sea breeze system. Appropriate caution should be exercised.

A3.2 Vancouver (Sunset) statistics

The observations relate to a site in south central Vancouver well within the built-up area. Depending on wind direction the site has a fetch of about 8-10 km from the coast during sea breeze inflow. Fig.A4 presents a schematic of the anticipated land/sea breeze circulation in the area based on the consensus of Keen and Lyons (1968) and includes the form of thermal internal boundary layers due to the discontinuities existing at the coast and urban/rural boundaries (see also Oke, 1982).

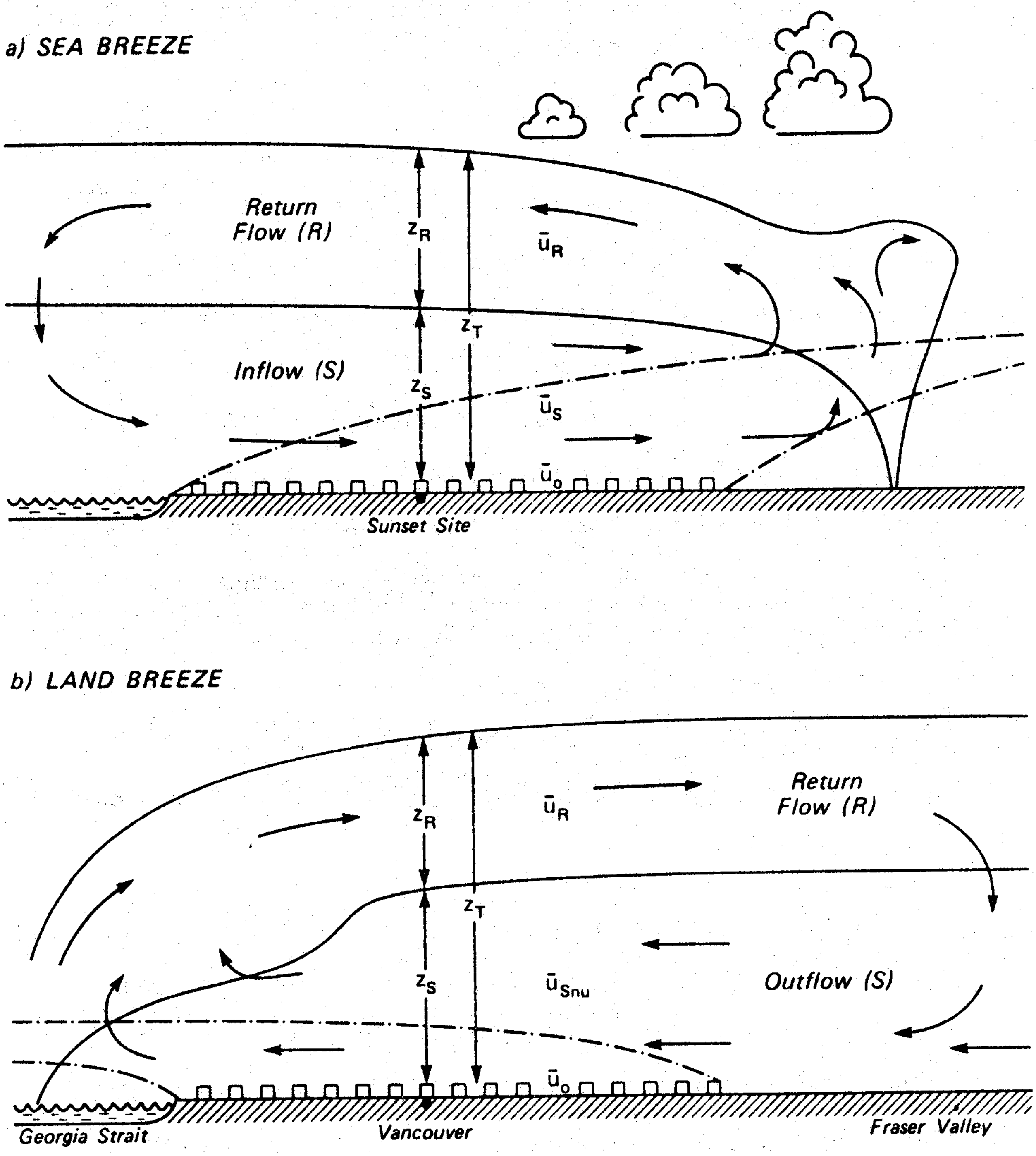

Figure A4. Schematic illustration of the flow in land and sea breeze cells in the vicinity of Vancouver and their relation to thermal internal boundary layers (—·—).

The following general points emerge:

. the strength of the sea breeze inflow (averaged over the depth z_S) is weak. The average speed is about 8 km h^{-1} with maxima of 14 km h^{-1}.

. the direction of the sea breeze is consistent with the orientation of the coast (typically 240-260°).

. the depth of the inflow is approximately double that of the urban thermal boundary (mixed) layer. Since the main O_3 production is likely to be limited to the mixed layer (see Section 4) the characteristics of the sea breeze inflow layer are the most important in relation to downwind impacts.

. the sea breeze return flow layer (z_R) is of similar strength to the inflow and is oriented parallel to the North Shore mountains (typically 80-100°).

. the land breeze characteristics were less well sampled but it appears the speed is in agreement with the surface statistics and is aligned parallel with the mountains. The depth may be augmented by flow from tributary valleys of the Fraser system.

4. METEOROLOGIC CHARACTERISTICS OF THE PERSISTENT OZONE EPISODE 21/22 JULY, 1978

4.1 Introduction

This persistent ozone episode occurred on two days of the urban meteorology project undertaken in South Vancouver. From the data gathered during this project and from the GVRD network data it is possible to characterize fairly completely the meso-meteorologic conditions prevailing over the Lower Fraser Valley during these two days and to provide some insight into the atmospheric dynamics that contribute to there being an air pollution episode.

4.2 Surface layer conditions

Under the influence of the prevailing synoptic conditions (cloudless skies and very weak pressure gradients), the surface layer over suburban Vancouver exhibited dramatic diurnal changes in stability. The surface layer turbulent sensible heat flux (as measured by eddy correlation techniques, Steyn, 1980) on both days was slightly negative (towards the surface) or near zero at night, became positive soon after sunrise and rose to a maximum of roughly 250 W m^{-2} before dropping back to its nighttime values around sunset. This heat flux behaviour in conjunction with low wind speeds (roughly 2.0 m s^{-1} at 10 m during the day with poorly defined minima at sunrise and sunset) resulted in a stable surface layer at night, a highly unstable one during the day and very short transitions between these two states.

A result of this variation of atmospheric stability will be that all pollutants emitted at or near the surface during the day will very quickly be mixed upward to the base of the capping inversion and will be advected over the region in a layer whose depth is defined by the height of this inversion. Pollutants emitted at night will suffer only minimal spread in the vertical until shortly after sunrise when they will be fumigated to be mixed with both primary and secondary pollutants from the previous days' emissions. The crucial variables in this topic are thus the mixed layer depth and its variability, the regional wind field and the emission and transformation patterns.

4.3 Mixed layer variability and ozone concentration

A major objective of the Vancouver urban meteorology study (Steyn, 1980) was an understanding of the variability of the mixed layer depth. Table A2 gives hourly average mixed layer depths extracted from that study for the two days in question, together with the ozone concentrations from station T7 of the GVRD network (Anmore School).

The mixed layer depth is not constant across the region due to advective topographic and surface effects (Steyn, 1980; Steyn and Oke, 1982). An estimate of the mixed layer depth at the monitoring site can be derived from:

$$z_{i,7} = \sqrt{\frac{x_7}{x_s}}\, z_{i,s}$$

where the subscripts 7 and s refer to site T7 and the Vancouver study site, z_i being the mixed layer depth and x the advective distance from the effective shoreline (Steyn and Oke, 1982). For the daytime wind directions encountered during the days given in Table A2 (roughly 180° to 250°) this results in the mixed layer depth at station T7 being between 7% (180°) and 55% (250°) greater than that at the Vancouver study site. This rough analysis assumes that the mixed layer follows the regional mean topography for the low relative relief parts of the Lower Fraser Valley.

An examination of the wind-speed and - direction profiles for the these days indicates that the depth of the sea-breeze inflow layer is much deeper than the mixed layer depth. This fact leads to the conclusion that the only effect of the sea breeze flow upon the air pollution episode is to force a particular wind field (that associated with the sea-breeze phenomenon) to be associated with the episode in this case (and presumably many others).

From Table A2, the major temporal variability in ozone concentration at station T7 reflects very strong diurnal influences. It may be hypothesized that this variability is due to secondary (photochemical) sources within the mixed layer, and that the spatial patterns are a product of advection and dilution within the mixed layer. Such an hypothesis could be tested by application of a fairly detailed advective/variable source model to the region. Such a model in its simplest (crudest) form may be similar to that used by Jensen and Petersen (1979). This was based on an equation of the form:

$$\frac{D}{Dt}\left(\chi(x) \int_o^x z_i(x)dx\right) = \int_o^x Q_v dV + \int_o^x Q_s dx + \overline{u}z_i(x)\ (\chi_o - \chi(x)) \qquad (1)$$

where $\frac{D}{Dt}$ is the advective derivative, χ a vertically averaged ozone concentration, x the downwind distance, Q_v a volume source of ozone, Q_s an area source of ozone and $\overline{u}$ the mean wind speed.

The effective operation of such a model would require knowledge of:

a) The spatial and temporal variability of the mixed layer depth.

b) The spatial and temporal variability of the mean wind field (speed and direction).

c) Temporal variability of source and sink strengths for ozone.

d) The regional background ozone levels (χ_o).

Given the above information, the model would need considerable computing power for its implementation but should as a return be able to cast light on the sources of regional elevated ozone levels and the meteorologic conditions which accompany episodes.

Table A2 Mixed layer depth, wind speed and direction at BCHPA Mainwaving Substation: 21/22 July, 1978. (hourly averages for hour ending). (N.B. times *may* vary by 1 h 19 min or 19 min).

	LAT[1]	z_i(m)	$\bar{u}_m$(ms^{-1})	$\bar{\theta}_m$(day)	Anmore Ozone: #7 (ppb)
July 21	0100	s[2]	0.75	103	19
	2	s	2.0	50	17
	3	s	1.9	14	14
	4	s	2.7	10	11
	5	s	2.3	10	10
	6	30	1.1	29	13
	7	110	1.8	36	33
	8	275	1.5	151	39
	9	410	2.0	174	62
	10	450	2.3	159	79
	11	460	2.6	171	96
	12	u[3]	2.7	210	125
	13	450	2.6	211	159
	14	390	2.2	228	173
	15	300	2.3	239	173
	16	110	2.8	240	140
	17	85	2.6	248	98
	18	70	2.9	255	96
	19	s	2.2	240	96
	20	s	1.7	345	20
	21	s	1.6	5	31
	22	s	0.7	159	35
	23	s	1.0	311	33
	24	s	1.8	45	34

Table A2 (cont'd)

	LAT[1]	z_i(m)	$\bar{u}_m$(ms^{-1})	$\bar{\theta}$m(day)	Anmore Ozone: #7 (ppb)
July 22	0100	s	1.3	93	36
	2	s	1.8	69	41
	3	s	2.5	6	36
	4	s	2.5	9	34
	5	s	2.0	13	31
	6	55	1.0	337	23
	7	105	1.0	265	42
	8	185	0.7	108	74
	9	250	1.8	206	98
	10	250	2.2	237	134
	11	225	2.6	245	123
	12	u	3.0	249	106
	13	u	2.6	237	110
	14	315	3.0	247	99
	15	290	2.5	251	91
	16	305	2.4	248	71
	17	260	2.1	300	58
	18	u	1.6	288	47
	19	s	2.8	264	39
	20	s	1.4	247	5
	21	s	1.9	324	14
	22	s	2.3	5	20
	23	s	2.0	271	23
	24	s	2.3	316	-

1 Local Apparent Time is used in the Vancouver Urban Meteorology study the local standard time of the network data is 19 minutes later at this time of the year.

2 s indicates a surface based temperature inversion.

3 u indicates an undefined mixed layer depth (usually due to poor signal returns from the acoustic sounder, and no minisonde flight at that time.

APPENDIX E 1.

ANNUAL SUMMARY FOR OZONE /PARAM=201/

ALL CONCENTRATIONS IN PPB

YEAR=1978

STATION	ADDRESS	N_DAYS	CES_PERC	PER_10	PER_25	PER_50	PER_75	PER_90	PER_99	AR_MEAN	MAX_1HR	MAX_24HR	N_DESIR	N_ACCEPT	N_TOL
0000005	CONFEDERATION P	232	64	5	10	15	21	26	39	[illegible]	110	52	86	18	0
0000006	GVRD BEACH WORKS	357	98	2	5	10	16	21	27	[illegible]	84	29	45	1	0
0000007	ANMORE ELEM SCH	312	85	6	12	21	31	40	62	22	178	74	562	134	9
0000008	LIONS GATE STP	355	97	2	5	10	17	23	32	12	80	35	53	0	0
0000010	DEP. OF HIGHWAYS	216	59	3	9	16	22	26	39	15	182	42	154	25	1
0100106	G.V.R.D. OFFICE	324	89	1	3	8	17	24	34	10	104	39	153	13	0
0100108	MANITOBA WORKS Y	322	88	1	4	10	18	24	32	12	92	38	77	2	0
0100109	B.C. HYDRO PARK	329	90	1	2	5	11	15	26	7	66	28	8	0	0
0100110	KENSINGTON PARK	342	94	4	9	16	25	31	42	17	133	53	260	42	0
0100111	ROCKY POINT PARK	315	86	1	4	11	18	23	36	12	130	45	190	34	0
1100030	ABBOTSFORD A	322	88	8	12	18	25	32	41	19	140	49	96	7	0

APPENDIX B 1.

- ANNUAL SUMMARY FOR OZONE /PARAM=201/

ALL CONCENTRATIONS IN PPB

-- YEAR=1979 --

STATION ADDRESS	N_DAYS	OBS_PERC	PER_10	PER_25	PER_50	PER_75	PER_90	PER_99	ANN_MEAN	MAX_1HR	MAX_24HR	N_DESIR	N_ACCEPT	N_TOL
0000005 CONFEDERATION P	265	73	4	10	15	19	22	37	14	160	40	66	13	1
0000006 GVRD BEACH WORKS	353	97	3	6	12	17	21	29	12	88	33	39	2	0
0000007 ANMORE ELEM SCH	301	82	9	17	25	32	38	59	25	151	65	543	84	0
0000008 LIONS GATE STP	319	87	2	6	13	21	28	37	14	104	47	225	7	0
0000010 DEP. OF HIGHWAYS	295	81	4	9	14	19	25	34	14	86	36	94	2	0
0100106 G.V.R.D. OFFICE	358	98	1	4	10	17	24	38	11	126	42	159	11	0
0100109 MANITOBA WORKS Y	348	95	2	5	11	18	24	35	12	87	37	86	5	0
0100107 B.C. HYDRO PARK	276	92	2	3	7	13	18	27	9	97	32	36	3	0
0100110 KENSINGTON PARK	226	89	4	9	15	21	26	38	15	160	43	127	18	1
0100111 ROCKY POINT PARK	284	78	1	4	13	24	30	46	15	175	83	380	76	4
0310173 CHILLIWACK A	311	85	5	14	22	29	36	49	22	105	54	248	20	0
1100031 ABBOTSFORD A	323	89	9	13	21	28	37	60	22	405	68	295	37	2

APPENDIX B 1.

ANNUAL SUMMARY FOR OZONE /PARAM=201/

ALL CONCENTRATIONS IN PPB

YEAR=1980

STATION ADDRESS	N_DAYS	OBS_PERC	PER_10	PER_25	PER_50	PER_75	PER_90	PER_99	ANN_MEAN	MAX_1HR	MAX_24HR	N_DESIR	N_ACCEPT	N_TOL
0000005 CONFEDERATION P	318	87	6	11	17	21	26	40	16	131	43	155	23	C
0000006 GVRD BEACH WORKS	311	85	5	8	12	16	21	28	13	85	33	36	1	0
0000007 ANMORE ELEM SCH	330	90	12	18	25	34	42	59	26	197	87	874	191	6
0000008 LIONS GATE STP	337	92	4	6	9	13	17	27	10	60	30	10	0	0
0000010 DEP. OF HIGHWAYS	306	84	4	7	12	19	25	36	14	101	47	123	3	0
0000040 SEYMOUR DAM	199	54	5	9	13	17	21	34	14	101	45	76	8	0
0100106 G.V.R.D. OFFICE	363	99	3	5	8	13	17	25	9	80	26	12	0	0
0100108 MANITOBA WORKS Y	350	96	2	6	12	17	22	33	12	114	40	76	10	0
0100109 B.C. HYDRO PARK	91	25	1	2	3	6	8	16	4	31	16	0	0	0
0100110 KENSINGTON PARK	319	87	1	4	10	15	19	27	10	109	31	31	5	0
0100111 ROCKY POINT PARK	302	83	4	8	17	25	32	48	18	245	69	502	60	4
0100112 B.C. HYDRO PARK	217	59	1	3	6	10	13	21	7	110	51	6	5	0
0310173 CHILLIWACK A	301	82	6	10	16	23	28	41	14	120	50	80	9	0
1100030 ABBOTSFORD A	296	81	8	12	20	25	30	41	20	95	46	96	3	0

APPENDIX B 1.

ANNUAL SUMMARY FOR OZONE /PARAM=201/

ALL CONCENTRATIONS IN PPB

YEAR=1981

STATION ADDRESS	N_DAYS	CES_PERC	PER_10	PER_25	PER_50	PER_75	PER_90	PER_99	ANN_MEAN	MAX_1HR	MAX_24HR	N_DESIR	N_ACCEPT	N_TOL
0000005 CONFEDERATION P	311	85	4	12	20	26	32	49	19	168	55	247	44	1
0000006 GVRD BEACH WORKS	184	50	5	10	15	20	25	34	15	95	37	73	3	0
0000007 ANMORE ELEM SCH	298	82	11	18	26	32	43	72	27	265	75	719	215	28
0000008 LIONS GATE STP	115	32	2	4	10	12	17	33	9	72	35	17	0	0
0000010 DEP. OF HIGHWAYS	266	73	3	8	12	18	22	41	13	186	44	100	36	2
0000040 SEYMOUR DAM	131	36	3	4	10	21	34	44	14	115	45	137	33	0
0100106 G.V.R.D. OFFICE	281	77	3	6	10	15	21	33	11	71	35	15	0	0
0100109 MANITOBA WORKS Y	171	47	3	6	10	17	21	32	12	73	32	49	0	0
0100110 KENSINGTON PARK	260	71	2	7	12	17	22	33	12	159	41	73	13	1
0100111 ROCKY POINT PARK	234	65	6	10	17	25	31	61	18	193	67	308	96	8
0100112 B.C. HYDRO PARK	163	45	3	5	7	11	14	18	8	38	19	0	0	0
0310173 CHILLIWACK A	300	82	9	12	19	24	28	46	18	150	55	102	26	0
1100030 ABBOTSFORD A	262	72	8	12	18	24	29	34	18	70	41	12	0	0

APPENDIX B 2.

SEASONAL SUMMARY FOR OZONE /PARAM=201/

ALL CONCENTRATIONS IN PPB

-- SEASON=WINTER --

STATION ADDRESS	OBS_PERC	N_DAYS	PER_10	PER_25	PER_50	PER_75	PER_90	PER_99	SSN_MEAN	MAX_1HR	MAX_24HR	N_DESIR	N_ACCEPT	N_TOL
0000005 CONFEDERATION P	72	260	2	5	11	17	23	34	12	81	41	7	0	0
0000006 GVRD BEACH WORKS	73	262	1	4	9	14	17	27	9	85	28	5	1	0
0000007 ANMORE ELEM SCH	73	263	5	10	21	28	33	52	20	165	59	218	16	1
0000008 LIONS GATE STP	73	264	1	3	8	14	18	34	9	56	44	9	0	0
0000010 DEP. OF HIGHWAYS	72	260	1	4	10	15	22	36	11	71	47	41	0	0
0000040 SEYMOUR DAM	11	38	2	3	4	6	8	11	5	17	11	0	0	0
0100106 G.V.R.D. OFFICE	36	309	1	4	7	10	16	26	8	48	41	0	0	0
0100108 MANITOBA WORKS Y	70	251	0	2	6	11	15	24	7	50	27	0	0	0
0100109 B.C. HYDRO PARK	70	254	0	1	4	6	10	21	5	39	22	0	0	0
0100110 KENSINGTON PARK	76	275	1	3	10	15	21	30	10	48	32	0	0	0
0100111 ROCKY POINT PARK	78	283	1	4	8	15	22	34	10	69	47	63	0	0
0100112 B.C. HYDRO PARK	24	87	3	6	7	11	14	18	8	26	18	0	0	0
0310173 CHILLIWACK A	53	193	6	11	17	22	26	35	12	55	36	2	0	0
1100030 ABBOTSFORD A	75	272	8	11	18	24	28	36	18	65	49	8	0	0

APPENDIX B 2.

SEASONAL SUMMARY FOR OZONE /PARAM=201/

ALL CONCENTRATIONS IN PPB

SEASON=SPRING

STATION ADDRESS	OBS_PERC	N_DAYS	PER_10	PER_25	PER_50	PER_75	PER_90	PER_99	SSN_MEAN	MAX_1HR	MAX_24HR	N_DESIR	N_ACCEPT	N_TOL
0000005 CONFEDERATION P	94	242	13	17	21	26	30	42	21	131	52	154	20	0
0000006 GVRD BEACH WORKS	81	295	12	14	18	22	25	32	18	88	33	49	2	0
0000007 ANMORE ELEM SCH	88	319	20	26	31	38	47	60	33	197	87	1202	201	5
0000008 LIONS GATE STP	78	283	8	13	18	25	29	37	19	104	47	226	7	0
0000010 DEP. OF HIGHWAYS	84	304	11	15	20	23	29	36	20	102	36	171	9	0
0000040 SEYMOUR DAM	11	39	7	9	12	16	21	34	13	61	34	12	0	0
0100106 G.V.R.D. OFFICE	94	341	8	11	16	22	27	38	17	126	42	194	12	0
0100108 MANITOBA WORKS Y	77	282	11	15	19	24	28	36	20	92	38	121	5	0
0100109 B.C. HYDRO PARK	48	173	6	10	14	19	22	29	14	97	32	37	3	0
0100110 KENSINGTON PARK	85	310	9	14	20	26	31	42	20	120	43	158	16	0
0100111 ROCKY POINT PARK	95	344	14	18	22	28	33	52	23	245	69	673	75	5
0100112 B.C. HYDRO PARK	37	135	4	7	9	12	15	40	10	110	51	5	4	0
0310173 CHILLIWACK A	66	239	14	19	24	30	35	47	25	90	48	147	5	0
1100030 ABBOTSFORD A	80	293	15	21	27	32	39	60	27	405	68	315	26	2

APPENDIX B 2.

SEASONAL SUMMARY FOR OZONE /PARAM=201/

ALL CONCENTRATIONS IN PPB

SEASON=SUMMER

STATION	ADDRESS	OBS_PERC	N_DAYS	PER_10	PER_25	PER_50	PER_75	PER_90	PER_95	SSN_MEAN	MAX_1HR	MAX_24HR	N_DESIR	N_ACCEPT	N_TOL
0000005	CONFEDERATION P	92	339	9	13	17	22	27	48	18	168	55	368	69	2
0000006	GVRD BEACH WORKS	100	367	7	10	13	17	21	32	13	95	37	130	4	0
0000007	ANMORE ELEM SCH	96	352	14	19	20	35	45	72	28	265	75	1200	402	36
0000008	LIONS GATE STP	80	293	6	9	12	15	19	26	12	80	35	66	0	0
0000010	DEP. OF HIGHWAYS	76	278	8	10	15	19	24	42	16	186	44	248	57	3
0000040	SEYMOUR DAM	47	173	8	11	17	22	32	45	18	115	45	201	41	0
0100106	G.V.R.D. OFFICE	95	249	5	7	11	16	21	28	12	104	39	145	12	0
0100108	MANITOBA WORKS Y	93	241	7	10	14	19	22	34	15	114	40	161	12	0
0100109	B.C. HYDRO PARK	43	159	3	5	9	12	15	20	8	66	20	7	0	0
0100110	KENSINGTON PARK	92	237	8	10	15	21	26	42	16	160	53	316	53	2
0100111	ROCKY POINT PARK	74	273	6	12	19	25	34	64	19	193	83	635	191	11
0100112	B.C. HYDRO PARK	13	47	4	6	8	11	12	15	8	38	15	0	0	0
0310173	CHILLIWACK A	73	270	10	14	21	27	35	51	22	120	55	278	48	0
1100030	ABBOTSFORD A	93	344	9	13	19	23	30	41	19	100	51	171	19	0

APPENDIX B.2.

SEASONAL SUMMARY FOR OZONE /PARAM=201/

ALL CONCENTRATIONS IN PPB

SEASON=FALL

STATION ADDRESS	OBS_PERC	N_DAYS	PER_10	PER_25	PER_50	PER_75	PER_90	PER_95	SSN_MEAN	MAX_1HR	MAX_24HR	N_DESIR	N_ACCEPT	N_TOL
0000005 CONFEDERATION P	43	124	2	4	9	15	21	43	11	126	43	25	9	0
0000006 GVRD BEACH WORKS	80	220	1	3	5	10	14	29	7	75	31	9	0	0
0000007 ANMORE ELEM SCH	83	247	7	10	16	24	31	41	17	162	43	72	5	1
0000008 LIONS GATE STP	94	260	2	3	5	8	12	21	6	60	27	4	0	0
0000010 DEP. OF HIGHWAYS	56	182	2	4	7	11	17	31	8	74	34	11	0	0
0000040 SEYMOUR BAY	29	80	4	6	9	12	15	26	9	47	26	0	0	0
0100106 G.V.R.D. OFFICE	100	275	1	2	4	6	11	21	5	50	24	0	0	0
0100108 MANITOBA WORKS Y	93	256	1	2	5	8	15	25	6	74	27	6	0	0
0100109 B.C. HYDRO PARK	52	170	1	2	4	5	7	13	4	30	16	0	0	0
0100110 KENSINGTON PARK	95	263	2	4	7	12	15	27	8	109	30	17	9	0
0100111 ROCKY POINT PARK	75	207	1	2	4	9	14	26	6	66	28	7	0	0
0100112 B.C. HYDRO PARK	31	86	1	2	3	5	6	11	4	100	11	1	1	0
0310173 CHILLIWACK A	61	167	5	8	11	15	19	27	12	50	27	0	0	0
1100030 ABBOTSFORD A	86	242	6	9	13	20	24	31	15	140	35	5	2	0

APPENDIX B 3.

ANNUAL SUMMARY FOR NITROGEN DIOXIDE /PARAM=203/

ALL CONCENTRATIONS IN PPB

YEAR=1978

STATION ADDRESS	N_DAYS	OBS_PERC	PER_10	PER_25	PER_50	PER_75	PER_90	PER_99	ANN_MEAN	MAX_1HR	MAX_24HR	N_ACC1HR	N_ACC24H
0000005 CONFEDERATION P	233	64	8	13	19	25	33	49	20	166	68	0	0
0000006 GVRD BEACH WORKS	273	75	9	13	18	24	30	51	19	133	55	0	0
0000007 ANMORE ELEM SCH	137	38	2	4	7	11	14	22	8	93	24	0	0
0000008 LIONS GATE STP	303	83	9	13	17	23	27	44	18	117	48	0	0
0000010 DEP. OF HIGHWAYS	30	8	12	17	26	41	46	52	27	146	52	0	0
0100106 G.V.R.D. OFFICE	306	84	13	17	23	29	35	42	24	97	45	0	0
0100108 MANITOBA WORKS Y	299	82	17	21	25	31	36	62	27	128	54	0	0
0100109 B.C. HYDRO PARK	113	31	15	21	31	46	59	111	34	210	116	1	1
0100110 KENSINGTON PARK	332	91	16	20	24	30	37	50	25	177	52	0	0
0100111 ROCKY POINT PARK	282	77	8	11	18	24	30	48	19	156	50	0	0

APPENDIX B 3.

ANNUAL SUMMARY FOR NITROGEN DIOXIDE /PARAM=203/

ALL CONCENTRATIONS IN PPB

YEAR=1979

STATION ADDRESS	N_DAYS	OBS_PERC	PER_10	PER_25	PER_50	PER_75	PER_90	PER_99	ANN_MEAN	MAX_1HR	MAX_24HR	N_ACC1HR	N_ACC24H
0000005 CONFEDERATION P	308	34	9	12	20	29	39	59	22	198	75	0	0
0000006 GVRD BEACH WORKS	253	69	8	11	16	23	31	59	18	179	59	0	0
0000007 ANMORE ELEM SCH	234	64	7	10	15	22	34	64	18	245	56	1	0
0000008 LIONS GATE STP	348	95	10	14	18	22	29	47	19	178	50	0	0
0000010 DEP. OF HIGHWAYS	149	41	10	14	18	25	33	50	20	138	59	0	0
0100106 G.V.R.D. OFFICE	303	83	14	19	23	28	34	57	24	161	57	0	0
0100107 MANITOBA WORKS Y	278	76	13	18	23	28	36	49	24	89	50	0	0
0100109 B.C. HYDRO PARK	324	89	16	21	28	35	44	69	29	153	76	0	0
0100110 KENSINGTON PARK	213	58	5	9	16	23	28	47	16	161	32	0	0
0100111 ROCKY POINT PARK	161	44	5	8	12	22	31	65	16	164	69	0	0

APPENDIX B 3.

ANNUAL SUMMARY FOR NITROGEN DIOXIDE /PARAM=203/

ALL CONCENTRATIONS IN PPB

YEAR=1990

STATION ADDRESS	N_DAYS	CPS_FEPC	PER_10	PER_25	PER_50	PER_75	PER_90	PER_99	ANN_MEAN	MAX_1HR	MAX_24HR	N_ACC1HR	N_ACC24H
0000005 CONFEDERATION P	317	87	10	14	20	27	39	62	22	157	90	0	0
0000006 GVRD BEACH WORKS	258	70	11	15	21	28	37	56	22	185	58	0	0
0000007 AMORE ELEM SCH	321	98	11	15	19	23	29	44	20	174	76	0	0
0000008 LIONS GATE STP	308	84	12	15	19	23	26	38	19	111	46	0	0
0000010 DEP. OF HIGHWAYS	350	96	7	12	16	22	29	46	17	166	54	0	0
0100106 G.V.R.D. OFFICE	361	99	13	17	22	26	31	40	22	180	54	0	0
0100108 MANITOBA WORKS Y	311	85	8	12	18	25	33	45	19	105	46	0	0
0100109 B.C. HYDRO PARK	84	23	23	24	27	31	37	47	28	89	47	0	0
0100110 KENSINGTON PARK	323	88	15	17	21	25	32	52	22	142	50	0	0
0100111 ROCKY POINT PARK	98	27	12	15	21	26	39	53	23	156	53	0	0
0100112 B.C. HYDRO PARK	252	69	14	21	28	36	44	56	29	160	70	0	0

APPENDIX B 3.

ANNUAL SUMMARY FOR NITROGEN DIOXIDE /PARAM=203/

ALL CONCENTRATIONS IN PPB

YEAR=1981

STATION ADDRESS	N_DAYS	OBS_PERC	PER_10	PER_25	PER_50	PER_75	PER_90	PER_99	ANN_MEAN	MAX_1HR	MAX_24HR	N_ACC1HR	N_ACC24H
0000005 CONFEDERATION P	199	55	14	17	23	29	41	61	25	180	56	0	0
0000006 GVRD BEACH WORKS	223	61	11	13	20	27	37	65	22	158	78	0	0
0000007 ANMORE ELEM SCH	255	70	6	9	15	21	29	42	16	155	44	0	0
0000008 LIONS GATE STP	14	4	29	34	42	49	61	67	42	119	57	0	0
0000010 DEP. OF HIGHWAYS	207	57	5	10	16	24	32	64	18	182	79	0	0
0100106 G.V.R.D. OFFICE	288	79	14	19	24	29	34	47	24	150	59	0	0
0100108 MANITOBA WORKS Y	173	47	13	17	21	27	34	47	23	110	48	0	0
0100110 KENSINGTON PARK	276	76	13	15	20	27	35	55	23	188	64	0	0
0100111 ROCKY POINT PARK	319	87	10	14	18	26	34	49	21	150	51	0	0
0100112 B.C. HYDRO PARK	120	33	21	25	30	36	49	78	33	194	90	0	0
0310173 CHILLIWACK A	4	1	1	1	2	2	3	3	2	25	3	0	0
1100030 ABBOTSFORD A	27	7	7	10	15	18	20	22	14	41	22	0	0

APPENDIX B 3.

ANNUAL SUMMARY FOR NITROGEN DIOXIDE /PARAM=203/

ALL CONCENTRATIONS IN PPB

YEAR=1990

STATION ADDRESS	N_DAYS	CPS_FCPC	PER_10	PER_25	PER_50	PER_75	PER_90	PER_99	ANN_MEAN	MAX_1HR	MAX_24HR	N_ACC1HR	N_ACC24H
0000005 CONFEDERATION P	317	87	10	14	20	27	39	62	22	157	90	0	0
0000006 GVRD BEACH WORKS	258	70	11	15	21	28	37	56	22	185	58	0	0
0000007 ANMORE ELEM SCH	321	98	11	15	19	23	29	44	20	174	76	0	0
0000008 LIONS GATE STP	308	84	12	15	19	23	26	38	19	111	46	0	0
0000010 DEP. OF HIGHWAYS	350	96	7	12	16	22	28	46	17	166	54	0	0
0100106 G.V.R.D. OFFICE	361	99	13	17	22	26	31	40	22	180	54	0	0
0100108 MANITOBA WORKS Y	311	85	8	12	18	25	33	45	19	105	46	0	0
0100109 B.C. HYDRO PARK	84	23	23	24	27	31	37	47	28	89	47	0	0
0100110 KENSINGTON PARK	323	88	15	17	21	25	32	52	22	142	50	0	0
0100111 ROCKY POINT PARK	98	27	12	15	21	26	39	53	23	156	53	0	0
0100112 B.C. HYDRO PARK	252	69	14	21	28	36	44	56	29	160	70	0	0

APPENDIX B 3.

ANNUAL SUMMARY FOR NITROGEN DIOXIDE /PARAM=203/

ALL CONCENTRATIONS IN PPB

YEAR=1981

STATION ADDRESS	N_DAYS	OBS_PERC	PER_10	PER_25	PER_50	PER_75	PER_90	PER_99	ANN_MEAN	MAX_1HR	MAX_24HR	N_ACC1HR	N_ACC24H
0000005 CONFEDERATION P	199	55	14	17	23	29	41	61	25	180	56	0	0
0000006 GVRD BEACH WORKS	223	61	11	13	20	27	37	65	22	158	78	0	0
0000007 ANMORE ELEM SCH	255	70	6	9	15	21	29	42	16	155	44	0	0
0000008 LIONS GATE STP	14	4	29	34	42	49	61	67	42	119	57	0	0
0000010 DEP. OF HIGHWAYS	207	57	5	10	16	24	32	64	18	182	79	0	0
0100106 G.V.R.D. OFFICE	288	79	14	19	24	29	34	47	24	150	59	0	0
0100108 MANITOBA WORKS Y	173	47	13	17	21	27	34	47	23	110	48	0	0
0100110 KENSINGTON PARK	276	76	13	15	20	27	35	55	23	188	64	0	0
0100111 ROCKY POINT PARK	319	87	10	14	18	26	34	49	21	150	51	0	0
0100112 B.C. HYDRO PARK	320	88	21	25	30	36	49	78	33	194	90	0	0
0310173 CHILLIWACK A	4	1	1	1	2	2	3	3	2	25	3	0	0
1100030 ABBOTSFORD A	27	7	7	10	15	18	20	22	14	41	22	0	0

APPENDIX P 4.

SEASONAL SUMMARY REPORT FOR NITROGEN DIOXIDE /PARAM=203/

ALL CONCENTRATIONS IN PPB

SEASON=WINTER

STATION ADDRESS	N_DAYS	CBS_PERC	PER_10	PER_25	PER_50	PER_75	PER_90	PER_99	SSN_MEAN	MAX_1HR	MAX_24HR	N_ACC1HR	N_ACC24H
0000005 CONFEDERATION P	158	44	12	19	25	33	46	61	27	156	52	0	0
0000006 GVRD BEACH WORKS	193	53	8	11	17	26	37	60	20	138	51	0	0
0000007 ANMORE ELEM SCH	209	58	5	9	15	22	31	44	16	155	44	0	0
0000008 LIONS GATE STP	258	71	14	17	21	25	30	43	22	178	49	0	0
0000010 DEP. OF HIGHWAYS	146	40	9	11	16	22	28	41	17	118	41	0	0
0100106 G.V.R.D. OFFICE	270	75	15	19	24	29	34	45	24	101	47	0	0
0100108 MANITOBA WORKS Y	242	67	15	21	24	29	37	50	25	79	51	0	0
0100109 B.C. HYDRO PARK	184	51	23	25	31	41	51	70	34	112	76	0	0
0100110 KENSINGTON PARK	330	91	13	18	22	28	34	45	23	132	47	0	0
0100111 ROCKY POINT PARK	242	67	8	12	19	26	34	50	20	150	53	0	0
0100112 B.C. HYDRO PARK	90	22	23	30	35	54	68	90	42	194	90	0	0

APPENDIX B 4.

SEASONAL SUMMARY REPORT FOR NITROGEN DIOXIDE /PARAM=203/

ALL CONCENTRATIONS IN PPB

SEASON=SPRING

STATION ADDRESS	N_DAYS	OBS_PERC	PER_10	PER_25	PER_50	PER_75	PER_90	PER_99	SSN_MEAN	MAX_1HR	MAX_24HR	N_ACC1HR	N_ACC24H
0000305 CONFEDERATION P	269	74	8	11	15	20	26	41	16	89	47	0	0
0000006 GVRD BEACH WORKS	259	71	9	13	17	24	30	54	19	133	58	0	0
0000007 ANMORE ELEM SCH	278	76	4	9	14	19	24	41	14	128	54	0	0
0000008 LIONS GATE STP	234	64	7	10	15	19	24	30	15	120	44	0	0
0000010 DEP. OF HIGHWAYS	179	49	4	8	15	21	26	59	15	182	64	0	0
0100106 G.V.R.D. OFFICE	336	92	14	18	23	28	34	43	23	100	57	0	0
0100103 MANITOBA WORKS Y	274	75	11	15	20	25	31	44	21	97	47	0	0
0100109 B.C. HYDRO PARK	117	32	17	23	29	36	43	70	30	153	74	0	0
0100110 KENSINGTON PARK	284	78	6	13	20	27	34	50	20	100	53	0	0
0100111 ROCKY POINT PARK	212	58	6	9	13	17	23	47	14	145	48	0	0
0100112 B.C. HYDRO PARK	161	44	23	29	35	41	47	62	34	103	70	0	0

APPENDIX B 4.

SEASONAL SUMMARY REPORT FOR NITROGEN DIOXIDE /PARAM=203/

ALL CONCENTRATIONS IN PPB

SEASON=SUMMER

STATION ADDRESS	N_DAYS	OBS_PERC	PER_10	PER_25	PER_50	PER_75	PER_90	PER_99	SSN_MEAN	MAX_1HR	MAX_24HR	N_ACC1HR	N_ACC24H
0000005 CONFEDERATION P	312	95	10	14	20	25	39	61	22	180	80	0	0
0000006 GVRD BEACH WORKS	318	86	10	14	20	27	35	56	21	164	78	0	0
0000007 ANMORE ELEM SCH	239	65	8	12	17	21	27	50	18	175	52	0	0
0000008 LIONS GATE STP	269	73	9	12	16	20	24	34	16	105	47	0	0
0000010 DEP. OF HIGHWAYS	138	51	9	14	20	28	34	53	21	166	54	0	0
0100106 G.V.R.D. OFFICE	327	89	13	17	22	28	33	51	23	161	56	0	0
0100108 MANITOBA WORKS Y	325	89	10	13	19	25	30	46	20	110	60	0	0
0100109 B.C. HYDRO PARK	153	42	13	17	23	30	37	47	24	101	47	0	0
0100110 KENSINGTON PARK	246	67	13	15	21	27	38	55	23	188	54	0	0
0100111 ROCKY POINT PARK	215	58	10	14	19	27	35	60	22	164	69	0	0
0100112 B.C. HYDRO PARK	192	49	14	18	25	31	36	58	25	151	74	0	0

APPENDIX B 4.

SEASONAL SUMMARY REPORT FOR NITROGEN DIOXIDE /PARAM=203/

ALL CONCENTRATIONS IN PPB

SEASON=FALL

STATION ADDRESS	N_DAYS	OBS_PERC	PER_10	PER_25	PER_50	PER_75	PER_90	PER_99	SSN_MEAN	MAX_1HR	MAX_24HR	N_ACC1HR	N_ACC24H
0000005 CONFEDERATION P	257	93	12	16	23	31	41	70	25	198	75	0	0
0000006 GVRD BEACH WORKS	192	70	11	14	19	25	35	59	21	185	59	0	0
0000007 ANMORE ELEM SCH	172	62	8	13	19	26	34	79	21	245	56	1	0
0000008 LIONS GATE STP	198	72	14	17	21	24	30	48	22	130	50	0	0
0000010 DEP. OF HIGHWAYS	183	66	8	12	16	20	27	53	17	146	59	0	0
0100106 G.V.R.D. OFFICE	264	96	13	17	22	27	33	54	23	180	57	0	0
0100108 MANITOBA WORKS Y	187	68	20	25	30	36	42	63	31	128	54	0	0
0100109 B.C. HYDRO PARK	67	24	16	20	27	32	60	116	32	210	116	1	1
0100110 KENSINGTON PARK	223	81	15	18	21	25	30	58	22	177	52	0	0
0100111 ROCKY POINT PARK	130	47	7	14	21	26	34	62	21	156	53	0	0
0100112 B.C. HYDRO PARK	88	32	18	23	28	33	38	54	28	160	54	0	0

APPENDIX B 5.

ANNUAL SUMMARY FOR NITRIC OXIDE /PARAM=202/

ALL CONCENTRATIONS IN PPB

YEAR=1980

STATION	ADDRESS	N_DAYS	OBS_PERC	PER_10	PER_25	PER_50	PER_75	PER_90	PER_99	ANN_MEAN	MAX_1HR	MAX_24HR
0000005	CONFEDERATION P	310	85	6	10	16	30	66	149	27	455	195
0000006	GVRD BEACH WORKS	251	69	19	24	32	40	61	97	36	254	110
0000007	ANMORE ELEM SCH	315	86	1	2	4	8	13	47	6	118	51
0000008	LIONS GATE STP	297	81	9	16	24	39	69	115	32	375	126
0000010	DEP. OF HIGHWAYS	334	91	13	20	33	63	111	174	48	632	260
0100106	G.V.R.D. OFFICE	354	97	17	23	39	71	118	235	55	713	306
0100108	MANITUBA WORKS Y	281	77	8	13	25	54	113	211	43	861	266
0100109	B.C. HYDRO PARK	94	26	31	45	65	88	126	274	75	694	274
0100110	KENSINGTON PARK	313	86	10	14	22	37	67	144	31	566	163
0100111	ROCKY POINT PARK	96	26	15	24	42	70	90	221	49	277	221
0100112	B.C. HYDRO PARK	234	64	35	47	64	98	147	247	79	725	278

APPENDIX B 5.

ANNUAL SUMMARY FOR NITRIC OXIDE /PARAM=202/

ALL CONCENTRATIONS IN PPB

YEAR=1981

STATION	ADDRESS	N_DAYS	OBS_PERC	PER_10	PER_25	PER_50	PER_75	PER_90	PER_99	ANN_MEAN	MAX_1HR	MAX_24HR
0000005	CONFEDERATION P	177	48	4	9	15	25	73	231	31	493	285
0000006	GVRD BEACH WORKS	199	55	13	20	33	44	68	180	39	432	188
0000007	ANMORE ELEM SCH	217	59	1	5	8	11	14	53	9	159	55
0000008	LIONS GATE STP	17	5	11	21	47	69	118	118	54	283	118
0000010	DEP. OF HIGHWAYS	177	48	8	15	24	57	115	249	47	1000	276
0100106	G.V.R.D. OFFICE	243	67	17	23	37	66	125	348	58	874	380
0100103	MANITOBA WORKS Y	137	38	15	25	43	88	178	536	74	783	644
0100110	KENSINGTON PARK	244	67	8	12	21	47	134	746	67	979	780
0100111	ROCKY POINT PARK	279	76	12	18	28	49	104	205	44	440	250
0100112	B.C. HYDRO PARK	280	77	35	52	75	118	191	364	97	844	566
0310173	CHILLIWACK A	0	0	.	.	.	.	.	.	.	.	.
1100030	ABBOTSFORD A	0	0	.	.	.	.	.	.	.	.	.

APPENDIX B 6.

ANNUAL SUMMARY FOR TOTAL NITROGEN OXIDES /PARAM=204/

ALL CONCENTRATIONS IN PPB

YEAR=1980

STATION	ADDRESS	N_DAYS	OBS_PERC	PER_10	PER_25	PER_50	PER_75	PER_90	PER_99	ANN_MEAN	MAX_1HR	MAX_24HR
0000005	CONFEDERATION P	310	95	20	27	38	57	106	201	50	495	258
0000006	GVRD BEACH WORKS	250	68	34	41	54	70	96	147	59	327	155
0000007	ANMORE ELEM SCH	315	86	16	20	25	32	40	85	27	189	92
0000008	LIONS GATE STP	298	81	25	33	43	62	92	140	51	395	156
0000010	DEP. OF HIGHWAYS	333	91	25	38	54	84	129	190	56	657	301
0100106	G.V.R.D. OFFICE	354	97	35	43	62	95	143	272	77	762	327
0100108	MANITOBA WORKS Y	288	79	18	29	41	71	123	233	58	905	296
0100109	B.C. HYDRO PARK	94	26	56	74	94	120	160	316	136	781	316
0100110	KENSINGTON PARK	312	85	27	34	46	62	95	184	54	595	201
0100111	ROCKY POINT PARK	97	27	32	42	64	100	120	227	73	306	227
0100112	B.C. HYDRO PARK	203	55	58	72	97	132	181	295	110	741	321

APPENDIX B 6.

ANNUAL SUMMARY FOR TOTAL NITROGEN OXIDES /PARAM=204/

ALL CONCENTRATIONS IN PPB

YEAR=1981

STATION	ADDRESS	N_DAYS	OBS_PERC	PER_10	PER_25	PER_50	PER_75	PER_90	PER_99	ANN_MEAN	MAX_1HR	MAX_24H
0000005	CONFEDERATION P	177	48	21	28	41	65	115	281	58	577	345
0000006	GVRD BEACH WORKS	195	55	26	37	54	73	104	241	52	525	248
0000007	ANMORE ELEM SCH	218	60	11	15	24	34	43	83	26	222	91
0000008	LIONS GATE STP	14	4	45	67	89	110	149	163	92	375	163
0000010	DEP. OF HIGHWAYS	176	48	15	28	43	77	140	278	54	597	317
0100106	G.V.R.D. OFFICE	243	67	36	47	65	92	153	381	52	877	427
0100108	MANITOBA WORKS Y	141	39	25	38	61	111	185	543	91	798	656
0100110	KENSINGTON PARK	241	66	23	30	45	74	176	758	91	990	783
0100111	ROCKY POINT PARK	279	76	25	33	51	77	137	246	56	508	297
0100112	B.C. HYDRO PARK	280	77	63	90	108	152	233	410	130	837	606
0310173	CHILLIWACK A	0	0	.	.	.	.	.	.	.	.	.
1100030	ABBOTSFORD A	0	0	.	.	.	.	.	.	.	.	.

APPENDIX B 7.

ANNUAL SUMMARY FOR TOTAL HYDROCARBONS /PARAM=205/

ALL CONCENTRATIONS IN PPB

YEAR=1979

STATION	ADDRESS	N_DAYS	OBS_PERC	PER_10	PER_25	PER_50	PER_75	PER_90	PER_99	ANN_MEAN	MAX_1HR	MAX_24HR
0000007	ANMORE ELEM SCH	253	69	2577	2896	3233	3535	4086	5207	3253	7000	5821
0100106	G.V.R.D. OFFICE	315	86	2088	2238	2621	2954	3441	4602	2667	8100	4739
0100111	ROCKY POINT PARK	64	18	2440	2740	3067	3695	6226	8417	3563	11900	8417

APPENDIX B 7.

ANNUAL SUMMARY FOR TOTAL HYDROCARBONS /PARAM=205/

ALL CONCENTRATIONS IN PPB

YEAR=1980

STATION	ADDRESS	N_DAYS	OBS_PERC	PER_10	PER_25	PER_50	PER_75	PER_90	PER_99	ANN_MEAN	MAX_1HR	MAX_24HR
0000007	ANMORE ELEM SCH	214	58	2300	2375	2509	2705	3025	3409	2579	3910	3671
0000040	SEYMOUR DAM	128	35	1391	2089	2246	2458	3246	7038	2367	10300	7250
0100106	G.V.R.D. OFFICE	348	95	2232	2379	2621	2909	3203	4004	2672	7380	4434
0100110	KENSINGTON PARK	8	2	1884	1989	2262	2582	2646	2646	2275	3720	2646
0100111	ROCKY POINT PARK	253	69	2237	2394	2600	2876	3162	3689	2653	6280	3965

APPENDIX B 7.

ANNUAL SUMMARY FOR TOTAL HYDROCARBONS /PARAM=205/

ALL CONCENTRATIONS IN PPB

YEAR=1981

STATION	ADDRESS	N_DAYS	OBS_PERC	PER_10	PER_25	PER_50	PER_75	PER_90	PER_99	ANN_MEAN	MAX_1HR	MAX_24HR
0000007	ANMORE ELEM SCH	94	26	1723	2078	2235	2781	3222	4351	2399	5880	4351
0000040	SEYMOUR DAM	59	16	921	1422	1633	1910	2571	3079	1586	5100	3079
0100105	G.V.R.D. OFFICE	192	53	1620	1905	2233	2868	3537	4802	2439	6800	4835
0100110	KENSINGTON PARK	203	56	1966	2268	2625	3014	3697	4821	2730	7600	6011
0100111	ROCKY POINT PARK	190	52	1389	1577	1913	2564	3304	4308	2145	6540	4339