OISTINS AND SPEIGHTSTOWN AMBIENT AIR QUALITY PASSIVE MONITORING PROJECT

AUGUST 2013-JULY 2014

FINAL REPORT

ENVIRONMENTAL PROTECTION DEPARTMENT

NOVEMBER 2016

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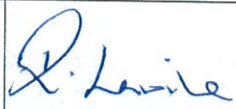
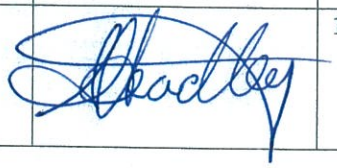
REVIEWED BY	Ingrid Lavine BSc Zoology and Geography; MSc Civil & Environmental Engineering		11/10/2016
APPROVED BY	Anthony Headley, B.Sc. Chemical Engineering; M.Sc. Environmental Engineering; P. Eng.		11/10/2016

EXECUTIVE SUMMARY

The Oistins and Speightstown Ambient Air Quality Passive Monitoring Study (OSAAQPMS) was designed to characterize the levels of sulphur dioxide (SO_2), nitrogen dioxide (NO_2), Ozone (O_3) and Volatile Organic Compounds (VOCs) generated by the combustion of fossil fuels and other industrial activities occurring in the smaller city centres of Oistins and Speightstown.

Exposure to primary and secondary pollutants may impact on human health and the environment. In terms of human health, impacts may include respiratory problems and allergic reactions in sensitive individuals triggered by exposure to SO_2, NO_2, O_3 and VOCs. Environmental damage can take the form of property damage and crop damage due to acid rain and sulphurous deposits; ground level ozone damage to electrical equipment; and ground water pollution.

In order to establish the baseline levels of primary and secondary pollutants in and around the Oistins and Speightstown areas, 30 day/monthly samples were taken at seven (7) locations over the period of a year (i.e. 12 samples from each location). The locations were selected based on the different types of activities i.e. commercial, industrial or residential along with combinations such as residential/industrial or residential/commercial activities common to the areas.

The highest recorded SO_2 level of 4.85 ppb was detected at a private residence (VTTH) in January 2013; conversely in October 2013 the level of SO_2 for all locations was below the detectable limit of the laboratory analysis. The average SO_2 level for Oistins and Speightstown combined was approximately one quarter of the average Bridgetown SO_2 concentration.

With respect to NO_2, the highest average concentration (5.78 ppb) was detected at First Caribbean CIBC Bank Speightstown (FCCIBC). The lowest average NO_2 concentration was below the detectable limit (< 0.05µg NO_2) and was detected at the background location at Ragged Point (RP), St. Philip. When compared to the Bridgetown study; both Speightstown and Oistins displayed lower average concentrations of NO_2. Although Oistins had a greater traffic volume than Speightstown, Oistins showed lower NO_2 and O_3 concentrations when compared to Speightstown. The highest O_3 concentrations were detected at Oistins Police Station (OPS) and the lowest were detected at the Speightstown Police Station (SPS). The top five VOC concentrations included fifty-three (53) individual compounds; consisting of various aldehydes, aromatic, ketone, alkene and alcohol groups with no particular pattern emerging. It must be noted

that in March 2014 the concentrations of VOCs were approximately 100 times higher than those recorded in other monitoring periods. The reason for this reading could not be determined.

At the conclusion of the study, the data collected could be used to establish initial baseline levels for NO_2, SO_2, O_3 and a range of Top 5 VOCs, within Oistins and Speightstown. Additionally, it was recommended that in order to establish a trend and to determine real time exposure comparable to international standards for the Oistins and Speightstown area, the study should be repeated using passive samplers co-located with continuous air monitoring equipment.

GLOSSARY OF TERMS AND ABBREVIATIONS

Aldehydes and Ketones	Simple compounds which contain a carbonyl group - a carbon-oxygen double bond. They are simple in the sense that they don't have other reactive groups like -OH or -Cl attached directly to the carbon atom in the carbonyl group
Alcohols	An organic compound in which the hydroxyl functional group is bound to a carbon atom. In particular, this carbon center should be saturated, having single bonds to three other atoms.
Alkanes	The simplest and least reactive hydrocarbon species due to the saturation of the carbon atoms containing only carbons and hydrogen.
Aromatics	A hydrocarbon with alternating double and single bonds between carbon atoms forming rings.
Baseline	A minimum or starting point used for future data comparisons
Co-located/ Duplicate	Two samples taken from and representative of the same population and carried through all steps of the sampling and analytical procedures in an identical manner. Duplicate samples are used to assess variance of the total method including sampling and analysis.
Detectable limits	Method detection limits are statistically determined values that define how easily measurements of a substance by a specific analytical protocol can be distinguished from measurements of a blank (background noise). Method detection limits are matrix, instrument and analyst specific and require a well defined analytical method. Method detection limits provide a useful mechanism for comparing different laboratories' capabilities with identical methods as well as different analytical methods within the same laboratory. In this report the detectable limits are as follows for SO_2 the DRL is < 0.03 µg S
EPD	Environmental Protection Department
Flexible scope of accreditation	Flexible scopes of accreditation can allow a laboratory to undertake certain tests/calibrations, and to report the results as accredited, even though they may not be explicitly stated on their accreditation schedule.
Guideline	A plan or explanation to guide one in setting standards or determining a course of action.
MTW	Ministry of Transport and Works
Nitrogen Dioxide (NO_2)	A toxic reddish brown gas NO_2 that is a strong oxidizing agent, is produced by combustion (as of fossil fuels), and is an atmospheric pollutant (as in smog).
OSAAQPM	Oistins and Speightstown Ambient Air Quality Passive Monitoring
Ozone (O_3)	Ground level ozone is not emitted directly into the air, but is created by chemical reactions between oxides of nitrogen (NOx) and volatile organic compounds (VOC) in the presence of sunlight. Emissions from industrial facilities and electric utilities, motor vehicle exhaust, gasoline vapours, and chemical solvents are some of the major sources of NOx and

	VOC.
ppb	Parts per billion
Primary Pollutant	An air pollutant emitted directly from a source
Secondary pollutant	An air pollutant that is not directly emitted, but forms when primary pollutants react in the atmosphere
Sorbent	A material used to absorb or adsorb liquids or gases
Sulphur Dioxide (SO_2)	A colourless, toxic gas with a strong odour. It is formed naturally by volcanic activity, and by the combustion of fossil fuels and several industrial processes. It is also a hazardous air pollutant and a major component of acid rain.
Standard	A level of quality or attainment which can be used for comparative evaluations.
Trip Blanks	Unopened passive samplers that are transported to and from the field with exposed and unexposed samplers. They are used to identify any contaminants introduced into the samples during transit to and from the laboratory.
UKAS	United Kingdom Accreditation Service
USEPA	United States Environmental Protection Agency
Volatile Organic Compounds (VOCs)	Compounds of carbon, excluding carbon monoxide, carbon dioxide, carbonic acid, metallic carbides or carbonates, and ammonium carbonate, which participate in atmospheric photochemical reactions. Excludes carbon compounds designated by EPA as having negligible photochemical reactivity.
WHO	World Health Organisation

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August 2013-July 2014 Final Report

Table of Contents

1.0 INTRODUCTION

The Environmental Protection Department has made representation in the draft Ambient Air Quality Policy Paper for continuous monitoring of the quality of the ambient air in Barbados. Continuous monitoring will act as a tool to determine peak pollutant concentrations which will allow the EPD to characterize the state of the ambient air in an effort to systematically achieve the goals set out in the Strategic Plan through focussed planning and development processes.

The study presented in this report is a continuation of the Bridgetown Ambient Air Quality Passive Sampling project conducted during the period 2012-2013, which utilized passive samplers to collect data on average concentrations of SO_2, NO_2, O_3 and top five VOCs at seven locations throughout Bridgetown.

The focus of this phase of the project was to determine the average concentrations of primary and secondary pollutants in the urban centres of Oistins, Christ Church and Speightstown, St. Peter. It is anticipated that data collected in this study, the previous Bridgetown study and future studies will be compiled to determine baseline levels of both primary and secondary pollutants in Barbados.

1.1 Speightstown and Oistins Study Area

Oistins was chosen as a study area due to the mix of residential, commercial and industrial activities such as fisheries, entertainment, and manufacturing occurring within the southern part of the island. In contrast Speightstown is located in the North of the island; but exhibits similar land use characteristics, albeit at a reduced level compared to Oistins. This may change in the future due to a renewed push for the revitalization of the Speightstown area by various private and public sector entities.

The Oistins study area was located in the southernmost parish of Christ Church. It was bounded to the west by the Cane Vale Seventh Day Adventist Church, with the Oistins Police Station in the centre and a residence located in Thornbury Hill to the east as shown in Figure 2.

Whereas, the geographic orientation of the Oistins study area ran west to east, the Speightstown study area ran in a north to south orientation and was situated in St. Peter, in the northwest part of the island. The study area as shown in Figure 3; was bounded to the north by the Sand Street sampling location, with the Speightstown Police Station (SPS) in the centre and the most southern of the sampling points at First Caribbean CIBC Bank (FCCIBC).

2.0 PROJECT OBJECTIVE

The objectives of the Oistins and Speightstown Ambient Air Quality Passive Monitoring Assessment (OSAAQPMA) were to:

1. characterize the air quality in and around different areas of Speightstown, and Oistins; and
2. determine any trends in primary and secondary pollutant levels at seven locations across Oistins and Speightstown over the course of twelve (12) months.

To assist with the analysis, weather data was collected from various sources and traffic data was collected by the Ministry of Transport and Works (MTW) at each location for eight (8) days during different months.

Primary and Secondary Pollutants

The draft Ambient Air Quality Policy Paper prepared by the EPD has identified the World Health Organization (WHO) Ambient Air Quality Guidelines as the primary reference standard. Therefore, the pollutants of focus in the study are those highlighted by the WHO guidelines as primary and secondary pollutants. These primary pollutants include sulphur dioxide (SO_2), nitrogen dioxide (NO_2) and Volatile Organic Compounds (VOCs). Ozone (O_3) is considered a secondary pollutant, because it is formed by photochemical reactions between nitrogen oxides and VOCs. It should be noted that SO_2 and NO_2 are utilized as indicators of the presence of sulphur oxides (SO_X) and nitrogen oxides (NO_X). Additionally, it must be noted that the laboratory detection limit is based on the amount of sulphur (S) and nitrogen (N) present with detectable limits of 0.03µg for sulphur and 0.05µg for nitrogen dioxide. The selected pollutants and their impacts are highlighted in Table 1.

Primary pollutants consist of air pollutants that may result in smog, acid rain and other health and infrastructural hazards, if present in sufficient quantities. In addition, primary pollutants are generally emitted from various stationary sources such as industrial activities, transportation, personal care (e.g. salons), agricultural activities and electricity generation. In Oistins and Speightstown, the most prominent sources of pollutants and VOCs would be industrial and commercial activities and the combustion of fossil fuels.

Table 1: List of Primary and Secondary Pollutants measured during the Oistins and Speightstown Ambient Air Quality Passive Monitoring Survey

PRIMARY POLLUTANT	DESCRIPTION
Sulphur Dioxide (SO_2)	By far the main source of sulphur dioxide is the combustion of fossil fuels such as diesel and fuel oil. According to the USEPA, short term (5 minutes to 24 hours) exposures to SO_2, may result in several adverse respiratory problems including the constriction of bronchial tubes and increased asthma symptoms in children and the elderly. It is also a component of acid rain formation which can cause property and environmental damage.
Nitrogen Dioxide (NO_2)	The main source of NO_2 would be high temperature combustion of fossil fuels and therefore, electricity generation and road traffic are the primary sources of NO_2. According to the USEPA, short-term (30 minutes to 24 hours) NO_2 exposure may trigger respiratory problems inclusive of airway inflammation in healthy people and increased respiratory symptoms in people with asthma. Emissions that lead to the formation of NO_2 generally also lead to the formation of other nitrogen oxides and tropospheric ozone (O_3).
Volatile Organic	VOCs comprise a very wide range of hydrocarbons, xygenates, halogenates and other carbon compounds existing in the atmosphere in

Compounds (VOCs)	the vapour phase. The predominant source of VOCs is typically through leakage from pressurized systems (e.g. natural gas, methane) or evaporation of a liquid fuel compounds such as benzene from fuel tanks of vehicles. However, the incomplete combustion of fossil fuels and other incineration processes may also give rise to fragments that are emitted in the form of VOCs.
SECONDARY POLLUTANT	**DESCRIPTION**
Ozone (O_3)	Ground level ozone is the main component of smog and is created by the chemical interactions between NO_2, VOCs and sunlight. The concentration generated is dependent on atmospheric convection, the thermal inversion layer and an optimal VOC/nitrogen oxides ratio ranging from 4:1 to 10:1[1]. At high concentrations, O_3 may irritate airways and cause breathing difficulties and damage lungs. It can also trigger asthma attacks, especially in children, the ill and the elderly. Additional impacts include damaged vegetation and reduced crop yields.

3.0 STUDY AREA AND METHODOLOGY

3.1 Study Area

The sampling programme consisted of seven sites as shown in Figures 1-3. Three (3) of the sites were located in the vicinity of Oistins, Christ Church, three (3) in Speightstown, St. Peter and one at Ragged Point, St. Philip, which served as a background site.

The background site was selected because it was an upwind location outside of the study area. Furthermore, this site was situated at the eastern-most part of the island and consequently should not be affected by any land based activities that may generate high levels of VOC, SO_2 or NO_2. Site selection was initially accomplished through the differentiation between activities occurring in the area and assigning the following classifications;

- Commercial activities

[1] World Health Organization, Europe. (2005). *Air Quality Guidelines 2005*.Available: http://www.euro.who.int/__data/assets/pdf_file/0005/78638/E90038.pdf. Last accessed January 15, 2014.

- Residential activity
- Industrial activity
- Mixed use activities (a combination of any of the three activities)

In addition to the activity type, the sample locations were also classified based on the recommendations provided by the passive sampler manufacturer and the proximity to the nearest heavily trafficked roadway. Table 2 outlines the criteria associated with each site.

Figure 1: Map of urban areas sampled in relation to the background sampling location.

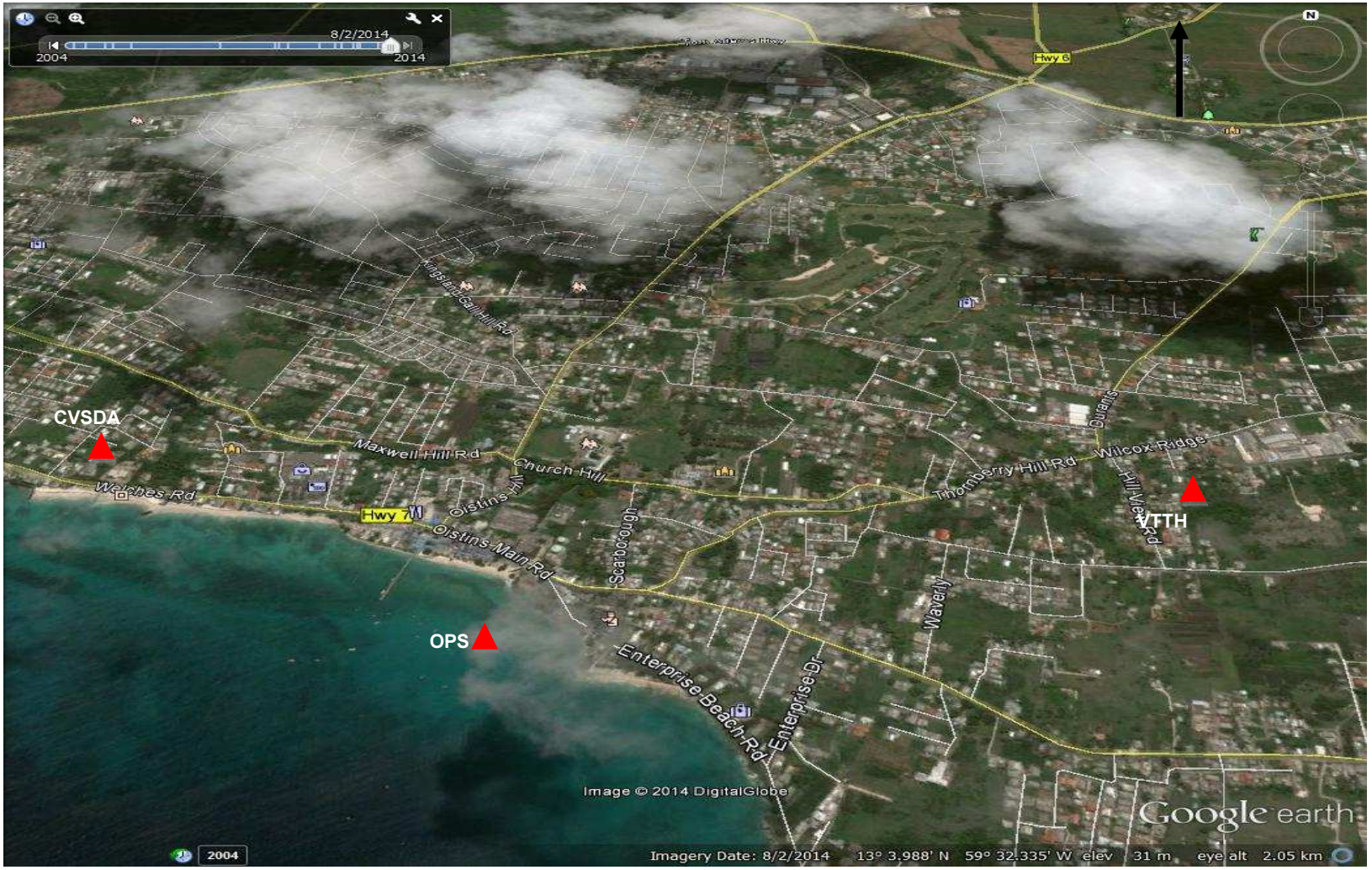


Figure 2: Locations of the selected sampling sites in Oistins: CVSDA (Cane Vale 7th Day Adventist Church); VTTH (Residence in Thornbury Hill) and OPS (Oistins Police Station)

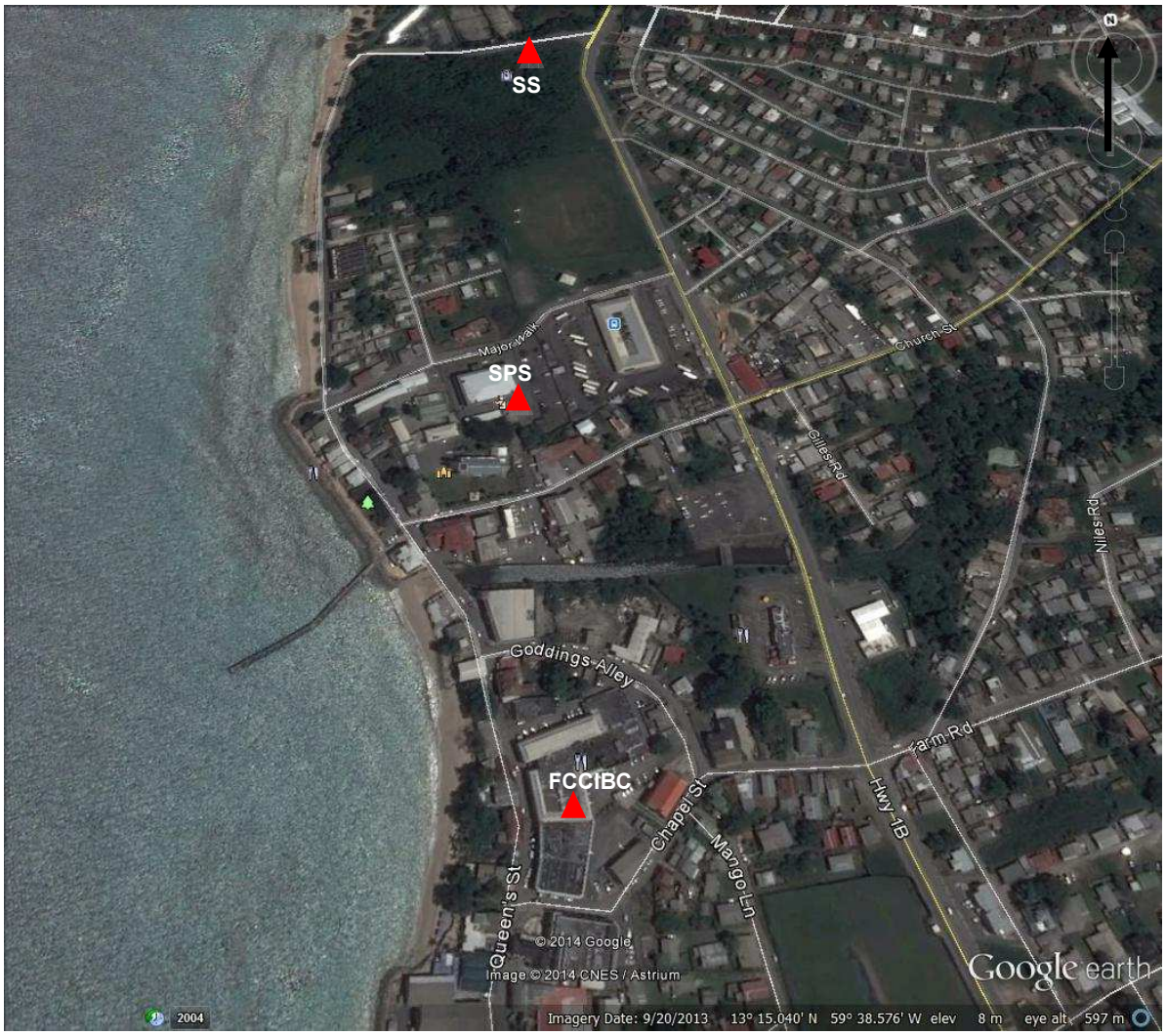


Figure 3 Locations of sampling sites located in Speightstown: SPS (Speightstown Police Station); FCCIBC (First Caribbean CIBC Bank) and SS (Sand Street)

Table 2: Site location and selection criteria

Site Location	Location Type	Distance From Major Roadway	Other Selection Criteria
Ragged Point, St. Philip (RP)	Background	>50 m	Located NE of Oistins and SE of Speightstown.
Residence, Thornbury Hill, Oistins, Christ Church (VTTH)	Residential Background	>50 m	Residential/Industrial
Oistins Police Station, Oistins, Christ Church (OPS)	Intermediate	20-30 m	Commercial/Residential
Cane Vale Seven Day Adventist Church, Cane Vale, Ch. Ch. (CVSDA)	Background	> 50 m	Residential
First Caribbean Commercial Bank, Speightstown, St. Peter (FCCIBC)	Near road	1-5 m	Commercial
Speightstown Police Station, Speightstown St. Peter (SPS)	Urban Background	>50 m	Residential/Commercial
Sand Street, St. Peter (SS)	Background	>50 m	Residential

3.2 Tube Deployment and Recovery

The air quality at seven (7) locations was assessed utilizing passive monitors designed to allow passive air flow over treated sampling media (TenaxTA Sorbent in the case of the VOC tubes), which was then analysed by gas chromatography and other proprietary methodologies by the manufacturer Enviro Technology Services PLC UK, within their flexible scope of accreditation.

The passive samplers were deployed at each of the sample sites in the following manner:

- Three types of passive samplers were utilized in the study: one that measured Top Five VOCs, another for SO_2/NO_2 and a third for O_3.

- One of each type of passive sample tube was placed at each of 7 locations
- In addition, a single duplicate tube was placed at various locations, resulting in four (4) tubes per site per month[2], as shown in Table 3.
- No duplicates were used at the background site. Therefore three (3) samplers (Top Five VOCs, SO_2/NO_2, and O_3) were deployed on a monthly basis at this site.
- Three trip blanks, one each for Top Five VOCs, SO_2/NO_2, and O_3 were utilized during the deployment and returned for analysis.
- Tubes were placed at a height between two (2) and four (4) metres from the ground and secured by zip ties and double sided tape.

3.3 Supplemental Data for Oistins and Speightstown

In addition to passive monitoring sampling, the following supplementary data was collected;

- Ministry of Transport traffic counters were utilized to conduct traffic counts along the main roads closest to the sampling sites for a period of eight (8) days, to account for both weekday and weekend traffic. No data was collected for VTTH as the location was outside of the defined boundary of Oistins as defined in the physical development plan. Therefore, any traffic recorded in this area cannot be considered as part of the overall Oistins traffic volume.
- Meteorological data was collected utilizing weather data from www.wunderground.com whose data was sourced from the weather station at the Grantley Adams International Airport, Christ Church which was the closest weather station to Oistins.

[2] A monthly sample is considered to be valid if the exposure period is within +/- 5 days of the 30 day period (calendar month); it is also desirable to have the 'on' and 'off' dates as close as possible to the start and end of a calendar month in order to minimize uncertainty in the determination of the exposure month. - **Operations Manual for Air Quality Monitoring in Ontario Ministry of the Environment Operations Division Technical Support Section**

Table 3: The diffusion tube allocation from August 2013 to July 2014. The value "2" indicates that a duplicate is placed on site.

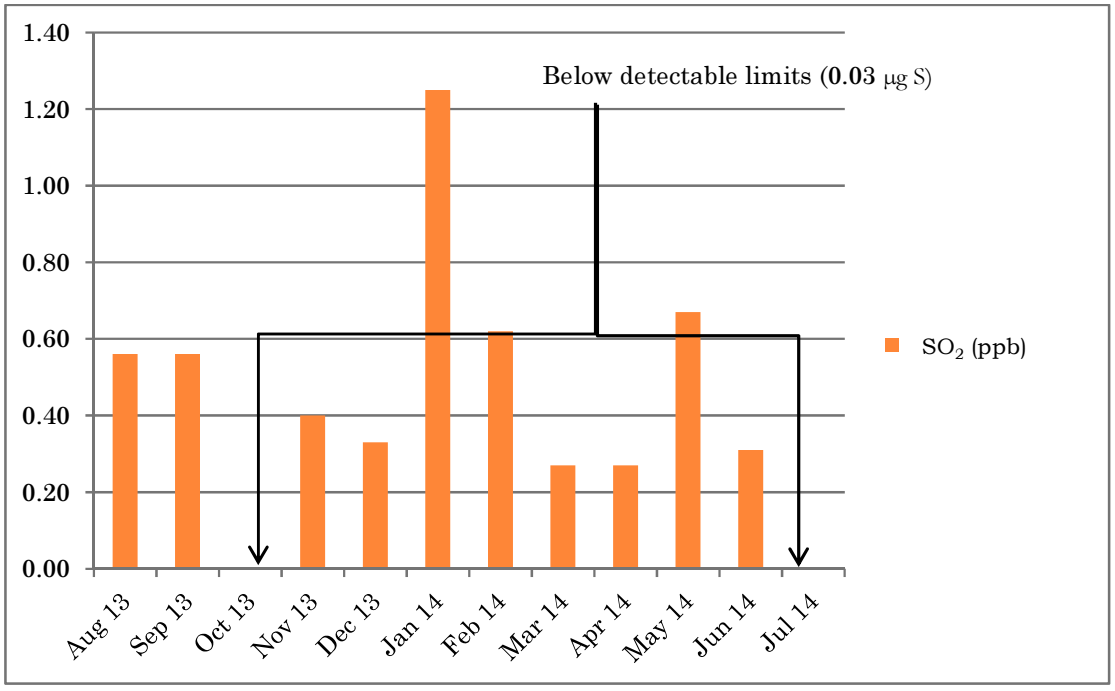
SITE ID#	PARAMETERS	AUG-13	SEPT-13	OCT-13	NOV-13	DEC-13	JAN-14	FEB-14	MAR-14	APR-14	MAY-14	JUN-13	JUL-14
Ragged Point (RP)	VOC	1	1	1	1	1	1	1	1	1	1	1	1
	SO_2 /NO_2	1	1	1	1	1	1	1	1	1	1	1	1
	(O_3)	1	1	1	1	1	1	1	1	1	1	1	1
Residence, Thornbury Hill (VTTH)	VOC	2	1	1	2	1	1	2	1	1	2	1	1
	SO_2 /NO_2	1	1	2	1	1	2	1	1	1	1	1	2
	(O_3)	1	2	1	1	2	1	1	2	1	1	2	1
Oistins Police Station (OPS)	VOC	1	2	1	1	2	1	1	2	1	1	2	1
	SO_2 /NO_2	2	1	1	2	1	1	2	1	1	2	1	1
	(O_3)	1	1	2	1	1	2	1	1	1	1	1	2
Cane Vale 7th Day Adventist Church (CVSDA)	VOC	1	1	2	1	1	2	1	1	1	1	1	2
	SO_2 /NO_2	1	2	1	1	2	1	1	2	1	1	2	1
	(O_3)	2	1	1	2	1	1	2	1	1	2	1	1
First Caribbean International Bank Speightstown (FCCIBC)	VOC	2	1	1	2	1	1	2	1	1	2	1	1
	SO_2 /NO_2	1	1	2	1	1	2	1	1	2	1	1	2
	(O_3)	1	2	1	1	2	1	1	2	2	1	2	1
Speightstown Police Station (SPS)	VOC	1	2	1	1	2	1	1	1	1	1	2	1
	SO_2 /NO_2	2	1	1	2	1	1	2	1	1	2	1	1
	(O_3)	1	1	2	1	1	2	1	1	1	1	1	2
Sand Street Sampling Point (SS)	VOC	1	1	2	1	1	2	1	1	2	1	1	2
	SO_2 /NO_2	1	2	1	1	2	1	1	1	1	1	2	1
	(O_3)	2	1	1	2	1	1	2	1	1	2	1	1

4.0 RESULTS

4.1 Ragged Point (RP), St. Philip Background Site

Sampling was conducted at Ragged Point, St. Philip which is the eastern-most point of Barbados, located north east of Oistins and south east of Speightstown.

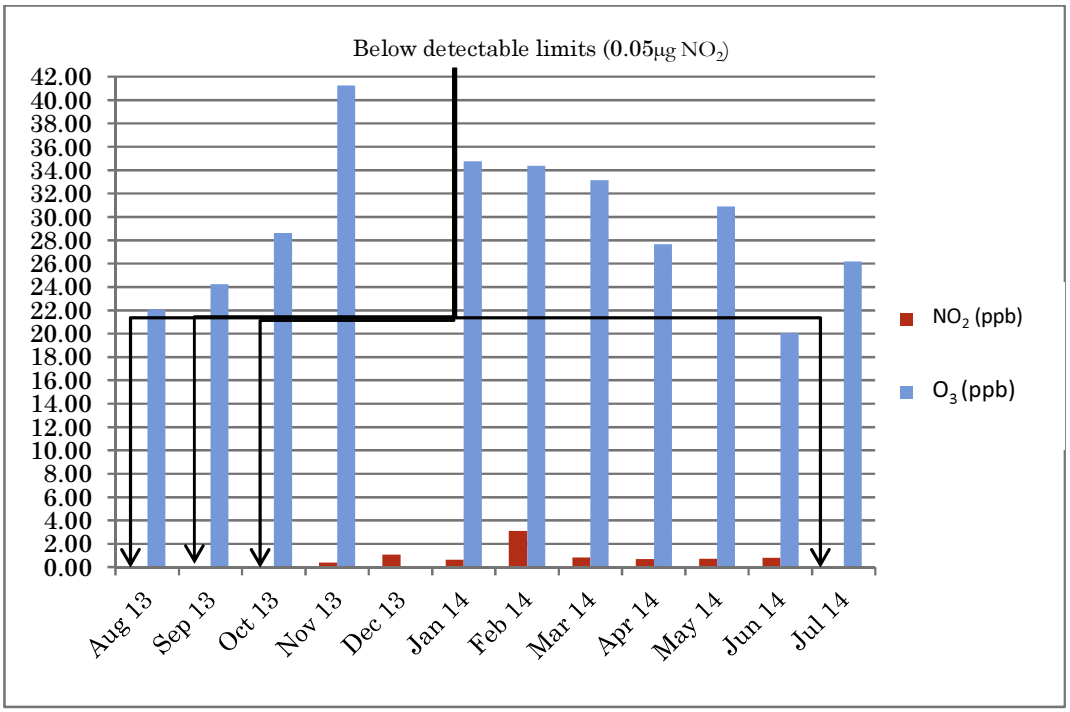
As depicted in Graph 1, the SO_2 concentrations observed at Ragged Point were highest (1.25 ppb) in January 2014 and lowest in October 2013 and July 2014 where the values were below the detectable limit for SO_2[3].



Graph 1: SO_2 levels detected at Ragged Point, St. Philip for the period August 2013 to July 2014.

In the case of NO_2, the highest level detected (3.11 ppb) was observed in February 2014. It must be noted that the lowest levels were observed during August 2013, September 2013, October 2013 and July 2014, where the laboratory analysis indicated that the concentrations were below the detectable limit for NO_2[4].

[3] 0.03µg is the laboratory detectable limit for SO_2.
[4] 0.05µg is the laboratory detectable limit for NO_2.

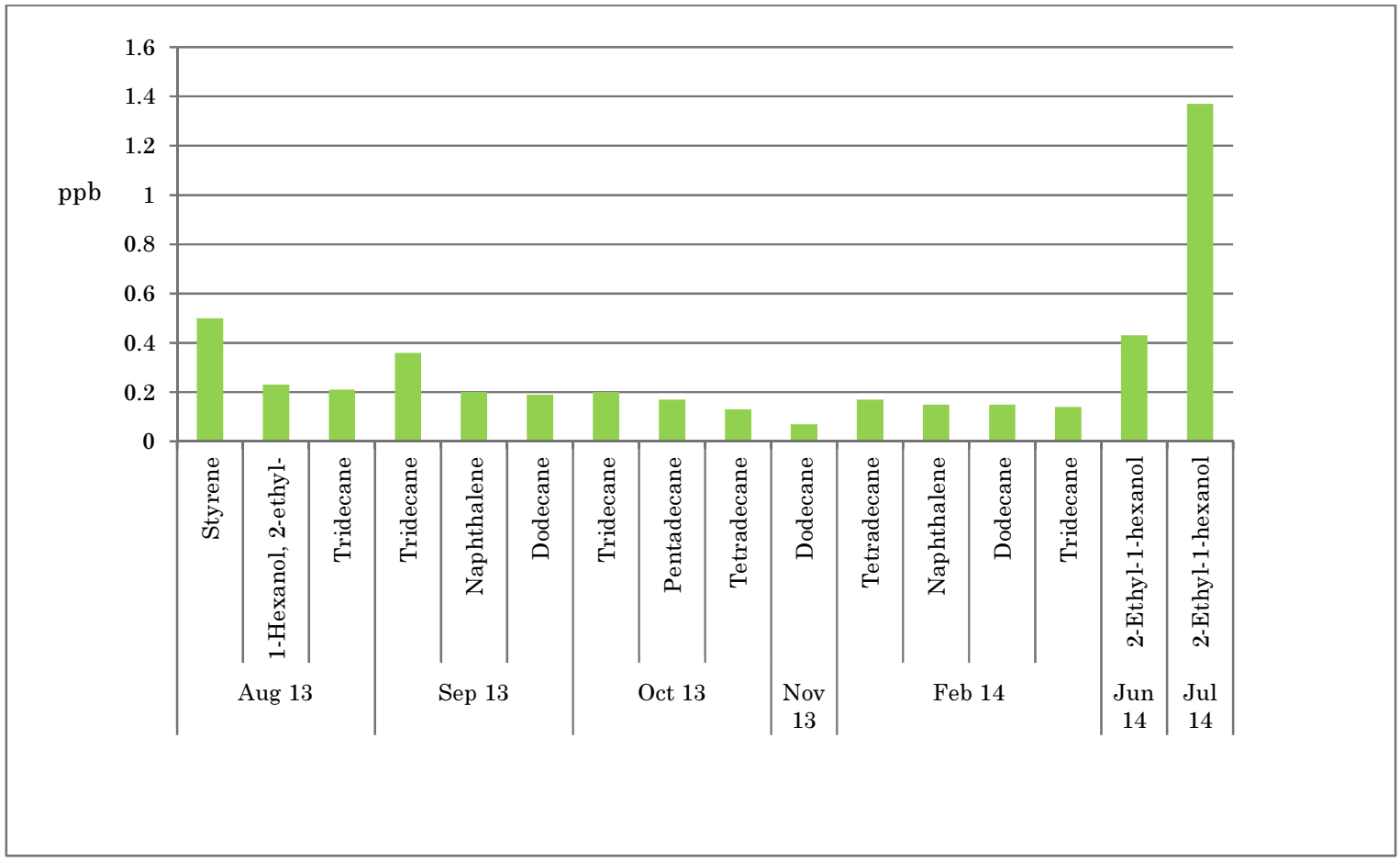


Graph 2: NO_2 and O_3 concentrations observed at Ragged Point, St. Philip for the period August 2013 to July 2014.

With respect to O_3, the highest value of 41 ppb was detected in November 2013; no data was collected in December 2013 as samplers at this site where not present when officers went to retrieve them. The lowest value of approximately 20.03 ppb was detected in June 2014. Both the high and low concentrations are shown in Graph 2.

In the case of the top five VOCs, Graph 3 highlights only those compounds detected that were within the UKAS accredited scope (i.e. the values can be considered accurate and verifiable) and those that were not formed as a result of interactions with O_3 and the sample media. During the months of January, March, April and May 2014, all of the top five VOCs were outside the flexible scope and were possibly the result of an artefact reaction with O_3, and as a result were not shown in Graph 3.

Additionally, no data was collected in December 2013 due to lost tubes. The highest concentration of any top five VOC detected was 1.37 ppb of 2-Ethyl-1-hexanol in July 2014. For the full list of compounds detected please refer to Appendix 1.

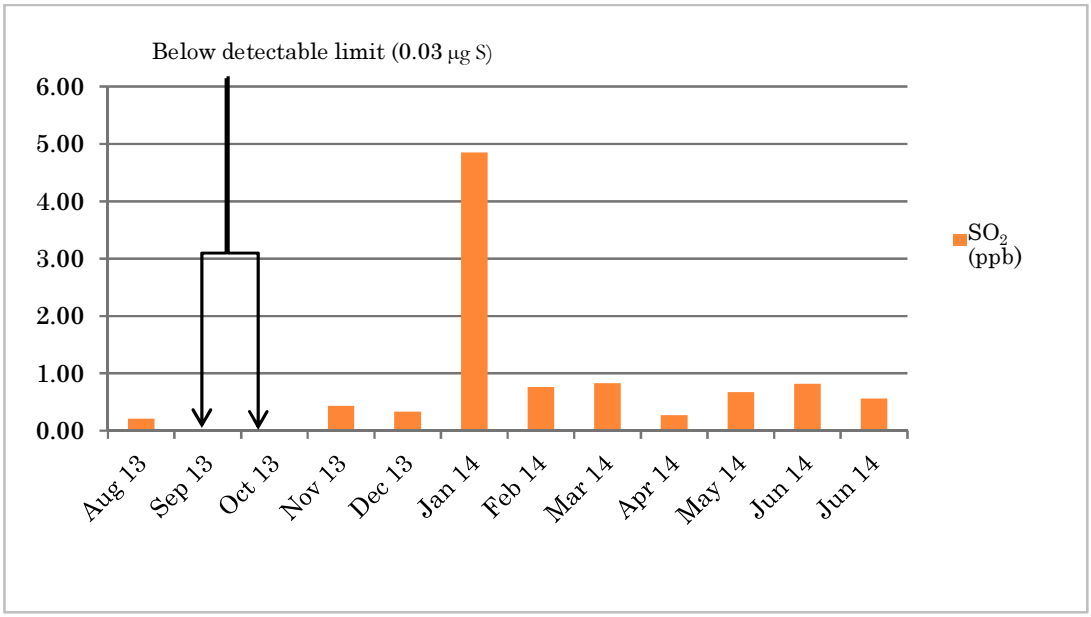


Graph 3: Top Five VOCs at detected at Ragged Point, St. Philip for the period August 2013 to July 2014. The compounds shown represent only those compounds covered in the laboratory accredited flexible scope and are not blank corrected and do not include compounds that may be the result of reactions between O_3 and the Tenax TA sorbent.

4.2 Private Residence, Thornbury Hill, Christ Church (VTTH)

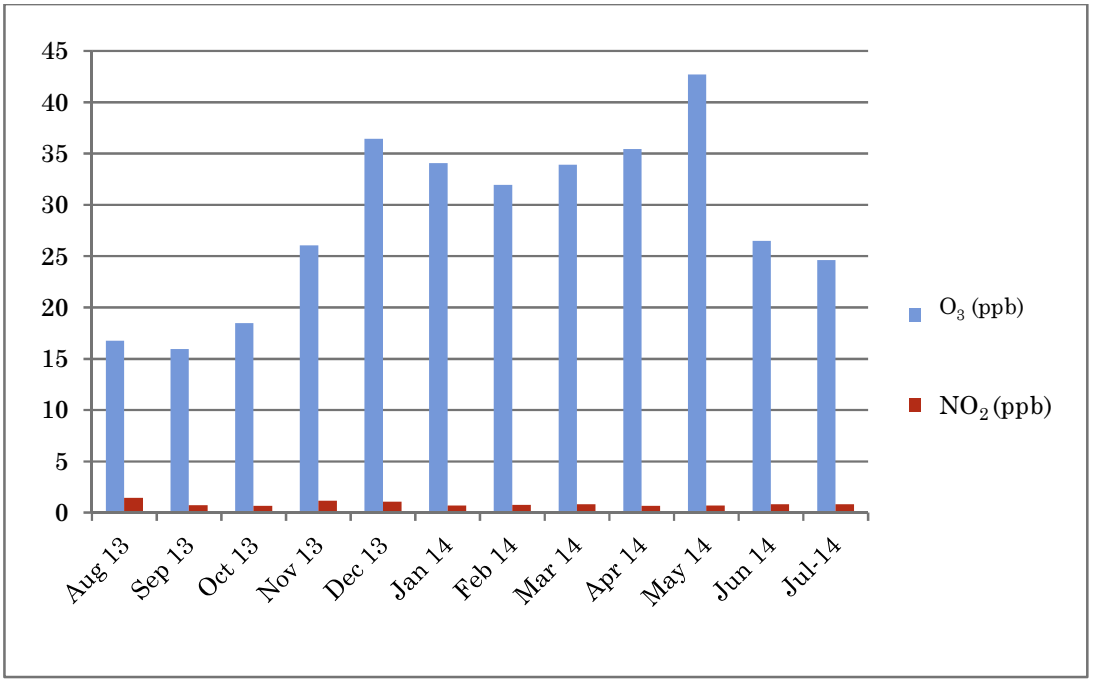
This location, represented a residential background location, greater than 50 m from the busiest roadway; it was also in close proximity less than 30 m away from an industrial park located north of the property.

Results showed, that SO_2 concentrations peaked (4.85 ppb) in January 2013. The lowest levels observed were those below the detectable limit in September and October 2013.



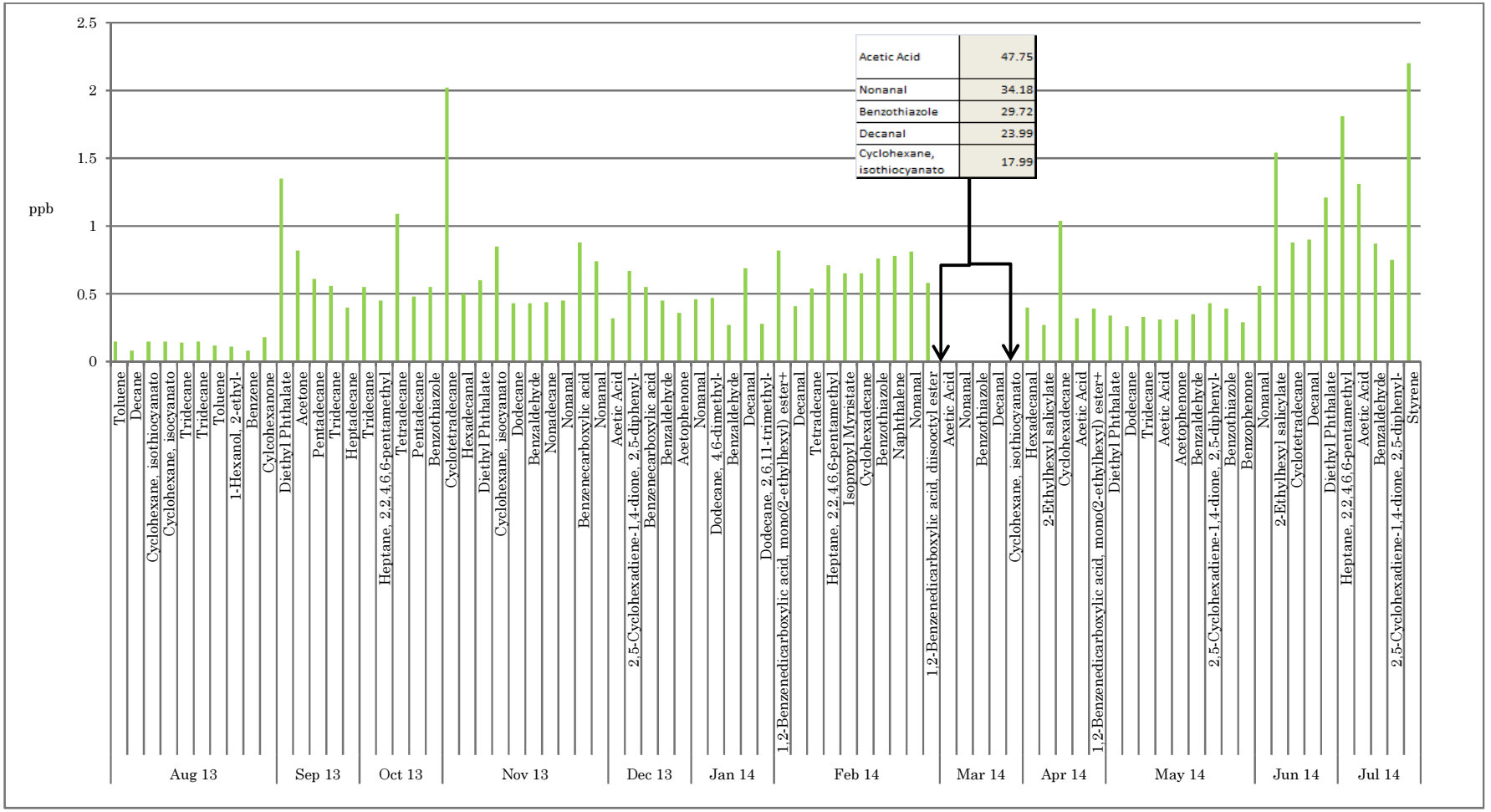
Graph 4: SO_2, levels at VTTH, Thornbury Hill, Christ Church during the period August 2013 to July 2014.

With respect to NO_2, the highest level (1.45 ppb) was detected in August 2013. The lowest level (0.65 ppb) was detected in April 2014. The highest level (42.73 ppb) of O_3 was detected in May 2014 and the lowest (15.95 ppb) in September 2013.



Graph 5: O_3 and NO_2 concentrations detected at a private residence in Thornbury Hill, Christ Church for the period August 2013 to July 2014.

With respect to the top five VOCs, the highest levels were detected in March 2014 with Acetic acid concentrations (47.75 ppb) being the highest, the lowest concentrations (< 0.15 ppb) in general were detected in August 2013, as shown in Graph 6. Additionally, the majority of the top five VOCs did not exceed 2.5 ppb.



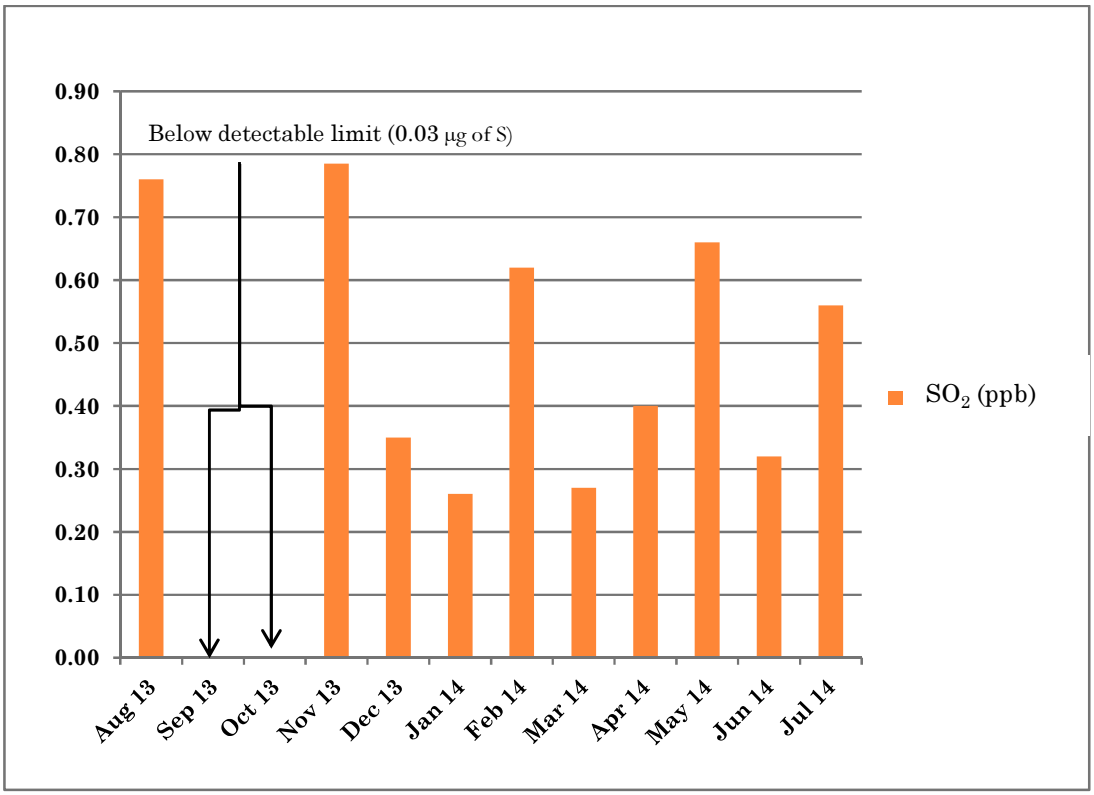
Graph 6: Top five VOC compounds detected at a private residence, located at Thornbury Hill Christ Church. The compounds shown represent only those which are covered in the laboratory accredited flexible scope, are not blank corrected and do not include those compounds that may be the result of reactions between O_3 and the TenaxTA sorbent.

As shown in Graph 6 the compounds detected were those included in the laboratory's UKAS accreditation and those compounds that were not formed as a result of the sample media sorbent interacting with O_3. For the full list of compounds please refer to Appendix 1.

4.3 Oistins Police Station (OPS)

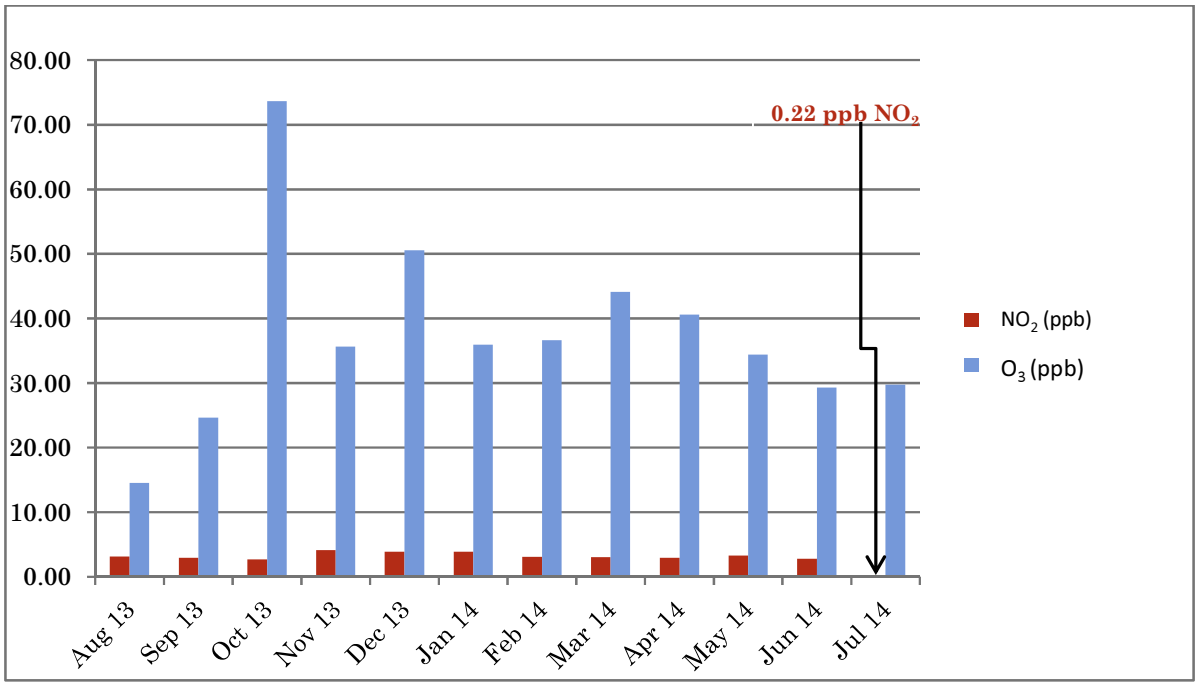
Samplers were placed near the entrance to Oistins Magistrates Court and Police Station. The results of the monthly samples have been presented below in Graphs 7-9.

The highest SO_2 concentration of 0.79 ppb was detected in November 2013. Lows were detected in September and October 2013 when those concentrations were observed to be below the laboratory detectable limit as seen below in Graph 7.



Graph 7: SO_2, concentrations at OPS for the period August 2013 to July 2014.

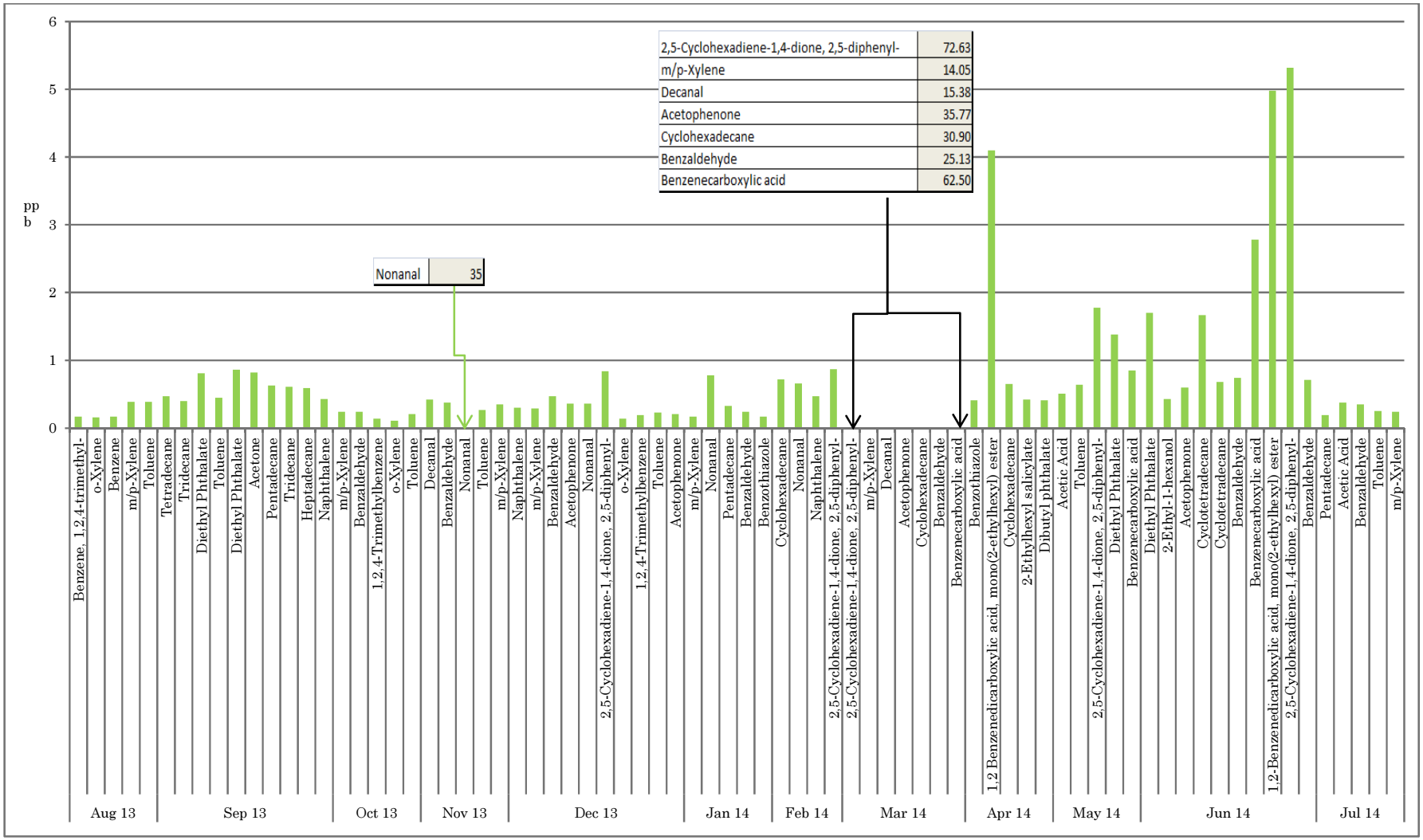
In the case of NO_2, the highest concentration (4.12 ppb) was detected in November 2013 with the lowest concentration (0.22 ppb) detected in July 2014. The highest recorded ozone level (73.66 ppb) was detected in October 2013, whereas the lowest (14.83 ppb) was detected in August 2013.



Graph 8: NO_2 and O_3 concentrations detected at OPS for the period August 2013 to July 2014.

As shown in Graph 9, the highest concentrations of top five VOCs were detected in March 2014. The highest value detected was 72.63 ppb of 2, 5-Cyclohexadiene- 1, 4 Dione, 2, 5 diphenyl and the lowest value (0.11 ppb) of σ-xylene was detected in October 2013. Additionally, in November 2013 there was a spike of Nonanal which had an average concentration of 35 ppb.

As represented in Graph 9, the compounds detected were those included in the laboratory's UKAS accreditation. Several compounds were detected during the analysis that fell outside of the laboratory flexible scope. Please refer to Appendix 1 for the full list of compounds detected.

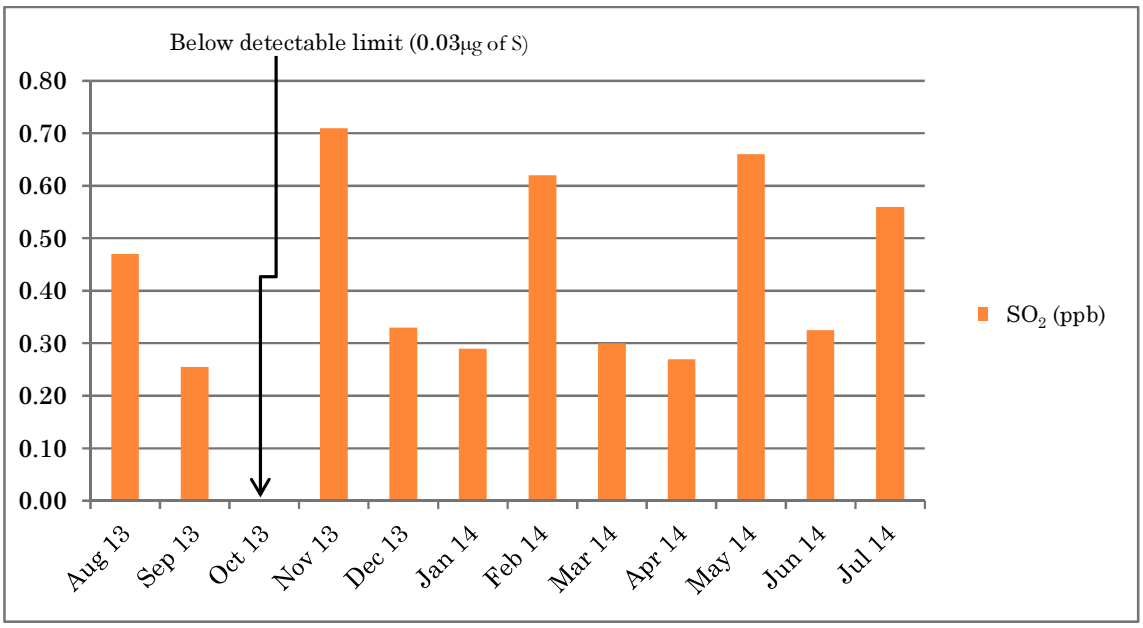


Graph 9: Top Five VOC compounds detected at the OPS sampling location during the study period August 2013 to July 2014. The compounds shown represent only those covered in the laboratory accredited flexible scope, are not blank corrected and do not include those reactions that may be the result of reactions between O_3 and the TenaxTA sorbent.

4.4 Cane Vale Seventh Day Adventist Church (CVSDA), Cane Vale, Oistins Christ Church

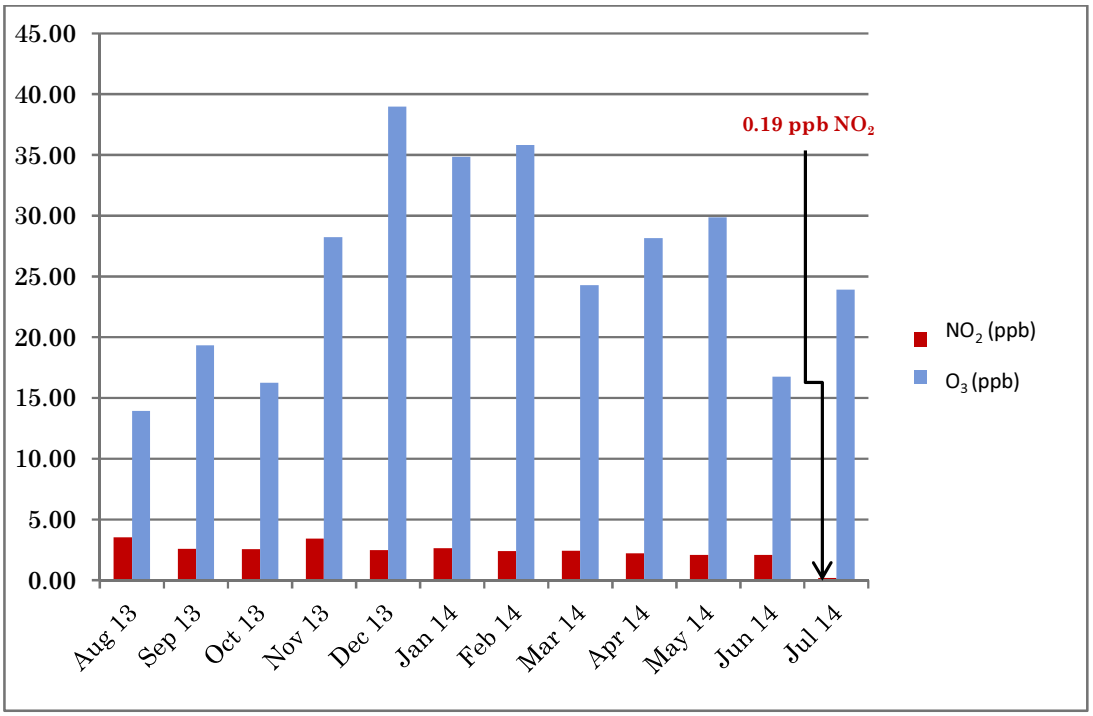
Passive samplers were placed on the exterior of the CVSDA which was classified as a residential area. The results of the sampling are shown in Graphs 10-12.

SO_2 levels peaked (0.71 ppb) in November 2013 and the lowest concentrations, which were below the detection limit, were recorded in October 2013.



Graph 10: SO_2 concentrations detected at CVSDA during the period August 2013 to July 2014.

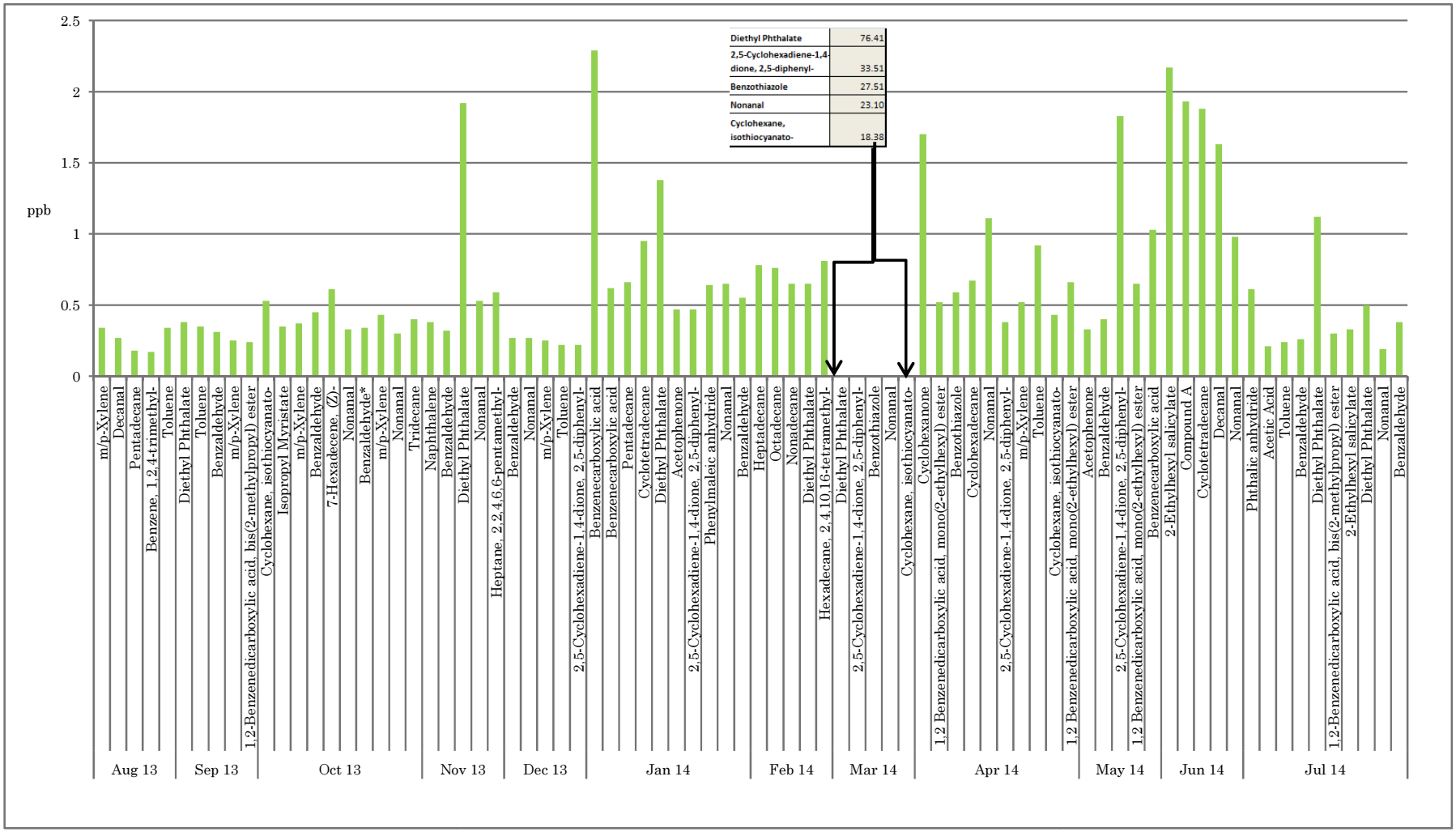
As shown in Graph 11; the highest NO_2 concentration (3.53 ppb) was detected in August 2013 and the lowest concentration (0.19 ppb) detected in July 2014. Ozone levels peaked (39.0 ppb) in December 2013 and the lowest (13.95 ppb) was detected in August 2013.



Graph 11: NO_2 and O_3 concentrations detected at CVSDA, for the period August 2013 to July 2014.

Based on Graph 12 below, the highest concentrations of top 5 VOCs were detected in March 2014. The highest concentration of any VOC detected was 76.41 ppb of Diethyl phthalate, the lowest concentration of any top 5 VOCs was 0.17 ppb of 1,2,4 trimethyl-benzene which was observed in August 2013.

As shown in Graph 12, the compounds detected were those included in the laboratory's UKAS accreditation. Several compounds were detected during the analysis that fell outside of the laboratory flexible scope. Please refer to Appendix 1 for the full list of compounds detected.

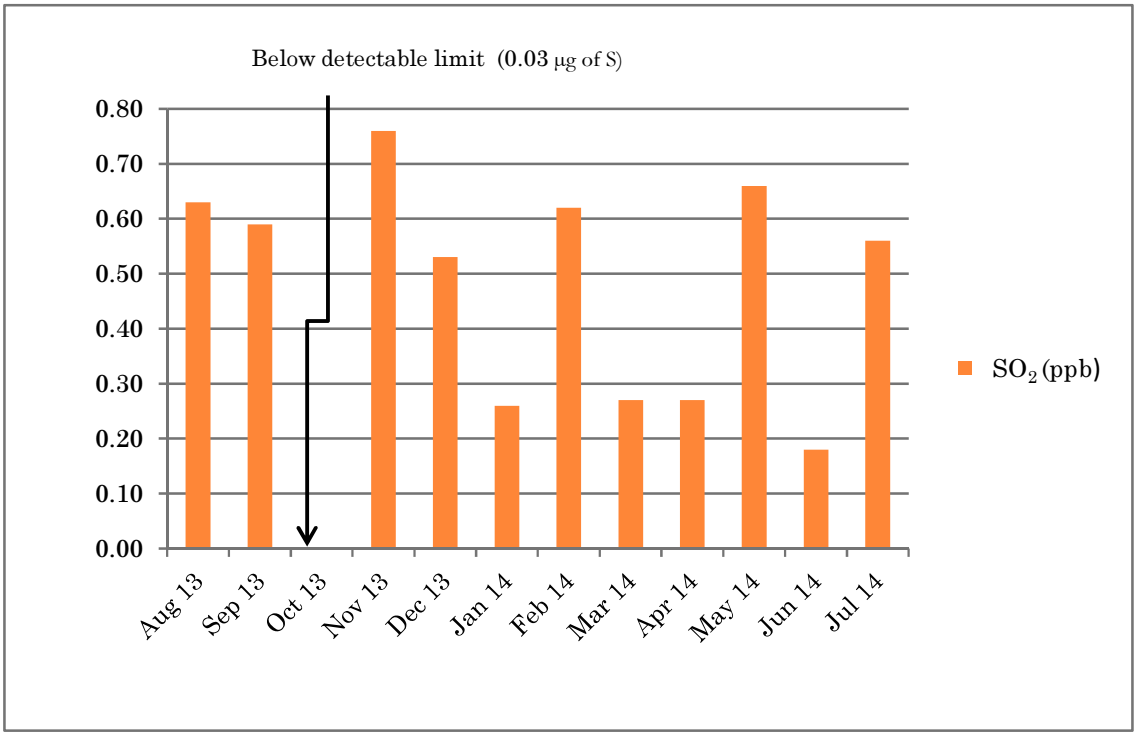


Graph 12: Top five VOC compounds detected at the CVSDA sampling location during the study period August 2013 to July 2014. The compounds shown represent only those covered in the laboratory accredited flexible scope, are not blank corrected and do not include tho reactions that may be the result of reactions between O_3 and the TenaxTA sorbent.

4.5 First Caribbean CIBC Speightstown (FCCIBC)

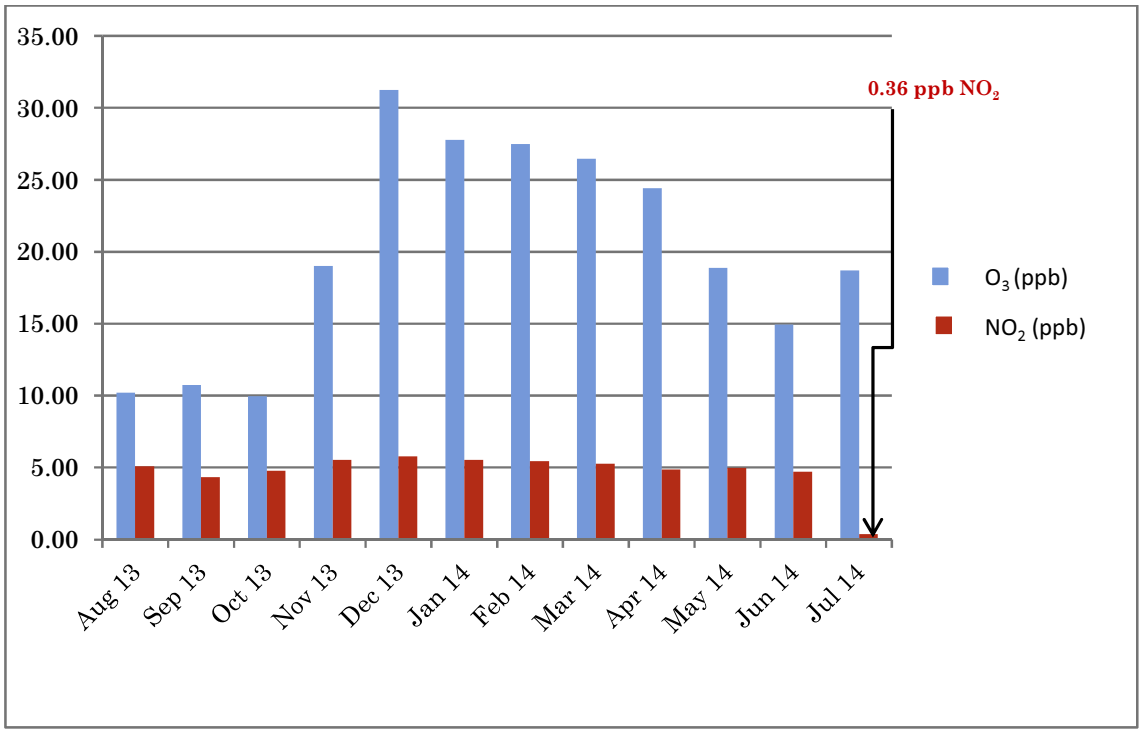
This location was considered as a near road sampling location in a commercial area zone due to the presence of several businesses. The results of the sampling are shown in the graphs 13-15 below.

Graph 13 shows that SO_2 levels peaked (0.76 ppb) in November 2013 and the lowest SO_2 concentration was below the detectable limit in October 2013.



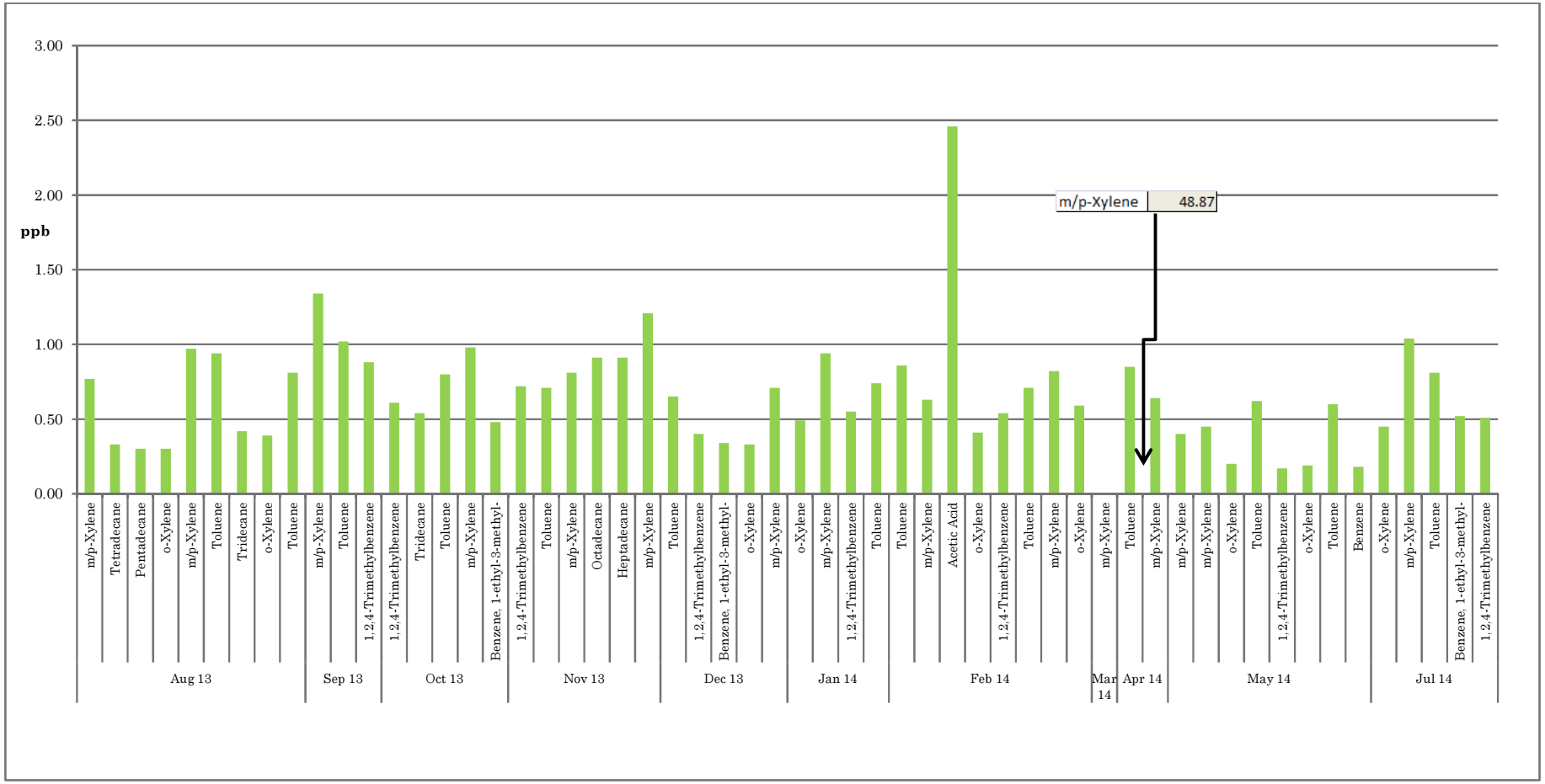
Graph 13: SO_2 concentrations at FCCIBC, Speightstown, St. Peter

The highest NO_2 concentration (5.78 ppb) was detected in December 2013 and the lowest detected (0.36 ppb) in July 2014. With the exception of September 2013 and July 2014, all other NO_2 concentrations were between 4.78 and 5.78 ppb. The highest ozone level (31.24 ppb) was detected in December 2013 and the lowest (9.96 ppb) in October 2013.



Graph 14: NO_2 and O_3 concentrations detected at FCCIBC, for the period August 2013 to July 2014.

As shown in Graph 15, during the sampling period the majority of the VOCs detected were below 2.50 ppb, except in March 2014 where a high of 48.87 ppb of m-p-xylene was detected. The lowest concentration of any top five VOC detected was 0.17 ppb of 1, 2, 4 trimethyl benzene in May 2014. Several compounds were detected during the analysis that fell outside of the laboratory flexible scope. Please refer to Appendix 1 for the full list of compounds detected.

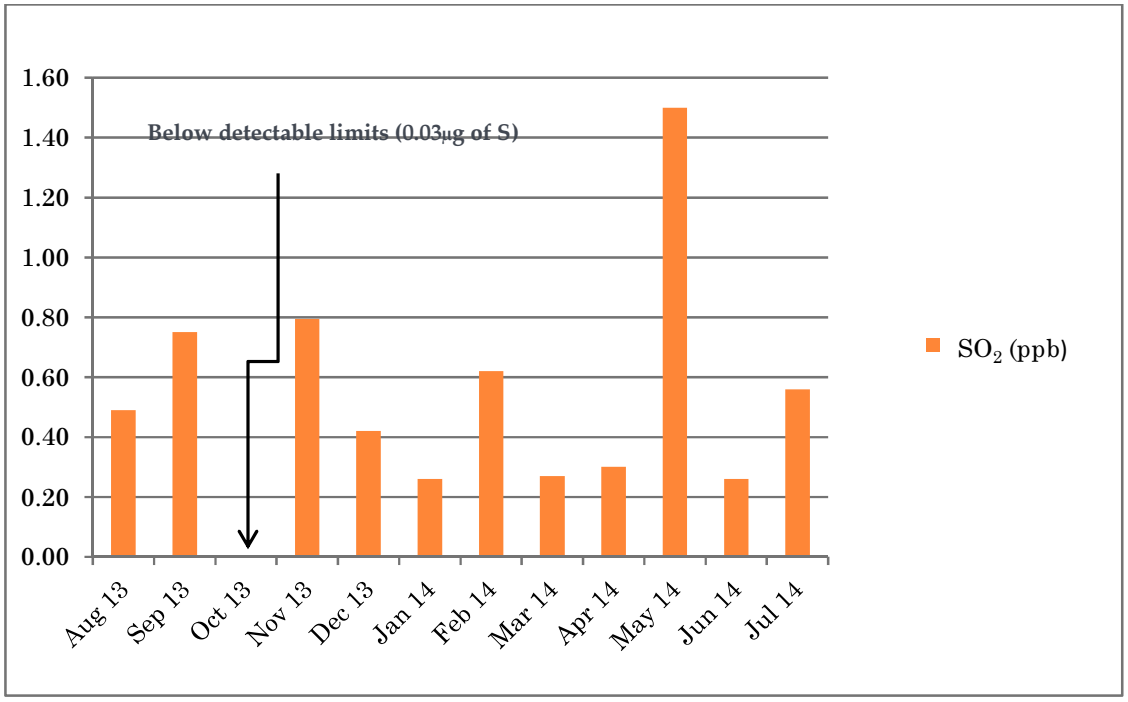


Graph 15: Top five VOC compounds detected at FCCIBC, Speightstown, St. Peter sampling location, during the study period August 2013 to July 2014. The compounds shown represent only those covered in the laboratory accredited flexible scope, are not blank corrected and do not include those reactions that may be the result of reactions between O_3 and the TenaxTA sorbent.

4.6 District E Police Station (SPS), Speightstown St. Peter

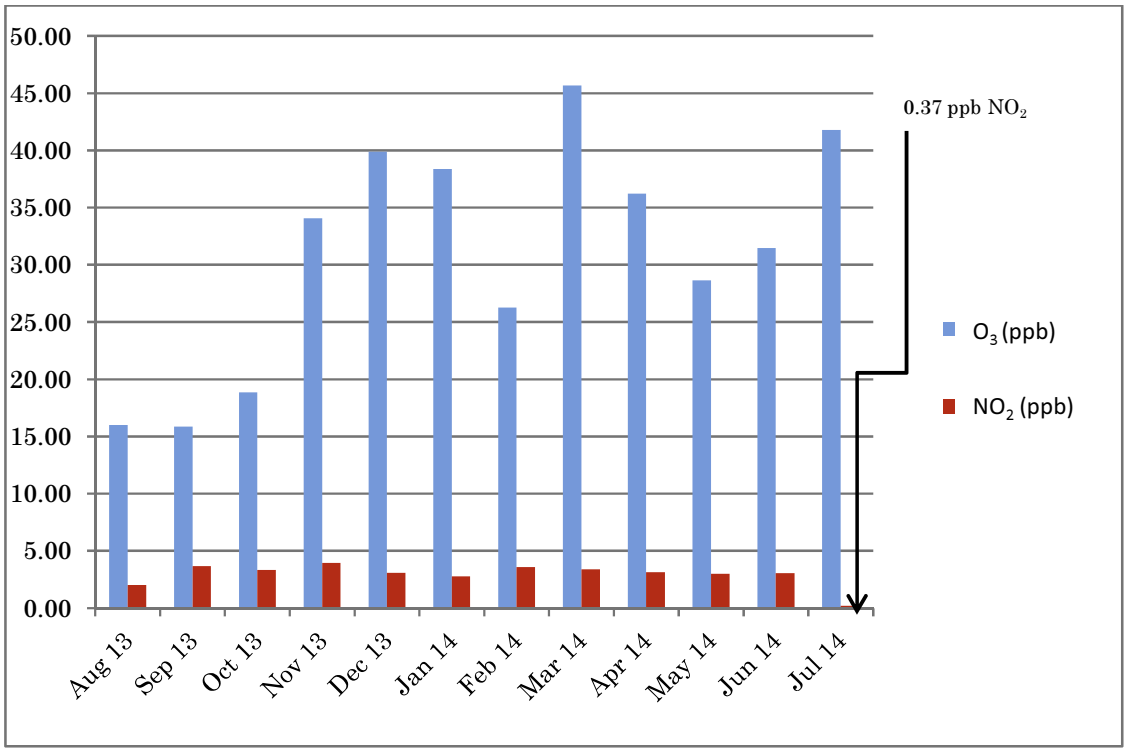
Passive samplers were deployed in the parking lot of the District E, Speightstown Police Station, St. Peter. The results of the sampling are provided below in Graphs 16-18.

The highest level (1.50 ppb) of SO_2 was detected in May 2014. The lowest level detected was below the detectable limit and was recorded in October 2013.



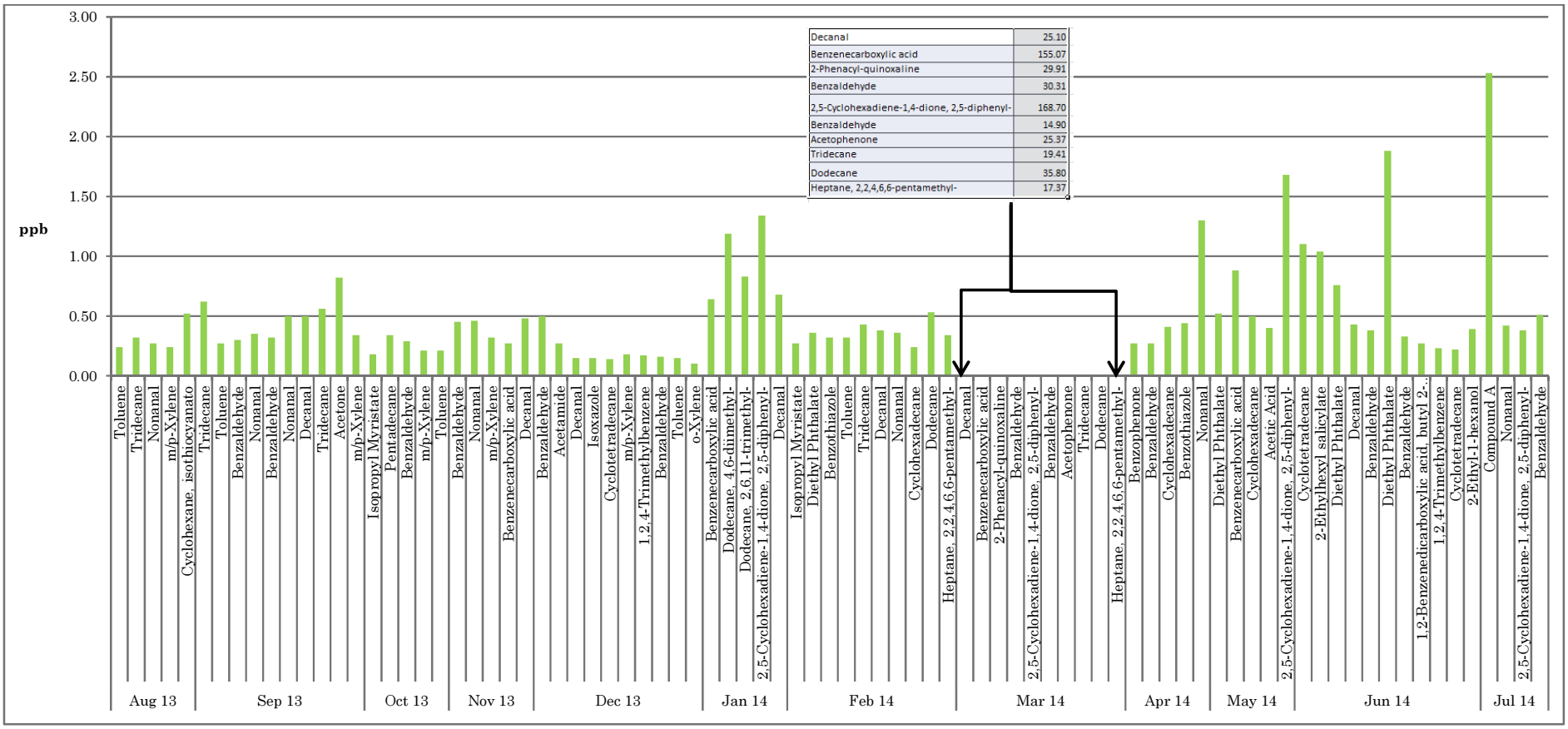
Graph 16: SO_2 concentrations for the District E Police Station (SPS), Speightstown, St. Peter.

As observed in Graph 17, the highest NO_2 concentration (3.97 ppb) was detected in November 2013, and the lowest concentration (0.37ppb) was detected in July 2014. The highest ozone concentration detected was 45.67 ppb in March 2014. The lowest O_3 concentration detected was 15.86 ppb in September 2013.



Graph 17: NO_2 and O_3 concentrations detected at SPS, for the period August 2013 to July 2014.

As demonstrated in Graph 18 below, the majority of the VOCs detected were below 1.50 ppb. However the levels in March 2014 were significantly higher, the highest of which was 2, 5-Cyclohexadiene-1,4-dione, 2-5 diphenyl with a concentration of 168.70 ppb. The lowest concentration of any top five VOC detected was 0.10 ppb of σ-xylene which was detected in December 2013. Several compounds were detected during the analysis that fell outside of the laboratory flexible scope. Please refer to Appendix 1 for the full list of compounds detected.



Graph 18: Top five VOC compounds detected at SPS, Speightstown, St. Peter sampling location during the study period August 2013 to July 2014. The compounds shown represent only those compounds covered in the laboratory accredited flexible scope, are not blank corrected and do not include those reactions that may be the result of reactions between O_3 and the TenaxTA sorbent.

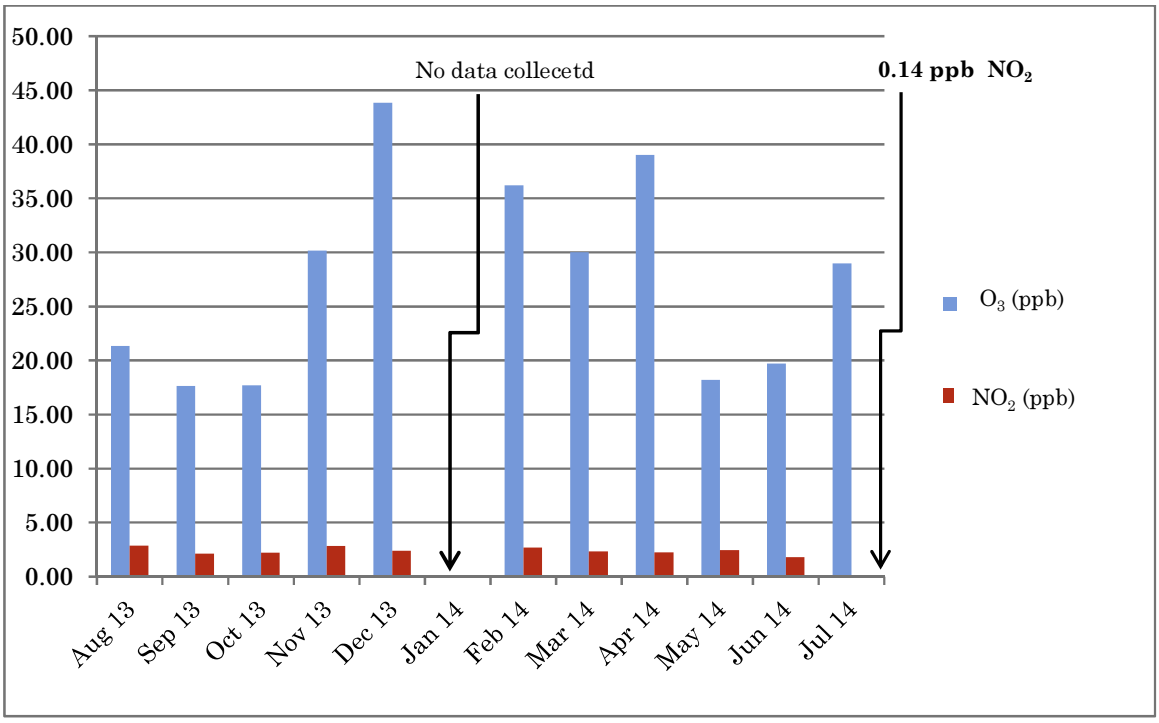
4.7 Sand Street, Speightstown (SS)

Sand Street, Speightstown was the northern most location sampled and was classified as a background residential sampling location. The results for SS are highlighted in Graph 19-21.

Graph 19: SO_2 concentrations at SS during the period August 2013 to July 2014.

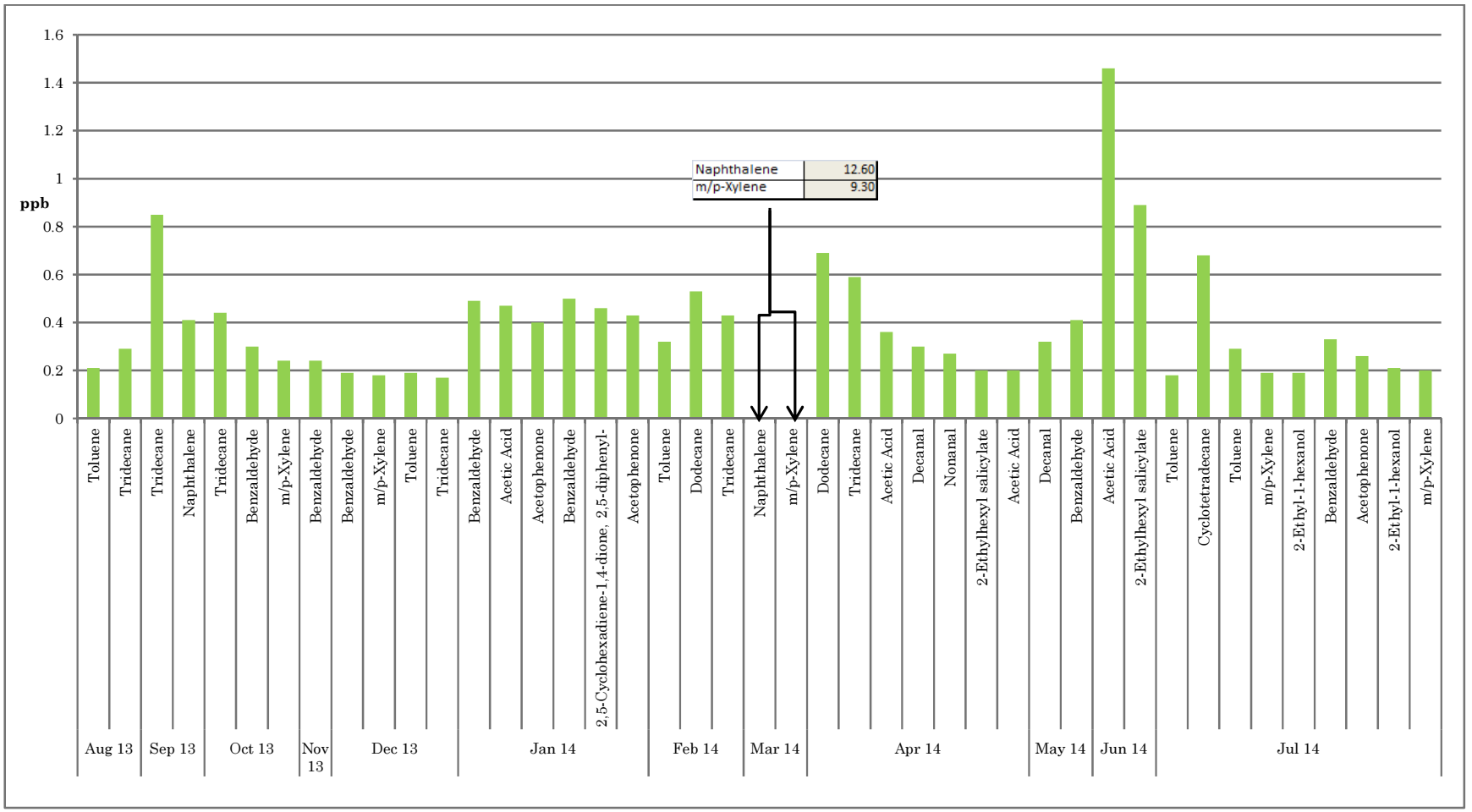
SO_2 concentrations (0.73 ppb) peaked in August 2013; the lowest detected concentrations were detected in September 2013 and October 2013 which were below the laboratory detectable limit of 0.03µg for S. No data was collected in January 2014 as the tubes were not present when officers went to retrieve them.

As observed in Graph 20, the highest NO_2 level of 2.87 ppb was detected in August 2013 and the lowest of 0.14 ppb in July 2014. The highest ozone concentration of 43.85 was observed during the month of December 2013 and the lowest of 17.71 ppb in October 2013.



Graph 20: NO_2 and O_3 concentrations detected at SPS, for the period August 2013 to July 2014.

As shown in graph 20, during the sampling period the majority of the VOCs detected ranged between 1.46 ppb and 0.17 ppb, however, the concentrations being detected in March 2014 were significantly higher, the highest of which was Napthalene with a concentration of 12.80 ppb. The lowest concentration of any top five VOC detected was that of 0.17 ppb of Tridecane in December 2013. Several compounds were detected during the analysis that fell outside of the laboratory flexible scope. Please refer to Appendix 1 for the full list of compounds detected.

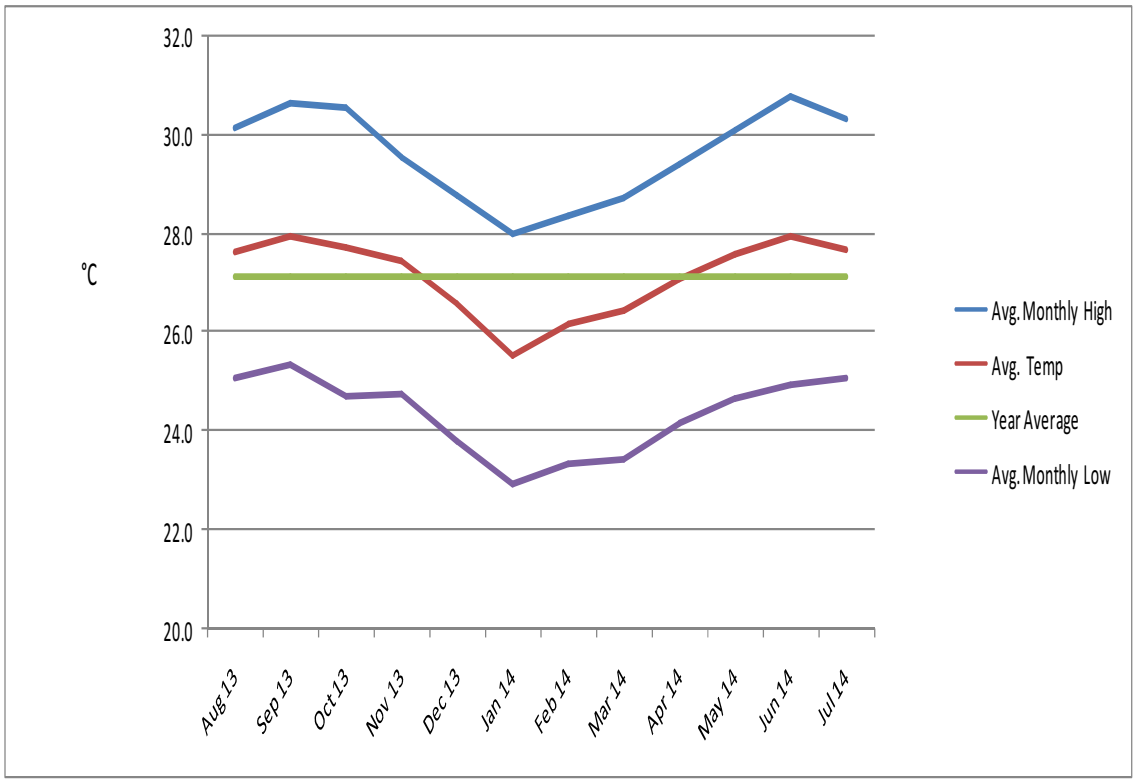


Graph 21: Top five VOC compounds detected at SS, Speightstown, St. Peter sampling location, during the study period August 2013 to July 2014. The compounds shown represent only those compounds covered in the laboratory accredited flexible scope, are not blank corrected and do not include those reactions that may be the result of reactions between O_3 and the TenaxTA sorbent.

4.8 Weather Data

Weather data was collected via Weather Underground[5] which cited the Coastal Zone Management Unit and independent weather stations as a source.

Graph 22 below, displays the average highest and average lowest temperatures, in addition to the average temperatures recorded during the monitoring period. Studies have demonstrated a link between temperature and ozone formation where temperatures above 26.7°C have been shown to increase ozone generation reactions.



Graph 22: Monthly Highs, Lows and Average Temperatures recorded during the period August 2013 to July 2014.

Graph 23, represents the average monthly wind speed recorded during the sampling period. According to the graph, the highest wind speed was recorded in June 2014.

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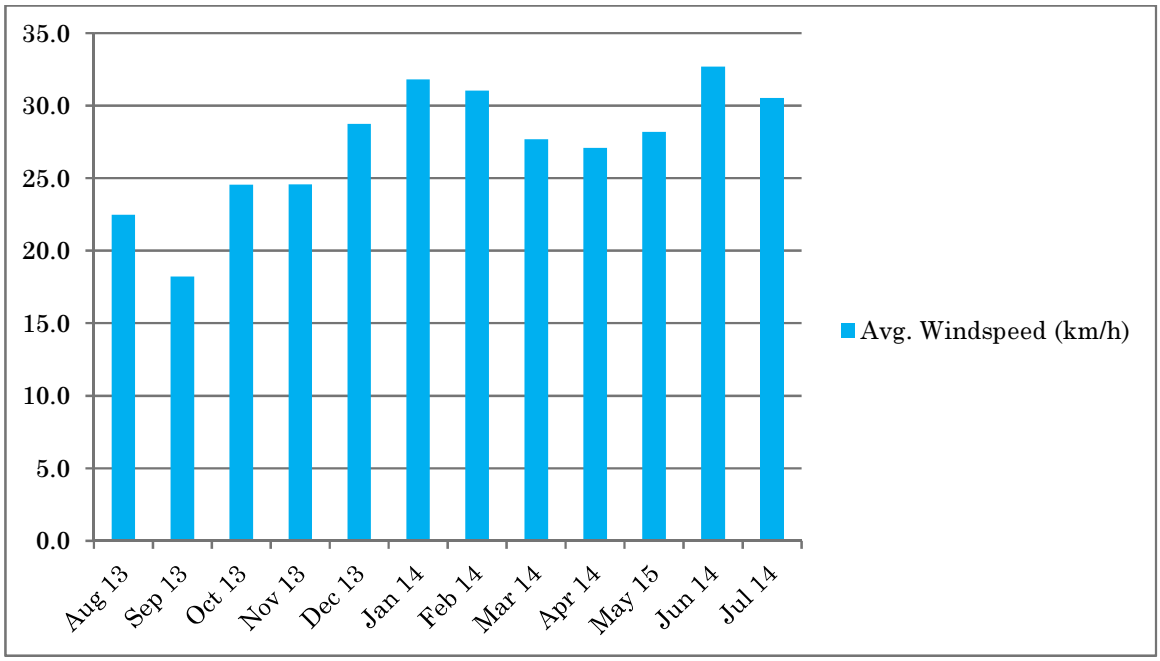
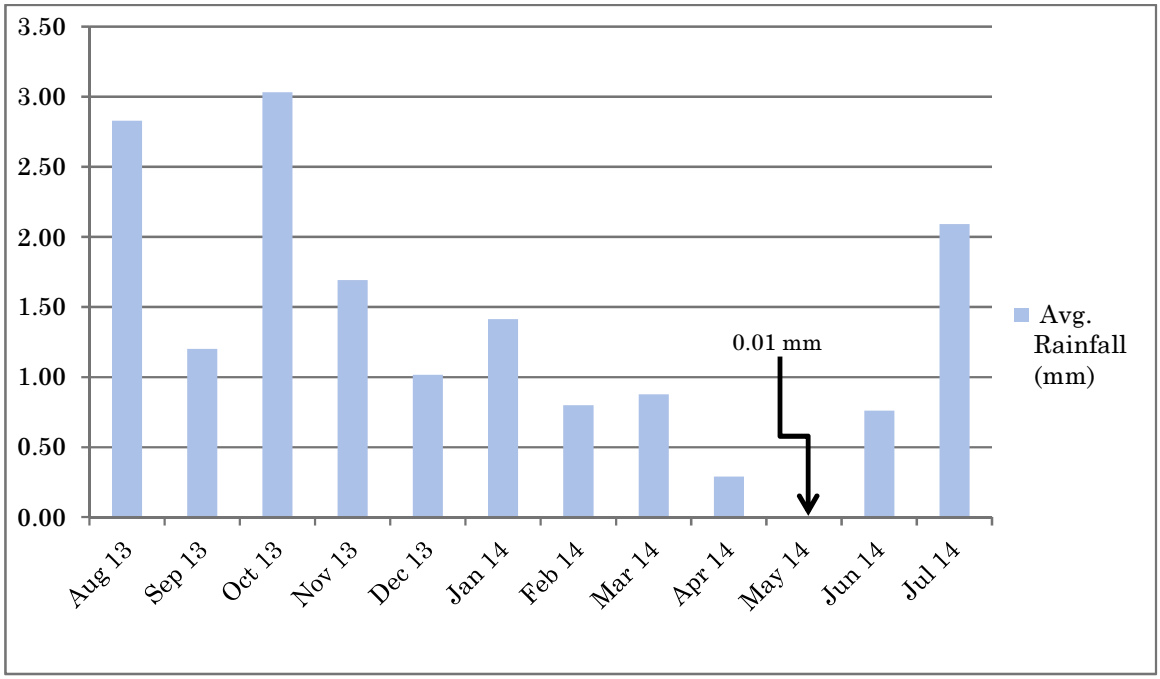
[5] Various. *Weather History at Grantley Adams International Airport*. Available: http://www.wunderground.com/history/airport/TBPB/2013/8/1/CustomHistory.html?dayend=31&monthend=7&yearend=2014&req_city=&req_state=&req_statename=&reqdb.zip=&reqdb.magic=&reqdb.wmo=. Last accessed Feb 20, 2015.

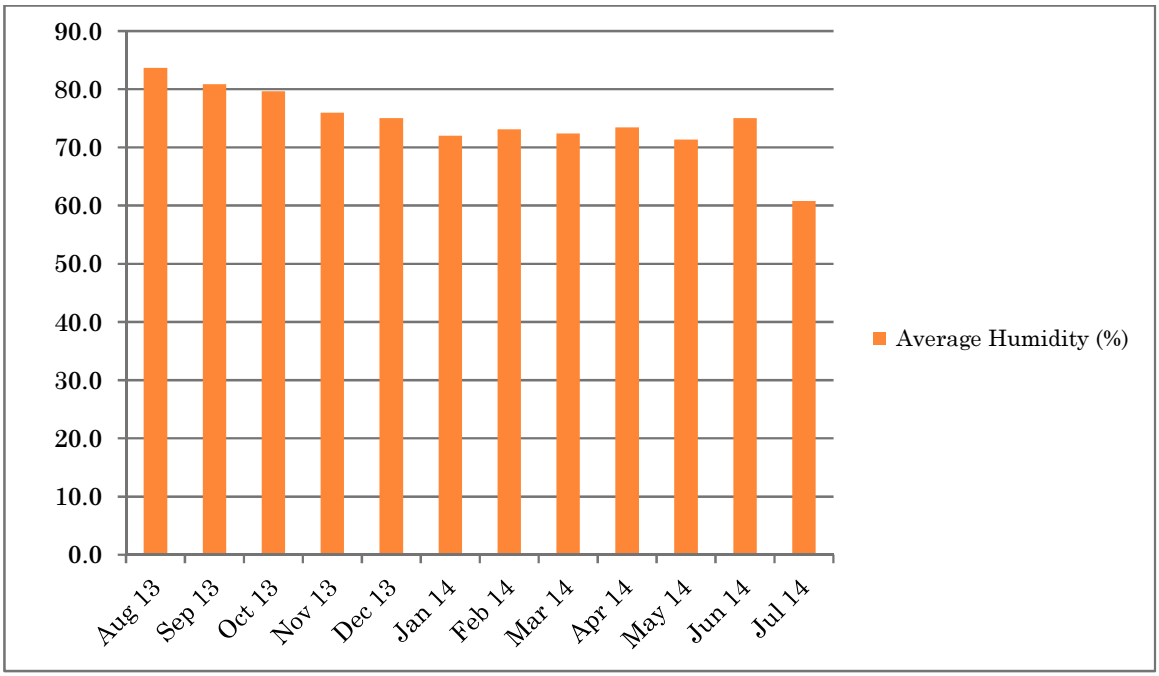


Graph 23: Average wind-speed (km/h) for the period sampled.

Graph 24, shows the average rainfall per month during the study period. According to the data, the highest levels of rainfall were recorded in October 2013 and the lowest in May 2014. Graph 25 shows the monthly average of the relative humidity during the study period.



Graph 24: Average monthly rainfall data collected during the period August 2013 to July 2014.

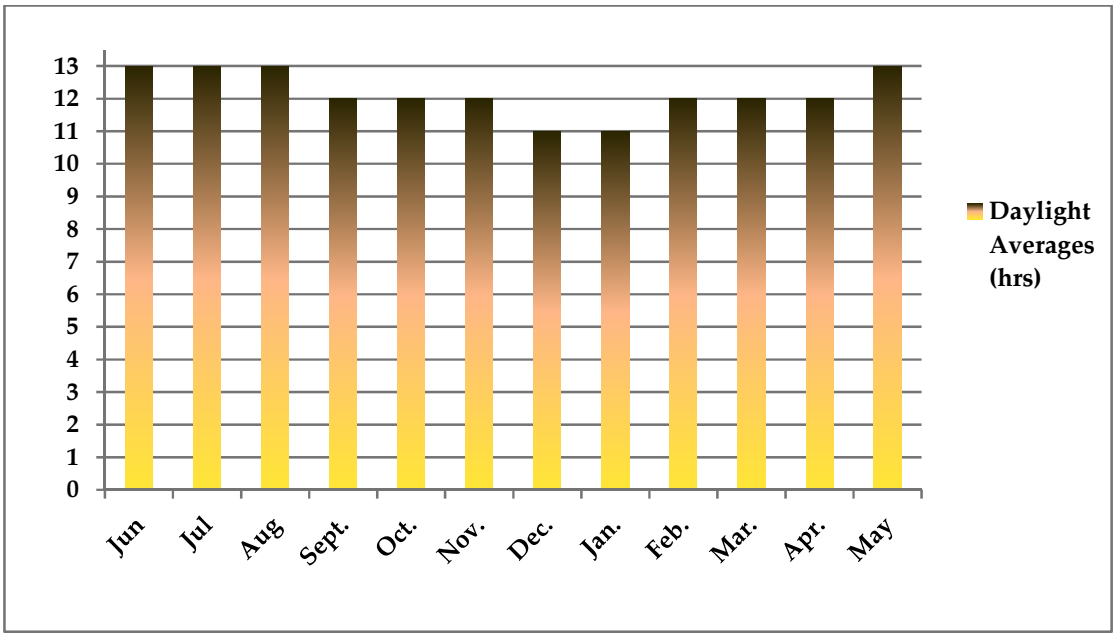


Graph 25: The average humidity recorded during the monitoring period of August 2013 to July 2014.

4.9 Daylight Hours

In addition to temperature, sunlight acts as catalyst for the generation of ozone along with the interactions of NO_2 and VOCs. Graph 26 below shows the average monthly daylight received by Barbados[6] throughout the year during the study period. The months with the lowest averages of daylight were December and January at 11 hours. A maximum of 13 hours are generally observed from May to August.

[6] http://www.barbados.climatemps.com/



Graph 26: Daylight averages for Barbados

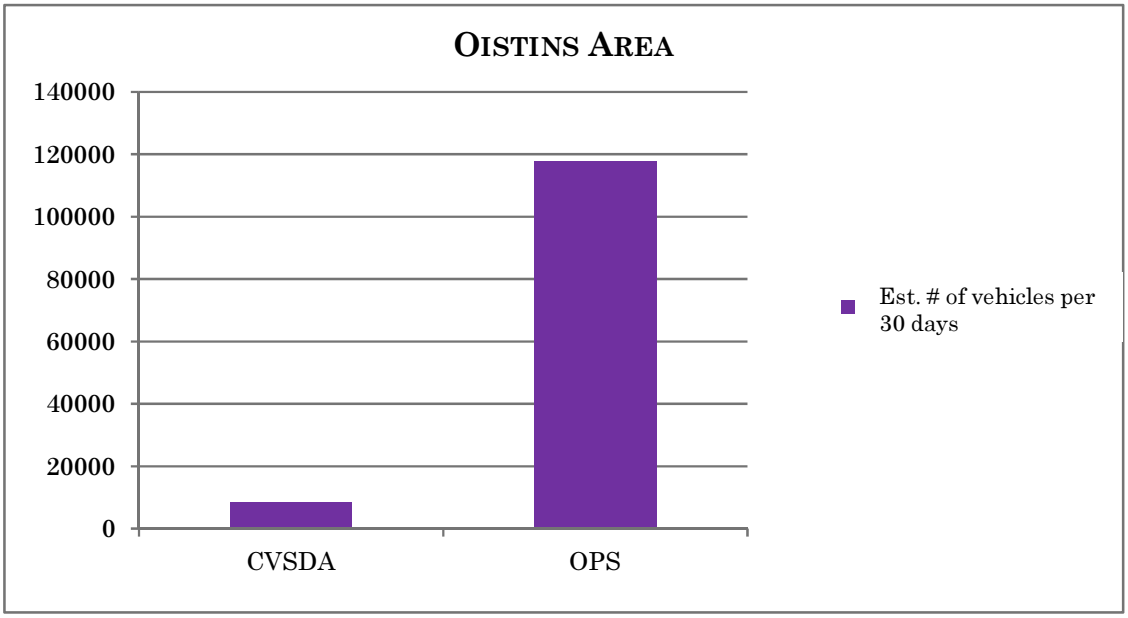
4.10 Ministry of Transport and Works Traffic Data

Using traffic data provided by the Ministry of Transport and Works through the use of traffic counters, an estimated 30 day average[7] of the number of vehicles utilizing the nearest busy road (in both directions) to the sampling points was calculated and the results are shown below in Graphs 27 and 28.

Based on the data it appears that in the case of Oistins, the nearest busy roadway was in the vicinity of OPS. When compared to CVSDA, the number of vehicles estimated per 30 days was less than 10% of the volume of OPS. No data

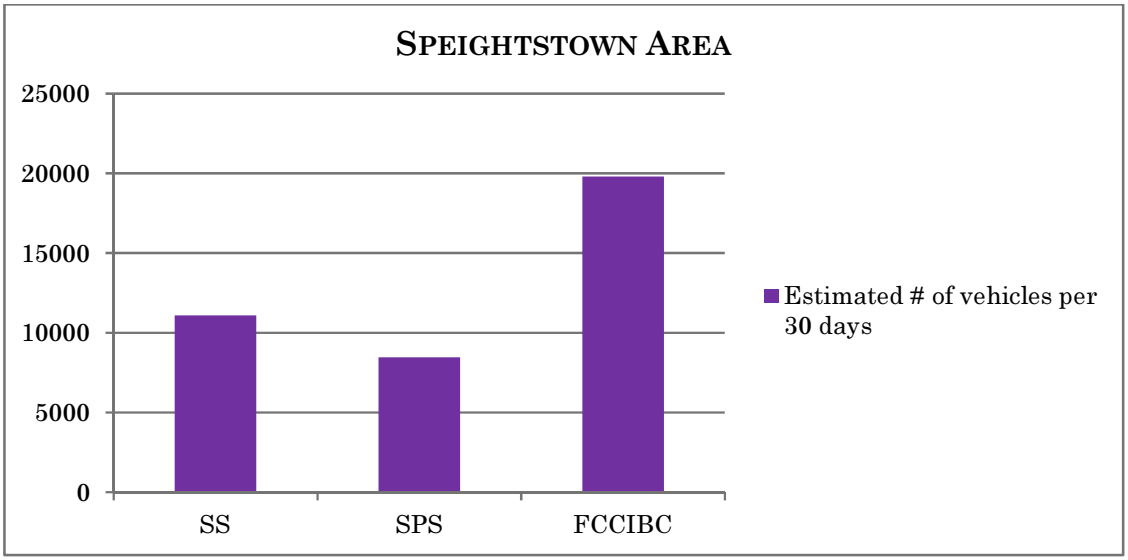
[7] Measurements were taken over 8 day periods. From this a single day estimate was calculated then multiplied by 30 to generate a 30 day average for each location.

was collected for VTTH as the location was located in a residential cul-de-sac.



Graph 27: Estimated number of vehicles per 30 days utilizing the busy roadway adjacent to the sampling points in Oistins, Christ Church.

As demonstrated in Graph 28 it appears that in the case of Speightstown, the nearest busy roadway was in the vicinity of FCCIBC. The traffic volume at SS and SPS were approximately 50% and 43% of the volume at FCCIBC respectively.



Graph 28: Estimated number of vehicles per 30 days utilizing the busy roadway adjacent to the sampling points in Speightstown, St. Peter.

5.0 DISCUSSION

The adopted WHO Ambient Air Quality Guidelines 2005 were developed using real time continuous sampling methodologies which are then used to formulate standards for both primary and secondary pollutants such as nitrogen dioxide (NO_2) and its derivatives, sulphur dioxide (SO_2) and its derivatives and ozone (O_3), due to the accuracy of the equipment and the rigid sampling methodologies. No standards have been derived from passive sampling methodologies. Consequently, the results obtained in this study cannot be compared to existing standards. However, it must be noted that passive studies trend lower but retain similar fluctuations over time compared to real time continuous monitoring studies. This enables a useful characterization of existing levels and changes based on activities within Oistins and Speightstown. Additionally, passive sampling results also represent chronic exposure to pollutants under investigation as they are composite samples and hence average concentrations over time.

Using information from the Barbados Statistical Service[8] there are approximately 1,203 residents in Oistins while 2,604 persons reside in Speightstown. These numbers do not take into account persons commuting to and from Oistins and Speightstown daily and persons living in the outlying areas. The impacts of exposure to the primary and secondary pollutants may vary according to an individual's health, tolerances and level of exposure. Sections 5.1 and 5.2 which follow, will address the areas with high and low concentrations, in addition to the potential impacts these persons may be exposed to on a daily basis based on the international guidelines.

5.1 Sulphur Oxides (SO_2)

5.1.1 Highs, Lows and Averages

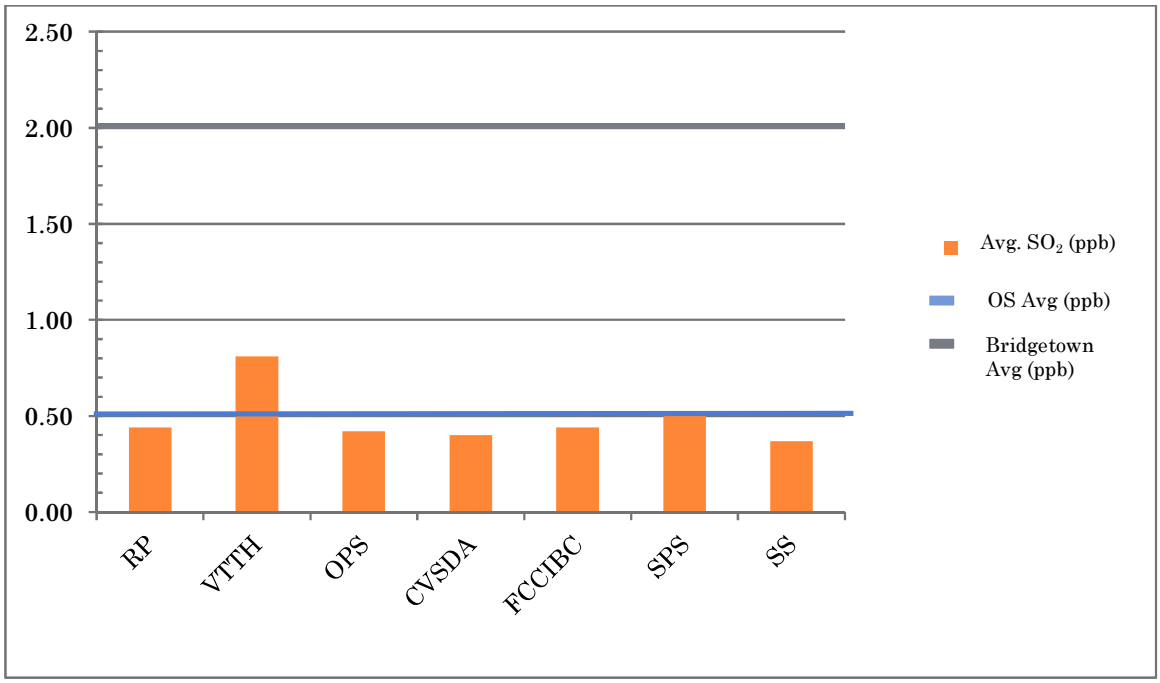
The highest recorded SO_2 level was 4.86 ppb, detected at VTTH in January 2013. This may be due to activity occurring at a nearby industrial park or activities occurring on the property, since the remainder of the readings were below 1ppb for the other monthis of the year.

During October 2013, the level of SO_2 for all locations was below the detectable limit of the laboratory analysis. The highest rainfall levels were

[8] Barbados Statistical Service, http://www.barstats.gov.bb/census/redatam-1/ Last accessed January 30th 2015.

recorded during this period of the study, which may have an impact upon SO_2 concentrations. However, it must be noted that other months recorded only slightly lower rainfall levels without the SO_2 levels dropping below detectable limits. Therefore, the low in October may be due to a combination of anthropogenic and natural factors.

Graph 29 below shows the average SO_2 levels at each location as well as the overall averages for the Bridgetown 2012 study and the overall averages for Oistins and Speightstown.

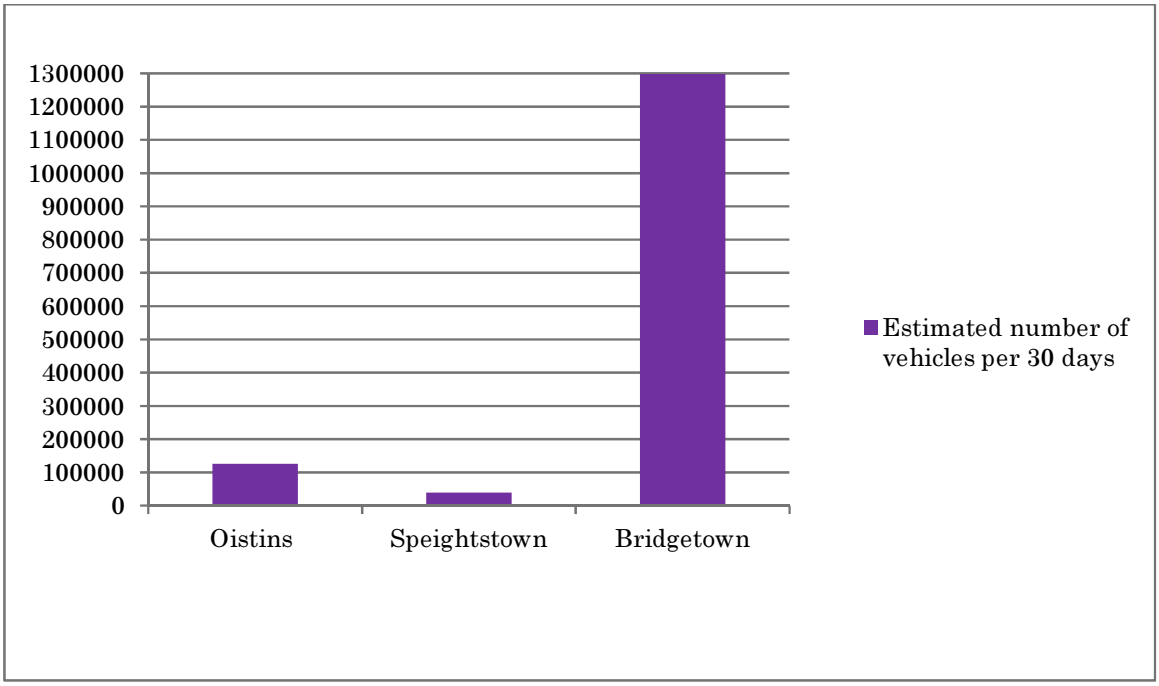


Graph 29: Average SO_2 levels for all locations, in addition to the average SO_2 levels for Bridgetown and total average for Oistins and Speightstown (OS)

When compared to the average SO_2 levels for the Bridgetown study (2.10 ppb), the average SO_2 combined average for both Oistins and Speightstown was approximately 0.5 ppb or 25% of the average Bridgetown SO_2 concentration.

6.1.2 Impacts on SO_2 Levels

SO_2 levels in Oistins and Speightstown may be impacted by several factors such as the introduction of low sulphur diesel to consumers in 2013, the different classes (buses, trucks, cars and motorcycles), different types and volume of activities such as kitchens and industrial processes and the noticeably different traffic volumes for Oistins and Speightstown in comparison to Bridgetown. Graph 30 below highlights the difference in traffic volume over a 30 day period between the different urban centres.



Graph 30: Estimated number of vehicles traversing Bridgetown, Oistins and Speightstown over a 30 day period.

As depicted in Graph 30, traffic in Bridgetown over a 30 day period was thirty (30) times higher compared to that in Speightstown during a 30 day period. In the case of Oistins, traffic volumes were ten (10%) percent of the volume experienced by Bridgetown over a 30 day period. It must be noted that the dates of traffic monitoring conducted for the Oistins and Speightstown study were dissimilar, when compared to the Bridgetown study.

The land use characteristics of Oistins and Speightstown (with the exception of FCCIBC) differed from Bridgetown; as the sampling locations in Oistins and Speightstown were not populated by as many tall buildings in close proximity to each other. As a result dilution via wind action was far more likely to occur. In the case of VTTH, where the highest SO_2 level was recorded in January 2014; the levels in the remaining months of the study were less than 1 ppb. However, if this outlying value were removed, the average SO_2 value would be similar to the average value calculated for Ragged Point (RP).

The residence time for SO_2 in the atmosphere can vary over several days depending on atmospheric conditions. For example SO_2 levels may be affected by precipitation and deposition of solid particulates on vegetation, soil and buildings. Additionally, high wind-speed can also disperse SO_2 over a greater distance and reduce concentrations.

Another potential source of sulphates may be the trans-boundary movement of sulphates attached to sea salts. Due to wind action, sulphates may be transported onshore from sources outside of Barbados.

Barbados is approximately 34 km x 23 km at its widest points and the average wind-speed for the period was between 18 and 32 km/h (Graph 23) in a north easterly direction. It may therefore be possible for contaminants to be transported from other locations or out to sea within a matter of hours if sufficiently high wind-speeds were maintained. However, it was unknown if the average wind-speed persisted at the sample locations.

5.1.3 Comparison to Other Passive Sampling Studies and Continuous Monitoring Studies

According to research[9] conducted by the World Meteorological Organization Global Atmosphere Watch, 1997 (WMO GAW) global annual averaged SO_2 values utilizing passive sampling methodologies in South Korea, Thailand and Malaysia did not exceed 3 ppb; which was higher than the averages for either; Bridgetown, Oistins or Speightstown.

Based on WHO documentation[10], the annual mean concentrations in urban areas were in the range of 7–21 ppb while daily means seldom exceeded 47.7 ppb. It appears that the data for the sites sampled in Barbados is below that average. However, it must be noted that WHO data was collected using real time continuous sampling methodologies and not passive sampling techniques. As was mentioned earlier, these results follow the trend of passive samplers' results trending lower than values obtained via continuous monitoring.

5.1.4 Impacts of SO_2 Exposure based on International Guidelines and Standards

In the case of SO_2,the the World Health Organization (WHO) guidelines are represented in terms of 24 hour exposures and 10 minute means. The USEPA National Ambient Air Quality Standards (NAAQS) are represented by 1 hour primary and 3 hour secondary standards. Table 12 below highlights the respective guideline and standards used by the WHO and the USEPA

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[9] World Meteorological Organization -Global Atmospheric Watch. (1997). Report on passive samplers for atmospheric chemistry measurements and their role in GAW. -. WMO TD No. 829, (122), 16.

[10] World Health Organization. (2000). *Air Quality Guidelines Chapter 2nd Ed. 7.4 Sulphur dioxide.* Available: http://www.euro.who.int/__data/assets/pdf_file/0020/123086/AQG2ndEd_7_4Sulfurdioxide.pdf. Last accessed December 5, 2013.

Table 4 Exposure limits for SO_2 based on WHO Guidelines and USEPA Standard

PRIMARY/SECONDARY	CONCENTRATION	TIME	AGENCY
Primary	20 µg/m^3 (7.63 ppb)	24-hour mean	WHO
	500 µg/m^3 (190.84 ppb)	10 minute mean	WHO
Primary	75 ppb (196.5 µg/m^3)	1 hour	USEPA
Secondary	500 ppb (1310 µg/m^3)	3 hour	USEPA

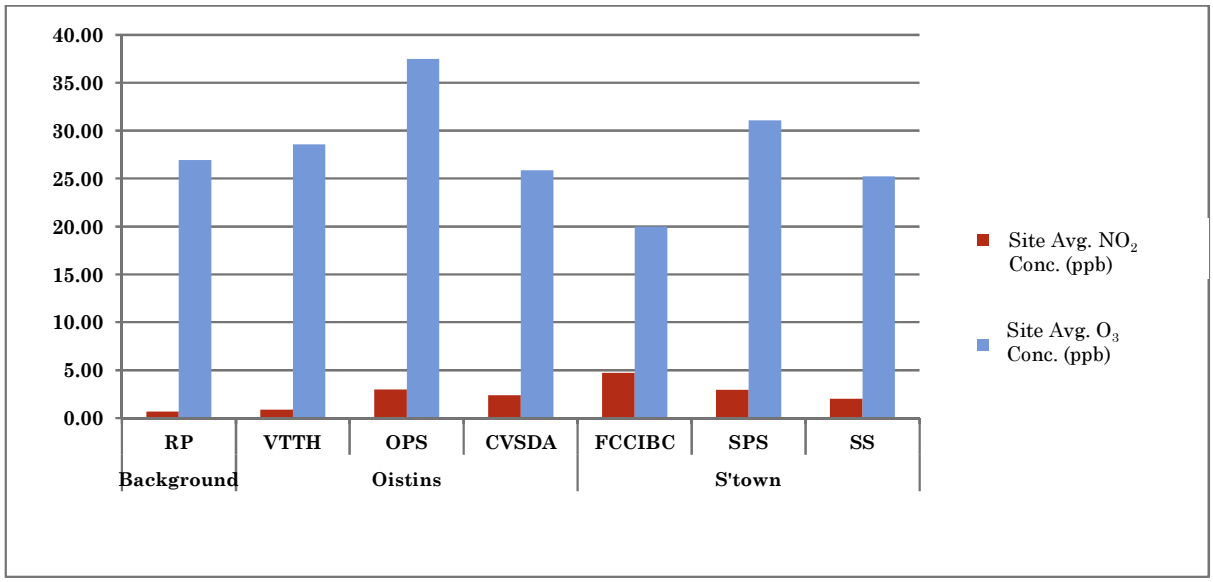
The WHO guideline indicates that the SO_2 concentration of 500µg/m^3 should not be exceeded for greater than 10 minutes. According to the WHO, studies have revealed that a proportion of asthmatics experience changes in pulmonary function and respiratory symptoms after periods of exposure to SO_2 in less than10 minutes.

The 24-hour guideline for SO_2, has been revised downwards from 125 µg/m^3 (47.71 ppb) to 20µg/m^3 (7.63 ppb) based on the belief that although the causality of the effects of low concentrations of SO_2 is still uncertain, a reduction in SO_2 was likely to decrease exposure to co-pollutants.

5.2. Nitrogen Dioxide (NO_2) and Ozone (O_3)

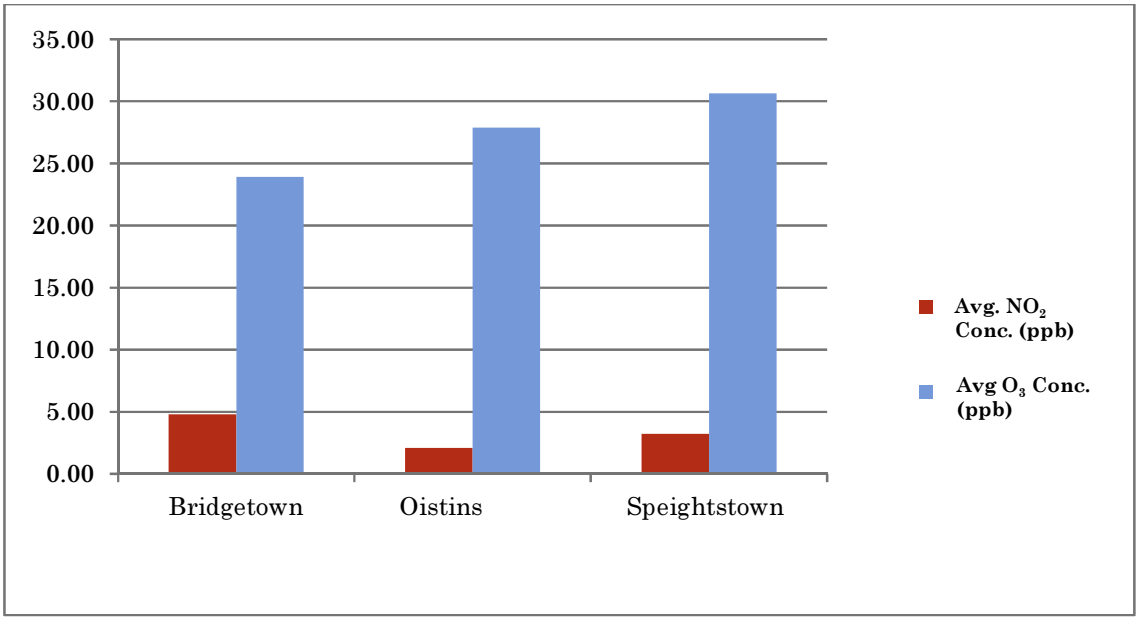
5.2.1 Highs and Lows

As shown in Graph 31, the highest average O_3 levels were observed at both police station locations OPS and SPS. Additionally, the lowest O_3 concentration was detected at FCCIBC which incidentally registered the highest NO_2 concentration.



Graph 31: The average NO_2 and O_3 concentrations per location.

With respect to NO_2, the highest average detected was 4.72 ppb at FCCIBC. The lowest average NO_2 concentration (0.69 ppb) was detected at the background location Ragged Point (RP). This may be due to the differences in the vehicular traffic volumes, where FCCIBC registered higher traffic volumes in comparison to RP which based on observations was not a frequently visited location and therefore should have a much smaller traffic volume.



Graph 32: Comparison of Urban Centre Average NO_2 and O_3 concentrations from Bridgetown in 2012-2013 and for Oistins and Speightstown 2013-2014

Based on the results in Graph 32, Bridgetown displayed a higher average concentration of NO_2 than both Speightstown and Oistins due to the higher traffic volume. Surprisingly, despite Oistins exhibiting greater traffic volume than Speightstown, Oistins showed lower concentrations for both NO_2 and O_3 when compared to Speightstown. This may be due to the Oistins locations being more open and therefore being more influenced by the sea breezes which may have resulted in the dilution and dispersion of pollutants via wind action.

In the case of Speightstown, higher pollutant concentrations may be due to the following factors; the high traffic volume at FCCIBC coupled with the presence of a narrow roadway and tall buildings on either side of the sample site at FCCIBC. Additionally the close proximity of the Speightstown Bus Terminal to the SPS location could potentially impact upon NO_2 and O_3 levels due to increased numbers of diesel vehicles located upwind of the sampling site.

Despite Bridgetown having higher traffic volumes, higher O_3 levels were detected in both Oistins and Speightstown, with the highest level detected in Speightstown. Therefore, the traffic volume may not be a major factor influencing O_3 concentration. A combination of NO_2, VOC concentrations and weather conditions may have a greater impact on O_3 concentration.

5.2.2 VOC Trends

The vast majority of the top 5 VOCs detected exhibited concentrations below 1 ppb. However, there were several instances where individual VOC compounds exhibited concentrations between 1 and 2.1 ppb. In March 2014, the VOC levels for each location ranged between a minimum of 12.6 ppb at Sand Street to a maximum of 168.70 ppb at SPS. No explanation for the dramatic increase in VOC levels across all sampling locations during March 2014 could be determined as it may have been the result of changes in weather or it may have been a problem with the sample media or an error during analysis .

5.2.3 Impacts of NO_2 and O_3 based on International Standards

The following table provides the WHO guidelines and USEPA standards for NO_2 for both annual and one hour rates.

Table 5: Primary and secondary NO_2 guidelines and standard for the WHO and USPEA

PRIMARY/SECONDARY	CONCENTRATION	TIME	AGENCY
Primary	40 µg/m^3 (21.3 ppb)	Annual	WHO
	200 µg/m^3 (106.4 ppb)	1 hr	WHO
Primary & Secondary	53 ppb	Annual	USEPA
Primary	100 ppb	1 hour	USEPA

In the case of the WHO guidelines[11] the current air quality guidelines for NO_2 have been set at the level for the following reasons:

1. Epidemiological studies have shown that symptoms of bronchitis in asthmatic children increase in association with long-term exposure to NO_2.
2. Reduced lung function is also linked to NO_2 at concentrations currently measured (or observed) in cities of Europe and North America.
3. Short term exposure to concentrations exceeding 200µg/m^3, may trigger significant inflammation of the airways.
4. NO_2 is the main source of nitrate aerosols, which form an important fraction of $PM_{2.5}$. In the presence of ultraviolet light, NO_2 is the main source of ozone.

5.3 Relationship between Nitrogen Oxides (NO_X), VOCs, Weather and Ozone

5.3.1 Mechanics of Ozone Formation

Ozone at ground level is formed through a series of complex photochemical reactions among NO_X and volatile organic compounds (VOCs) in the presence of heat and sunlight. Major sources of ground level ozone are the result of photochemical processes and the movement of stratospheric ozone into the lower atmosphere.

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[11]World Health Organization, Europe. (2005). *Air Quality Guidelines 2005.*Available: http://www.euro.who.int/__data/assets/pdf_file/0005/78638/E90038.pdf. Last accessed January 15, 2014

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The formation of ground level ozone is dependent on the intensity of solar radiation and the sensitive ratio of NO_X to VOCs usually in the range of 4: 1 to 10:1. Ozone is a photochemical pollutant and forms roughly 2-3 hours after initial NO_X and VOCs emissions. Ozone is only formed during daylight hours when sunlight is intense and air temperature is warm, but is destroyed at night due to the NO_X and ozone combining to form nitrogen monoxide (NO) and oxygen. This conversion process continues until either the NO or ozone is consumed in the process.

The formation of ozone in rural sites or areas with reduced sources of NO_X is governed by the following;

- the decreasing intensity of the regional ozone pollution episodes, tending to reduce the ozone metric[12]
- the decreasing depletion of ozone by traffic generated NO_X emissions, which increases the metric

Therefore, rural concentrations may be a combination of background ozone and that produced by more national activities (probably up to the regional scale). When precursor emissions such as NOx and VOCs are diminished, there is a decrease in rural ozone, though not necessarily in proportion to the decrease in precursors.

In urban areas or areas with a number of either point or mobile NO_X and VOC sources, ozone levels are expected to be lower than in rural areas due to depletion of any ozone formed by its reaction with NO which is produced from NO_X sources. Therefore, it is expected that a reduction in VOC and NO_X emissions may result in an initial ozone increase. However, provided there was a drastic reduction in VOCs and NO_X levels, ozone concentrations should diminish.

The relative balance of VOCs and NO_X at a particular location may determine whether the NO_X behaves as a net ozone generator or a net ozone inhibitor. When the VOC/NO_x ratio in the ambient air is low, NO_x concentrations are higher relative to VOC concentrations. As a result NO_x tends to inhibit ozone formation and the resultant ozone formation is called "VOC limited". When the VOC/ NO_x ratio is high, the VOC concentration is higher relative to the NO_X

[12] The metric is a measure of the number of 'good' air quality days (as defined by EPA's Air Quality
Index - AQI) in a quarter. The AQI is calculated by EPA as a measure of local air quality and its effect on human health. The higher the AQI value the greater the level of air pollution and the greater the health concern. 'Good' air quality corresponds to an AQI of 50 or less (on a scale of 0-500) and poses little or no risk of adverse health effects. An ozone target of 75% 'Good' days in a quarter was selected to evaluate local air quality conditions.

concentration and NO_x tends to generate ozone. In this instance, ozone formation is considered as "NO_x limited".

The VOC/NO_x ratio can differ substantially by location and time-of-day between location specific microclimates. Furthermore, the VOC/ NO_x ratio measured near the ground might not represent the ratio that prevails in the air above the breathing zone, where most of the tropospheric ozone is generated.

UV radiation derived from sunlight exposure may not be a limiting factor year round in the formation of ozone as the yearly daylight hours range between 11 and 13 hours of sunlight daily. Temperatures over 26.7°C[13] may enhance the rate of the reactions associated with ozone formation and increase the rate of evaporative emissions of VOCs. However, the amount of cloud cover present may reduce ozone production. When cloud cover is high it will prevent the penetration of excessive UV radiation reducing the potential of photochemical reactions occurring and generating ozone.

Additionally, low wind speeds allow for the accumulation of precursors of ozone formation (VOCs and NO_x) and the subsequent formation of ozone. Higher wind speeds tend to dilute or disperse emissions. However, they can still transport ozone from other locations.

Dry weather is generally favourable to ozone generation as low precipitation allows ozone to remain in the air. Additionally, the occurrence of scattered showers may not produce enough precipitation to completely eliminate ozone, but heavier prolonged rainfall may be adequate in cleansing ozone from the atmosphere. The presence of other weather phenomena such as weather fronts and tropical waves may impact upon ozone production due to their potential to affect cloud cover, precipitation, air mass variations and temperature.

5.3.2 Observed NO_X, VOC and O_3 interactions

The data collected included NO_2, O_3 and Top 5 VOCs. Unfortunately, no total VOC data was collected and as a result it was difficult to determine the exact relationship between VOC levels and NO_2.

Although areas with higher traffic volumes showed higher NO_2 concentrations, the reverse trend was observed when compared to O_3. For instance in Graph 28, FCCIBC registered the highest traffic volume per 30 days,

[13] West Michigan Clean Air Coalition. (2009). *Factors that Contribute to the Formation of Ozone and Particulate Matter*. Available: http://www.wmcac.org/airquality/factors.html. Last accessed September 5, 2013

but when O_3 concentrations were compared to those at SPS and SS which showed lower traffic volumes, the O_3 levels were lower at FCCIBC, indicating that O_3 production may be limited by NO_2 concentration. However, without total VOC concentrations available, it may be difficult to establish a more comprehensive relationship between NO_2 and VOC concentrations.

Based on the available meteorological data, the average temperature for the year was approximately 27.2°C, compared to 27.3 in 2012-2013. Both average temperatures were above the optimal temperature of 26°C for ozone generation. No data for the individual sites was available and therefore localized variations may have occurred. Additionally, the monthly averages and the year average (27.3km/hr) for wind speed exceeded the 16 km/h maximum allowable wind speed for ozone propagation. Wind speeds above 16 km/hr do not allow for the necessary accumulation of precursors of ozone formation (VOCs and NOx) and as a result dilute or disperse the subsequent formation of ozone conversely; O_3 may be transported from their formation points to other locations.

6.0 Study Limitations

The study suffered from similar limitations of the Bridgetown 2012-2013 study as the methodology did not allow for any real time correlation with respect to meteorological parameters, real time traffic counts and an inventory of all industrial operations and their emissions in proximity to the sampling locations, ongoing activities and weather conditions specific to the sample sites. As a result, it was difficult to accurately assess the relationships observed between SO_2, NO_2, ozone and VOC levels and other factors such as weather conditions, mobile and stationary sources.

There were some challenges associated with the use of Top Five VOC as an analytical tool in that it did not provide a total of all VOCs detected and instead reflected the top five VOCs. As a result, no relationship could be established between VOCs and NO_2 and the resultant O_3 concentrations. Additionally, the Top Five (5) VOCs varied considerably between the sampling locations in terms of concentrations and the individual VOCs detected.

7.0 CONCLUSION

The objective of the assessment was to characterize the air quality and to determine any possible trends in primary and secondary pollutant levels in and around different areas of Oistins and Speightstown was achieved. The passive sampling methodology utilized allowed for the determination of the average concentrations of primary and secondary pollutants as well as VOCs in Oistins and Speightstown. The release of the various organic and inorganic compounds may be the result of the emissions from restaurants, hair and nail salons, industrial activities and transportation.

As previously mentioned, although the methodology utilized in the passive sampling is less costly than real time sampling, it is not comparable to the adopted WHO methodologies and the associated standards. The results observed may be the result of existing economic activities, along with the introduction of low sulphur diesel to Barbadian consumers.

In light of the fact that there may be changes in terms of economic activity and general human activities over time, further assessment should be conducted using continuous sampling, which would allow comparison to the WHO standards for the primary and secondary pollutants.

8.0 RECOMMENDATIONS

8.1 Real-Time/Continuous Monitoring

The use of real time continuous monitoring of primary and secondary pollutants would be beneficial as the existing ambient air quality could be compared to an established guideline such as the WHO Air Quality Guidelines 2005. This would allow for the assessment of the accuracy of the passive samplers in comparison to the real time samplers.

Additionally, real time data (pollutant, traffic and meteorological) will allow for the recognition of spikes in levels, instead of an average which provides an incomplete view of the accumulation/dispersion and interaction of pollutants and the effects throughout the course of the day.

In totality, it will allow for the determination of whether pollution was emanating from mobile (vehicle or trans-boundary transport) or stationary sources, setting emission limits when comparing to establish standards, setting attainment or non attainment goals for urban centres and determining the impact of future development on the human health and environment.

8.2 Total VOCs

The analysis of the VOC samples taken was represented as the top five VOCs. This would have provided insight as to which VOCs were most popular and most concentrated at each sampling location. Throughout the analysis it was observed that the type of VOCs along with their concentrations varied from month to month at each site and therefore no distinct pattern could be detected. VOC trends in future monitoring plans would be better displayed as Total VOCs (TVOCs) and it would allow for an investigation into the relationship between NO_2 and TVOCs in ozone formation.

9.0 REFERENCES

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APPENDIX I

TOP 5 VOCS

LABORATORY ANALYSIS REPORT

REPORT NUMBER	**Y2862R**
CUSTOMER	**Ministry of Environment, Water Resources Management & Drainage**
GRADKO LAB REFERENCE	**PE6H1528-1537**
DATE SAMPLES RECEIVED	**02.10.13**
DESPATCH REF.NUMBER	**SOR012668**
JOB NUMBER	**9892**
BOOKING IN REF.	**Y2862**

IDENTIFICATION AND ESTIMATION (SEMI-QUANTITATIVE ANALYSIS) FOR TOP 5 VOC ON TENAX DIFFUSION TUBES BY GC/MS
Analysis has been carried out in accordance with in-house method GLM 13

Tube Number	**GRA 04847**
Sample Location	**Ragged Point**
Exposure Time (mins)	**38821**

TOP 5 VOC	**ng on tube**	**ppb**
Styrene	39.08	0.50
1-Hexanol, 2-ethyl-	18.22	0.23
Tridecane	16.42	0.21
Benzaldehyde** +	16.14	0.21
Acetophenone** +	12.70	0.16

Tube Number	**GRA 11704**
Sample Location	**Thornbury Hill**
Exposure Time (mins)	**38812**

TOP 5 VOC	**ng on tube**	**ppb in**
Cylcohexanone +	14.27	0.18
Cyclohexane, isothiocyanato +	11.85	0.15
Toluene	11.63	0.15
Cyclohexane, isocyanato +	11.38	0.15
Tridecane	11.16	0.14

Tube Number	**GRA 11993**
Sample Location	**Thornbury Hill**
Exposure Time (mins)	**38812**

TOP 5 VOC	**ng on tube**	**ppb in**
Tridecane	11.85	0.15
Toluene	9.27	0.12
1-Hexanol, 2-ethyl-	8.38	0.11
Benzene	6.25	0.08
Decane	6.21	0.08

Tube Number	**GRA 09731**
Sample Location	**Oistins Police**
Exposure Time (mins)	**38806**

TOP 5 VOC	**ng on tube**	**ppb in**
Toluene	30.35	0.39
m/p-Xylene	30.16	0.39
Benzene	12.82	0.17
Benzene, 1,2,4-trimethyl-	12.81	0.17
o-Xylene	12.42	0.16

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Tube Number	**GRA 09619**
Sample Location	**Cane Vale S.D.A. Church**
Exposure Time (mins)	**38806**

TOP 5 VOC	**ng on tube**	**ppb in**
Toluene	26.46	0.34
m/p-Xylene	26.36	0.34
Decanal** +	20.83	0.27
Pentadecane	13.97	0.18
Benzene, 1,2,4-trimethyl-	13.15	0.17

Tube Number	**GRA 04578**
Sample Location	**CIBC Speightstown**
Exposure Time (mins)	**38919**

TOP 5 VOC	**ng on tube**	**ppb in**
Toluene	63.25	0.81
m/p-Xylene	59.76	0.77
Tetradecane	25.62	0.33
Pentadecane	23.71	0.30
o-Xylene	23.47	0.30

Tube Number	**GRA 09650**
Sample Location	**CIBC Speightstown**
Exposure Time (mins)	**38919**

TOP 5 VOC	**ng on tube**	**ppb in**
m/p-Xylene	75.38	0.97
Toluene	73.55	0.94
Nonanal** +	57.97	0.74
Tridecane	32.65	0.42
o-Xylene	30.30	0.39

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Tube Number	**GRA 09468**
Sample Location	**Speightstown Police**
Exposure Time (mins)	**38903**

TOP 5 VOC	**ng on tube**	**ppb in air***
Cyclohexane, isothiocyanato +	40.38	0.52
Tridecane	25.21	0.32
Nonanal** +	20.88	0.27
m/p-Xylene	18.71	0.24
Toluene	18.39	0.24

Tube Number	**GRA 03040**
Sample Location	**Geed**
Exposure Time (mins)	**38905**

TOP 5 VOC	**ng on tube**	**ppb in air***
Cyclohexane, isocyanato +	33.57	0.43
Nonanal** +	28.36	0.36
Tridecane	22.74	0.29
Cyclohexane, isothiocyanato +	19.19	0.25
Toluene	16.17	0.21

Tube Number	**GRA 11928**
Sample Location	**Blank**

TOP 5 VOC	**ng on tube**
Tetradecane	<5
Benzene	<5
Pentadecane	<5
Hexadecane	<5
Heptane, 2,2,4,6,6-pentamethyl +	<5

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Comments:

Results are not blank I

+ These compounds are not covered by our UKAS accredited flexible scope.

****Compounds may be an artifact due to reaction of ozone with the Tenax**

Identification and estimation results for ng on tube are calculated using toluene standards.

Tubes are outside the recommended shelf-life.

		Date of Analysis	**14.10.13**
Analysts Name	**G. Aikman**	**Date of Report**	**15.10.13**

LABORATORY ANALYSIS REPORT

REPORT NUMBER	**Y3036R**
CUSTOMER	**Ministry of Environment, Water Resources Management & Drainage**
GRADKO LAB REFERENCE	**GMSH1625-1635**
DESPATCH NOTE No.	**SOR012668**
JOB REFERENCE	**9832**
DATE SAMPLES RECEIVED	**24.10.13**
BOOKING IN REF.	**Y3036**

IDENTIFICATION AND ESTIMATION (SEMI-QUANTITATIVE ANALYSIS) OF TOP 5 VOC ON TENAX DIFFUSION TUBES BY GC/MS
Analysis has been carried out in accordance with in-house method GLM 13

Tube Number	**GRA 08820**
Exposure Time(mins)	**43176**
Sample ID	**Ragged Point**

Top 5 VOC	**ng on tube**	**ppb in air***
Tridecane	31.51	0.36
Cyclohexane, isothiocyanato- **+**	20.22	0.23
Nonanal** **+**	19.13	0.22
Naphthalene	17.52	0.20
Dodecane	16.49	0.19

Tube Number	**GRA 09328**
Exposure Time(mins)	**43170**
Sample ID	**Velda Thomas**

Top 5 VOC	**ng on tube**	**ppb in air***
Diethyl Phthalate **+**	116.34	1.35
Acetone **+**	70.91	0.82
Pentadecane	53.09	0.61
Tridecane	47.97	0.56
Heptadecane	34.57	0.40

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Tube Number	**GRA 09337**
Exposure Time(mins)	**43170**
Sample ID	**Oistins Police**

Top 5 VOC	**ng on tube**	**ppb in air***
Diethyl Phthalate **+**	69.77	0.81
Tube Number	40.86	0.47
Toluene	38.55	0.45
Naphthalene	37.11	0.43
Tridecane	34.25	0.40

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Tube Number	**GRA 02049**
Exposure Time(mins)	**43092**
Sample ID	**Speightstown Police**

Top 5 VOC	**ng on tube**	**ppb in air***
Tridecane	53.45	0.62
Nonanal** +	29.91	0.35
m/p-Xylene	28.93	0.34
Benzaldehyde**	26.19	0.30
Toluene	23.20	0.27

Tube Number	**GRA 07935**
Exposure Time(mins)	**43080**
Sample ID	**Geed Sand Street**

Top 5 VOC	**ng on tube**	**ppb in air***
1,2-Benzenedicarboxylic acid, diisooctyl ester +	325.08	3.77
Diethyl Phthalate +	85.18	0.99
Tridecane	73.59	0.85
Nonanal** +	52.01	0.60
Naphthalene	35.38	0.41

Tube Number	**GRA 06200**
Sample ID	**BLANK**

Top 5 VOC	**ng on tube**
Diethyl Phthalate +	61.44
Decanal** +	28.38
Nonanal** +	20.69
Isopropyl Myristate +	13.89
Benzaldehyde**	13.19

Tube Number	**GRA 06926**
Sample ID	**Unlabelled**

Top 5 VOC	**ng on tube**
1,2-Benzenedicarboxylic acid, diisooctyl ester +	587.50
Nonanal** +	131.84
Decanal** +	122.35
Isopropyl Myristate +	45.93
Benzaldehyde**	32.49

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Comment: Results are not Blank corrected.
Tubes are outside the recommended shelf-life.
****Compounds may be an artifact due to reaction of ozone with the Tenax sorbent.**
Identification and estimation results for ng on tube are calculated by reference to toluene and toluene-d8 Internal standard.
[+] These compounds are not covered by our UKAS accredited flexible scope.
Two extra tubes received, but have not been analysed.Tube numbers GRA 09992 and GRA 07936

		Date of Analysis	**31.10.13**
Analysts Name	**Mariella Angelova**	**Date of Report**	**11.11.13**