A REVIEW OF EMISSIONS OF VOLATILE ORGANIC COMPOUNDS FROM INDUSTRIAL PROCESSES IN THE KING'S LYNN AREA

Work Undertaken

by

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Executive Summary

EMC Environment Engineering Ltd (EMC) was commissioned by the Environmental Health Department of King's Lynn BC as an action arising from the Air Quality sub-group to undertake a desktop study of air quality in the King's Lynn area. There is concern within the local community living close to the North Lynn industrial estates that pollutant releases, particularly volatile organic compounds (VOCs) from nearby industrial processes may be adversely affecting the health of the more vulnerable members of the community.

The aim of the study was fourfold:

1. To undertake a desk study of VOC release from industrial process operations within the locality;
2. To assess possible methods of estimating the likely impact of this VOC release on the local community;
3. To recommend a strategy, if appropriate, for continuous monitoring of VOCs in the ambient air within the North Lynn area, and,
4. To assess the feasibility of monitoring for specific VOCs of concern identified by the study.

EMC reviewed the available data on emissions of VOCs from industrial processes within the North Lynn area and commented on their potential impact on local air quality. The study identified several issues that may warrant further investigation, however, it is the responsibility of the Air Quality Sub Group to make recommendations for further action on the basis of the results and conclusions presented in this report.

Particular emphasis was given in the study to identifying the major industrial sources of VOC emissions in the North Lynn area and to estimating their likely impact on local air quality. The following conclusions have been drawn from the study: Information supplied by King's Lynn BC and the Environment Agency showed that there are appreciable releases of certain VOC species from industrial processes in the North Lynn area of the town. However, emissions of VOCs from all of the sites considered in this study are within their respective prescribed limits as defined in their IPC (Environment Agency) or LAAPC (Kings Lynn BC) Authorisations.

Information from the Environment Agency's Pollution Inventory indicates that the VOC with the greatest annual release is dimethylformamide, of which 272 tonne was released during 2001 from the Porvair International Ltd site (AK3169). Examination of the historical data shows a significant downward trend in emissions of all major species, apart from tetrachloroethene which shows a slight increase over the past three years.

Releases of VOCs from the IPC Authorised processes operated by the Dow Chemical Company are at a lower level than those from Porvair International Ltd. Nevertheless, emissions of 1,3-butadiene, acrylonitrile, styrene and butene represent appreciable quantities, which may have a measurable impact on local air quality.

Of the smaller industrial processes within the North Lynn area that are outside the IPC regulatory framework, Williams Refrigeration is responsible for appreciable releases of VOCs, particularly dichloromethane and trichloroethylene.

The potential impact of VOC releases on air quality within the area is related primarily to the magnitude of the release, whether or not it is released in a controlled manner from a stack or chimney, or whether it is an uncontrolled, fugitive release. Of all of the specific VOCs identified in the Environment Agency Pollution Inventory data, dimethylformamide is probably the most important in terms of its potential impact on local air quality.

The results from screening analyses of the dispersal of dimethylformamide from the Porvair International Ltd site suggest that the impact on local air quality might warrant further investigation. The magnitude of the predicted maximum contribution to ground level concentrations was well below respective Environmental Assessment Levels (EALs), but represents an appreciable proportion of the EAL and exceeds both the short term and long term significance threshold.

The air quality standard for 1,3-butadiene is low (2.25 $\mu g\ m^{-3}$), and the release of this pollutant from the Dow site in Estuary Road may have a measurable impact on local air quality. However, screening methodologies carried out in conjunction with the Environment Agency during the Stage 2 Air Quality Review concluded that there was not a significant risk of exceeding the 2003 Objective Value. No measurements of ambient concentrations of 1,3-butadiene have been undertaken to date by King's Lynn BC. It may be appropriate to undertake measurements to quantify the impact of this release on air quality and to confirm the Stage 2 Review conclusion.

Glossary of Terms

$\mu g\ m^{-3}$ - micrograms per cubic metre = 1 millionth of a gram per cubic metre

ADMS - Atmospheric Dispersion Modelling System

AQMA - Air Quality Management Area

AQS - Air Quality Strategy for England, Scotland, Wales and Northern Ireland

BAT - best available techniques (the EU equivalent of BATNEEC – BAT incorporates the concept of an assessment of costs and benefits)

BATNEEC - best available techniques not entailing excessive cost

CO - carbon monoxide

CO_2 - carbon dioxide

EA - Environment Agency

EAL – Environmental Assessment Level. The EAL is the concentration of a substance which in a particular environmental medium the Regulators (EA or LA) regard as a comparator value to enable a comparison to be made between the environmental effects of different substances in that medium.

EC - European Community

EPA 90 - Environmental Protection Act 1990

EPAQS - Expert Panel on Air Quality Standards, reporting to DETR and devolved administrations epidemiology statistical studies of health effects in populations

EQS - Environmental Quality Standard

EU - European Union

Fugitive Emissions –Emissions not caught by an abatement system which are often due to equipment leaks, evaporative processes and windblown disturbances.

IPC - Integrated Pollution Control regime

IPPC - Integrated Pollution Prevention and Control Directive

ktonne - kilotonnes (thousand tonne)

LAPC - Local Air Pollution Control

LAQM - Local Air Quality Management

Long Term EAL - Derived from Health & Safety Executive, EH40/2002, Occupational Exposure Limits 2002, 8 hour reference period converted to annual mean.

$mg\ m^{-3}$ - milligrammes per cubic metre (1 milligramme = one thousandth of a gramme)

NAEI - National Atmospheric Emissions Inventory

NAQS - UK National Air Quality Strategy 1997

ng m^{-3} - or nanograms per cubic metre (1000 ng = l mg)

NMVOC - Non-methane volatile organic compound

NO - nitric oxide

NO_2 - nitrogen dioxide

NO_X - oxides of nitrogen, the sum of NO and NO_2

O_3 - ozone

OEL - Occupational Exposure Limit set by the Health and Safety Commission

PAHs - polycyclic aromatic hydrocarbons

PM_1 - particulate matter which passes through a size-selective inlet with a 50% efficiency cut-off at 1 µm aerodynamic diameter

PM_{10} - particulate matter which passes through a size-selective inlet with a 50% efficiency cut-off at 10 µm aerodynamic diameter

$PM_{2.5}$ - particulate matter which passes through a size-selective inlet with a 50% efficiency cut-off at 2.5 µm aerodynamic diameter

PPC - Pollution Prevention and Control regime

ppm - parts per million

QUARG - Quality of Urban Air Review Group, reporting to DETR

SO_2 - sulphur dioxide

Short Term EAL - Derived from Health & Safety Executive, EH40/2002, Occupational Exposure Limits 2002, 15 minute reference period converted to hourly mean.

TEOM - Tapered Element Oscillating Microbalance

Tonne - metric unit of mass equal to 1000 kilogrammes

VOCs - volatile organic compounds

WHO - World Health Organisation

1. Background to the Study

In September 1999, residents of the North Lynn area raised concerns over air pollution in the area and potential adverse health effects, particularly in the vicinity of St Edmund County Primary School. As a result of local concerns, the North Lynn and North End Area Group was formed to look into the problem. Two sub-groups were formed:

1. Health - to determine whether the health of the community was being affected by pollutant releases, and,
2. Air Quality - to quantify air pollution levels within the area.

The work undertaken by EMC Environment Engineering Ltd (EMC) was commissioned by the Environmental Health Department of King’s Lynn BC as an action arising from the Air Quality sub-group. EMC was contracted to undertake a desktop study of air quality in the King’s Lynn area. There is concern within the local community living close to the North Lynn industrial estates that pollutant releases, particularly volatile organic compounds (VOCs) from nearby industrial processes may be adversely affecting the health of the more vulnerable members of the community.

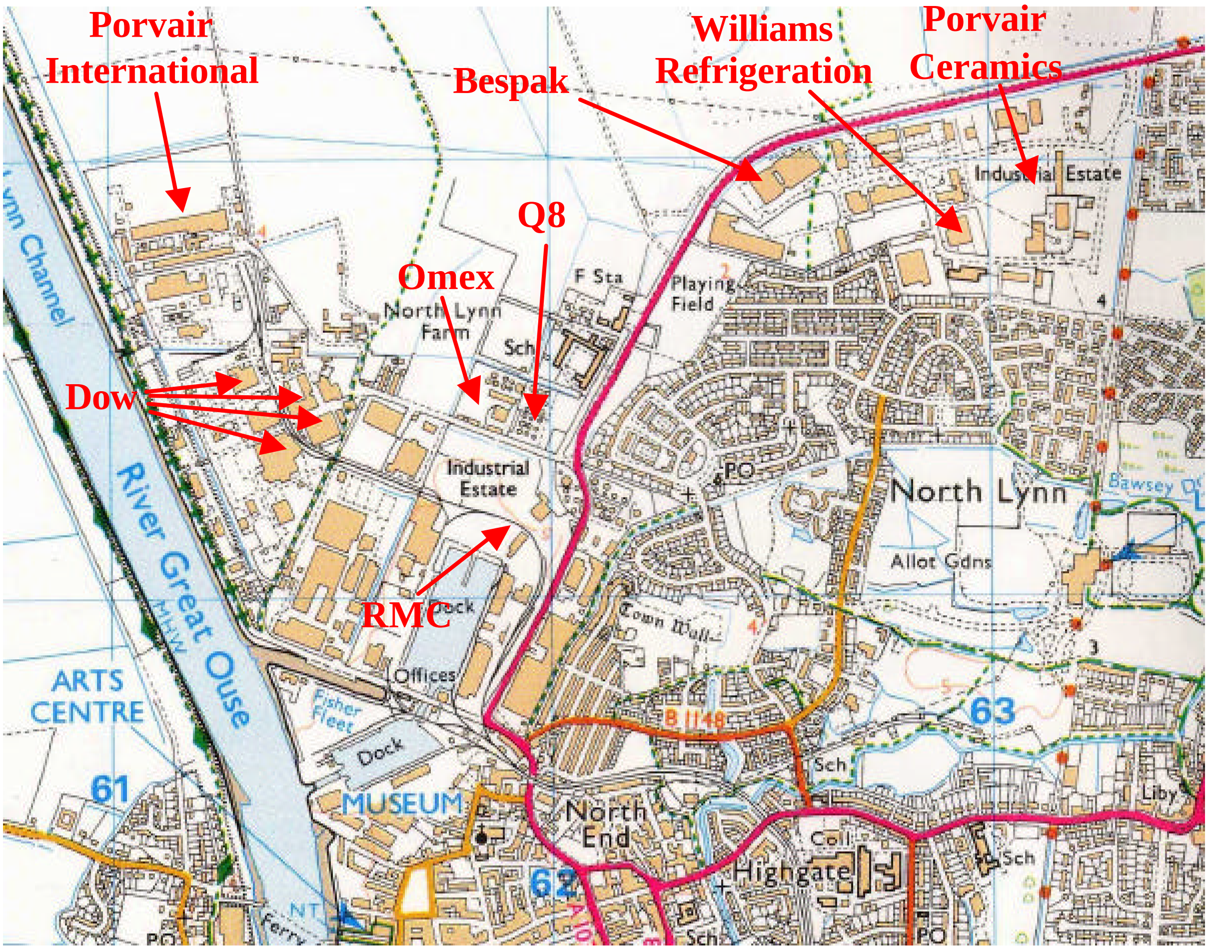
The aim of the study is fourfold:

5. To undertake a desk study of VOC release from industrial process operations within the locality;
6. To assess possible methods of estimating the likely impact of this VOC release on the local community;
7. To recommend a strategy, if appropriate, for continuous monitoring of VOCs in the ambient air within the North Lynn area, and,
8. To assess the feasibility of monitoring for specific VOCs of concern identified by the study.

This report summarises the findings of the study undertaken by EMC Environment Engineering Ltd.

2. Industrial Activity Within the North Lynn Area

The area involved in the study is situated to the north of King's Lynn and incorporates the residential areas of North Lynn and North End. This area of King's Lynn has several industrial sites that are responsible for the release of a range of pollutants into the atmosphere. Of particular concern to this study were those sites responsible for the release of VOCs into the atmosphere. The location of the major industrial sites for which VOC release data were provided are shown in Figure 1 below.



Map Reproduced with the Permission of the Ordnance Survey

Figure 1 **The Air Quality Study Area and Approximate Location of the Principal Source of VOC Emissions**

As can be seen, there are two industrial areas adjacent to the North Lynn residential area. To the west is the Riverside Industrial Estate which incorporates the docks and a number of Schedule A processes regulated by the Environment Agency. These include:

Porvair International Ltd - Production of Polyurethane
Omex Agricultural Ltd - Fertiliser Manufacture
Dow Chemical Company Ltd - Latex Rubber and Pesticide Plant

In addition to the Schedule A Processes there is also a Schedule B Process, as well as other non-IPC/LAAPC industrial processes with the potential for release of VOCs. These include:

RMC Roadstone - Bitumen Coating Plant
Kuwait Petroleum (GB) Ltd - Fuel Storage Depot
Dow Chemical Company Ltd - Styrofoam Plant

To the north east is another industrial estate where there is one Schedule A Process, Porvair Ceramics, and a number of other processes where there is a known release of VOCs into the atmosphere. These include:

Bespak Europe Ltd, and,
Williams Refrigeration Ltd

3. Volatile Organic Compounds (VOCs)

Volatile organic compounds (VOCs) incorporate a wide range of carbon-containing compounds that are emitted into the atmosphere from a variety of industrial processes. The term VOCs covers a range of chemical classes, including aliphatic, aromatic and chlorinated hydrocarbons; aldehydes; ketones; esters; ethers; acids; and alcohols. They contribute directly or indirectly to a number of important environmental issues and concerns, but the nature and extent of their contributions depend on the chemical structure of each individual compound.

VOCs are generally divided into three categories:

- Extremely hazardous to health;
- Class A compounds: those organic compounds that may cause significant harm to the environment.
- Class B compounds: organic compounds of lower environmental impact than Class A compounds.

VOCs have a variety of direct and indirect impacts on man and the environment. The main issues of concern are:

- harmful effects on human health and on natural ecosystems through toxicity, carcinogenicity and other adverse physiological effects;
- damage to materials;
- tropospheric photochemical oxidant formation;
- stratospheric ozone depletion;
- global climate change;
- odour.

The Environment Agency proposed a system for the categorisation of VOCs[1]. The basic premise was that the method should categorise VOCs according to their harmfulness. The Environment Agency proposed that there should continue to be 3 basic categories for VOCs, corresponding approximately to the existing categories. The method draws on agreed and published data concerning the adverse effects of VOCs.

The categories are summarised as follows:

High	CHIP[a] category 1 or 2 carcinogens, mutagens or teratogens; CHIP class - very toxic.
Medium	CHIP category 3 carcinogens, mutagens or teratogens; CHIP class - toxic by inhalation.
Low	All other VOCs.

Note: a Chemical (Hazard Information and Packaging) Regulations

The VOCs of concern to the current study are categorised as follows:

Pollutant	Categorisation
Dimethylformamide	Medium
Dichloromethane	Medium
Cyclohexanone	Low
Tetrachloroethene	Medium
1,3-butadiene	High
Styrene	Medium
Acrylonitrile	High

Many VOCs have an odour, and in certain circumstances emissions can give rise to localised odour nuisance problems. The strength of a given compound's odour may be expressed by its odour threshold, i.e., the concentration at which half the population could not detect an odour. It is difficult to predict the odour threshold of a mixture of VOCs since there are often complex and non-linear synergistic effects that can alter both the strength and quality of the perceived odour.

The odour threshold values[2,3] for the VOCs of concern to the current study are summarised below:

Pollutant	**Odour Threshold (mg m^{-3})**
Dimethylformamide [3]	6.6
Dichloromethane	3.42
Cyclohexanone	0.083
Tetrachloroethene	8.0
1,3-butadiene	1.1
Styrene	0.16
Acrylonitrile [3]	4.7

4. Air Quality Review and Assessment by King's Lynn BC.

As part of its statutory obligations under the Air Quality Strategy (AQS) for England, Scotland Wales and Northern Ireland, King's Lynn BC undertook a Stage 1 and 2 Review and Assessment of air quality within the Borough. The AQS requires local authorities to assess air quality levels within their areas in relation to certain priority pollutants:

Benzene
1,3-butadiene
Carbon Monoxide
Lead
Nitrogen Dioxide
Fine Particles - PM_{10}
Sulphur Dioxide

All of the above have been shown to have adverse effects on human health when present in sufficient concentrations. The Stage 2 assessment concluded that air quality was generally good with regard to current and likely concentrations of benzene and 1,3-butadiene. The results from the Stage 2 Review and Assessment were presented previously to the Air Quality sub-group. Details from the Stage 2 report relating to benzene and 1,3-butadiene are summarised in the following sections because of their relevance to the current study.

4.1 Benzene

All the benzene measured in the ambient air is likely to have resulted from human activities, in particular the use of petrol and oil. Benzene is present in petrol and can escape into the air, for example, at filling stations. Measurement of ambient benzene levels in the North Lynn area have been undertaken to assess the possible impact of fugitive releases from the petrol storage depot operated by the Kuwait Petroleum Company. Monitoring of ambient benzene levels was initiated in February 1999 as part of the AQS review and Assessment procedure. The results are summarised below.

Location	Annual Average (ppb)	Standard (ppb)
West Norfolk Professional Centre	0.6	5
St Edmunds School		
Staff Room	0.5	5
Head's Room	0.7	5
St Edmundsbury Road	0.4	5
Kilhams Way	0.4	5

The AQS Objective Value for benzene, to be achieved by 2004, is 5 ppb as a running annual mean. The measured values are well within the AQS Objective Value, and with reducing levels in petrol from 2003 onwards, and the introduction of vapour recovery measures at the petrol terminal, air quality problems associated with benzene are considered unlikely to be significant.

4.2 1,3-Butadiene

1,3 butadiene is a colourless, flammable gas under normal ambient conditions. It is a known carcinogen, and as with benzene it is not possible to demonstrate a level at which there is zero risk. There are no natural sources of 1,3 butadiene and all of the 1,3-butadiene in the atmosphere derives solely from human activities. It is an important industrial chemical used particularly in the manufacture of synthetic rubber. The main source of 1,3-butadiene in the air is from vehicle exhaust emissions where it is formed in the combustion process. Approximately 78% of national emissions to the atmosphere (1995) were derived from motor vehicles. Industrial sources account for 13% of the total atmospheric emissions.

According to information taken from the Stage 1 and 2 Air Quality Review and Assessment document prepared by King's Lynn BC, Dow Chemical is a potentially significant emitter of 1,3 butadiene. The plant may utilise approximately 10,000 tonne annum^{-1} of 1,3-butadiene as a feedstock for the production of latex rubber. The nearest domestic residences are within about 300 metres of the Dow Chemicals site.

The Environment Agency is satisfied that the company uses BATNEEC in prevention/minimisation of emissions of 1,3-butadiene, and information supplied by King's Lynn BC[4] indicates that releases of 1,3-butadiene are within prescribed limits. Dow undertook modifications at the site in 2001 to vent all VOC stack emissions through a boiler to ensure complete decomposition of this source of emissions of 1,3-butadiene prior to release to atmosphere. The remaining source of emissions is fugitive in nature from flanges, pumps and valves etc. There are no other known significant industrial sources of 1,3 butadiene within the Borough.

King's Lynn BC considered 1,3-butadiene during Phase 2 and 3 of their air quality review and assessment procedure. Screening methodologies were used to assess potential ground level concentrations of 1,3-butadiene arising from fugitive releases from the Dow Chemical site. Technical Guidance, TG4(00) (DETR 2000)3 was used to assess the potential impact of a fugitive release of 120 kg annum^{-1} at a distance of 330 m and 0 m height. This was predicted to gives rise to a running annual mean of less than 0.225 µg m^{-3}, i.e. one tenth of the air quality standard. To exceed the NAQS limit value of 2.25 µg m^{-3}, in excess of 600 kg of 1,3-butadiene would have to be released.

The Environment Agency is satisfied that the calculation of releases is sound and is more likely to give an over-estimation. The following conservatism is inherent to the method. Firstly the release height of fugitive releases is generally above 0 m, the minimum distance is 330 m, releases are spread over an area approximately 100 m x 30 m and the Environment Agency has stated that the basis for the calculation of releases is sound and is more likely to be an over-estimation of the releases.

On the basis of the above assessment, King's Lynn BC concluded that there was not a significant risk of exceedence of the air quality standard for 1,3-butadiene from fugitive releases from the Dow Chemical site.

4.3 Conclusions of Air Quality Review and Assessment

In their consultation document[5], King's Lynn BC concluded that there was no requirement for further assessment of AQS pollutants other than for nitrogen dioxide and fine particles. Accordingly, it is concluded that current measured levels of pollutants such as benzene and 1,3-butadiene do not pose a significant threat to air quality in the King's Lynn area.

Other than the measurements undertaken for benzene, no measurements have been undertaken of the range of VOCs that are released from industrial processes in the North Lynn area; hence the need for the current study.

5. Emissions Inventory for VOC Release in North Lynn

The terms of reference for the present study require the contractor to determine the mass and type of VOC emissions from the regulated and non-regulated processes within the North Lynn area. Data relating to the Schedule A Processes were obtained from the Environment Agency's Pollution Inventory website[6]. Data relating to other process emissions were supplied by King's Lynn BC.

It should be emphasised that all of the companies identified within this report are operating within the emission limits specified within their IPC or LAAPC license conditions. Furthermore, in most instances there is an ongoing programme of reducing emissions of VOCs as a result of implementation of improvement programmes set as conditions within licenses.

The Environment Agency website identified the following Schedule A Processes within a two kilometre radius of North Lynn:

Company Name	Authorisation No.	Process	Post Code
Porvair International Ltd	AP3169	Petrochemical Process	PE30 2HS
Porvair Ceramics Ltd	BC2211	Manufacture and Use of Organic Chemicals	PE30 2JG
Omex Agriculture Ltd	AL6972	Chemical fertiliser Production	PE30 2HH
Dow Chemical Co. Ltd	BG9285	Manufacture and Use of Organic Chemicals	PE30 2JD
Dow Chemical Co. Ltd	AM5700	Manufacture and Use of Organic Chemicals	PE30 2JD
Dow Chemical Co. Ltd	AK3200	Manufacture and Use of Organic Chemicals	PE30 2JD
Dow Chemical Co. Ltd	AK3196	Pesticide Production	PE30 2JD

Omex Agriculture Ltd is included in the above table as it is a Schedule A Process within the study area. However, operation of the process does not result in the release of VOCs and no further reference will be made to this process.

The following information relating to VOC release to atmosphere was obtained from the Environment Agency's Pollution Inventory website[7]:

5.1 Porvair International Ltd (AP3169)

Porvair International Ltd manufactures a range of advanced polyurethane-based membrane materials for use in high-performance applications in the textiles and footwear industries. The site is regulated by the Environment Agency and all emissions are subject to the IPC Authorisation and well below authorised limits.

According to information available from the Environment Agency, during the past 2 years Porvair has installed modern low emission technology to their process as part of an ongoing IPC improvement programme. In addition to the reduction in gaseous emissions, the use of solvents has been reduced by over 30%. This has been achieved through installation of a new coating line that recovers and recycles solvents as part of the manufacturing process. Emissions of dimethylformamide and cyclohexanone are expected to fall further.

The following information relating to VOC release was obtained from the Environment Agency's Pollution Inventory, based on submissions by Porvair:

	Total Release (kg)					
Substance	**2002**	**2001**	**2000**	**1999**	**1998**	**1997**
Dichloromethane	21,500	56,400	54,980	56,540	-	-
Dimethylformamide	138,000	272,100	296,000	351,360	397,520	419,000
Tetrachloroethene	9,600	7,500	12,400	12,300	10,640	-
Cyclohexanone	-	77,200	118,600	180,700	212,400	-
Total VOCs (As C)	-	413,200	601,000	-	-	-

Note: Total VOCs includes all of the named VOC species within the inventory.

There are a number of potentially harmful VOCs released from the Porvair International Ltd site. The most significant among the release of VOCs are dimethylformamide, cyclohexanone, dichloromethane and tetrachloroethene. For the majority of the above species the trend in emissions has been consistently downwards over the period 1997 to 2002, particularly emissions of dimethylformamide.

Data supplied by Porvair[8] give estimates of expected annual release of cyclohexanone.

Cyclohexanone	70,000 kg

5.2 Porvair Ceramics Ltd (BC2211)

	Total Release					
Substance	**2002**	**2001**	**2000**	**1999**	**1998**	**1997**
Dichloromethane	<1000 kg	202 kg	<100 kg	<100 kg	-	-
Total VOCs (As C)	-	202 kg	<1 tonne	-	-	-

Note: Total VOCs includes all of the named VOC species within the inventory.

5.3 Dow Chemical Company Ltd (AM5700)

	Total Release					
Substance	**2002**	**2001**	**2000**	**1999**	**1998**	**1997**
Acrylamide	-	-	0.17 kg	0.16 kg	1.17 kg	1.17 kg
Total VOCs (As C)	-	-	<1 tonne	<1 tonne	<1 tonne	-

Note: Total VOCs includes all of the named VOC species within the inventory.

5.4 Dow Chemical Company Ltd (AK3200)

	Total Release (kg)					
Substance	**2002**	**2001**	**2000**	**1999**	**1998**	**1997**
1,3 Butadiene	<1,000	569	408	290	388	-
Acrylonitrile	-	<100	<100	170	<100	-
Butene (All isomers)	<10,000	20,000	18,000	13,000	31,600	-
Styrene	499	13,000	8,130	6,400	6,310	-
Total VOCs (As C)	-	29,000	24,000	18,000	33,800	64,790

Note: Total VOCs includes all of the named VOC species within the inventory.

5.5 Dow Chemical Company Ltd (AK3196)

	Total Release (kg)					
Substance	**2002**	**2001**	**2000**	**1999**	**1998**	**1997**
Dichloromethane	-	897	895	860	870	833
Total VOCs (As C)	-	1,100	1,200	1,200	1,010	302*
Xylene (All Isomers)	<10,000	<100	<100	<100	<100	-

Note: Total VOCs includes all of the named VOC species within the inventory.

5.6 Dow Chemical Company Ltd (BG9285)

	Total Release					
Substance	**2002**	**2001**	**2000**	**1999**	**1998**	**1997**
Styrene	-		<100 kg	N.R.	N.R.	N.R.
Total VOCs	-	-	<1 tonne	-	-	-

Note: N.R. = Not Released or below the reporting threshold
Total VOCs includes all of the named VOC species within the inventory.

This process was never fully commissioned, and latest information from the Environment Agency[9] states that the license has been revoked and that this process is no longer operational, although it still features in the Pollution Inventory website.

5.7 RMC Aggregates (UK) Ltd

RMC Aggregates operate a road stone coating plant at their site in Bentinck Dock. The process, Authorisation Number 00014584.VAR.1, is regulated by King's Lynn BC as a Schedule B Process in line with Secretary of State's Guidance Note PG 3/15(96). Emission limits for the plant are specified within the Authorisation and relate solely to particulates.

The asphalt coating process may release organic vapours derived from the hot bitumen used to coat the stone chippings. There is no regulatory limit on VOC release specified within the statutory guidance note and no information is available on the magnitude of such releases. However, emissions of VOCs from this site were considered to be insignificant by King's Lynn BC during their air quality review and assessment.

5.8 Kuwait Petroleum (GB) Ltd

Kuwait Petroleum (GB) Ltd operate a hydrocarbon fuel storage and distribution depot at their depot in Kings Lynn. According to information supplied by the company[10] 7,820 tonne of motor spirit passed through the depot in 2000. According to the National Atmospheric Emissions Inventory website[11], the emission factor for fugitive release of non-methane VOCs (NMVOC) is 1.27 ktonne NMVOC per Mtonne of petrol. Accordingly, on the basis of the annual throughput of motor spirit for the year 2000 of 7,820 tonne, it might be expected that there could be a fugitive release of ~10 tonne per annum of NMVOC. Vapour recovery has been incorporated on some of the storage tanks at the site.

5.9 Bespak Europe Ltd

Bespak Europe Ltd manufacture drug delivery systems for medical applications. According to information supplied by the company[12], it uses approximately 40 tonne of trichlorofluoromethane per annum. However, they state that there are unlikely to be any releases to atmosphere as it is used in a closed loop system. Waste material is stored in sealed containers, prior to removal by an authorised waste disposal operator.

The other significant VOC usage on site is that of ethanol. Approximately 100,000 litres (~90 tonne) of ethanol is used each year in the component processing department. Emissions of ethanol are abated by means of a scrubber designed by QVF. According to information supplied by QVF[13] under current operating conditions the scrubber has to cope with ~75% of the worst case conditions for which it was designed. Under worst case conditions an ethanol release rate of 0.363 kg per hour was measured. Accordingly, the worst case release of ethanol might be expected to be ~0.27 kg per hour (~2 tonne per annum) under current operating conditions.

5.10 Williams Refrigeration Ltd

Williams Refrigeration Ltd operate two sites in King's Lynn manufacturing an extensive range of chiller and refrigeration cabinets and counters for commercial and bakery requirements. In addition, the company also manufacture a range of heat exchange products. The company uses significant quantities of specific VOCs as part of its manufacturing operations.

According to information supplied by the company[14], two main VOC species are released to atmosphere from the site. These include 6.7 tonne of trichloroethene and 6.2 tonne of dichloromethane.

Information supplied in July 2002[15] showed that the amount of degreaser, trichloroethene, used within the factory has fallen from 5.6 tonne in 1997 to 2.5 tonne in 2001, and that figures for this year-to-date indicate a further reduction.

The chlorinated species are released to atmosphere by means of a vent on the roof of the factory. The fugitive di-isocyanate release is from a number of low level sources in and around the site.

5.11 Other Industrial Processes Operating Within the Kings Lynn Area

The Hardwicke Industrial Estate is located to the south of Kings Lynn where certain industrial processes have the potential to release VOCs to the atmosphere. These are Warner Jenkinson Ltd and Foster Refrigeration Ltd. However, it is unlikely that releases from these sites would have a significant impact on air quality within the North Lynn area.

6. Air Quality Standards Regulations

The introduction of the UK Air Quality Strategy has placed a requirement on Local Authorities to manage the quality of ambient air within their area. Operators of industrial processes are increasingly required to quantify the potential impact of their pollutant releases on local air quality with reference to the Air Quality Regulations (2000)[16] and the Air Quality Limit Value Regulations (2001)[17]. However, this does not include limits for the VOC species modelled.

In the absence of air quality standards, reference has been made to relevant environmental assessment levels (EALs) specified by the Environment Agency in IPPC Horizontal Guidance Note H1[18].

6.1 Derivation of Environmental Assessment Levels for Air (Environment Agency, IPPC Horizontal Guidance Note H1)[19]

For many substances that are released into the atmosphere Environmental Quality Standards (EQSs) have not been defined. Where the necessary criteria are absent then the Regulators have adopted interim values known as Environmental Assessment Levels (EALs). The EAL is the concentration of a substance which in a particular environmental medium the Regulators regard as a reference value to enable a comparison to be made between the environmental effects of different substances in that medium and between environmental effects in different media and to enable the summation of those effects.

Ideally EALs to fulfil this objective would be defined for each pollutant:

- based on the sensitivity of particular habitats or receptors (in particular three main types of receptor should be considered, protection of human health, protection of natural ecosystems and protection of specific sensitive receptors, e.g. materials, commercial activities requiring a particular environmental quality;
- be produced according to a standardised protocol to ensure that they are consistent, reproducible and readily understood;
- provide similar measure of protection for different receptors both within and between media;
- take account of habitat specific environmental factors such as pH, nutrient status, bio-accumulation, transfer and transformation processes where necessary.

EALs derived in this manner are not currently available, therefore, interim values based on published information have been adopted. The table below shows the sources from which information has been obtained.

Currently some 460 substances or groups of substances are authorised by the Regulators for release to the environment and many of these may be released to air. However, established environmental criteria (other than a limited number of EQSs) are available for only a small fraction of this number.

Expert Panel on Air Quality Standards (EPAQS)
EC Air Quality Directives - limit values and guidelines
World Health Organisation Air Quality Guidelines for Europe (1987, 1995)
Other International Organisations (e.g. United Nations Economic Commission for Europe)
Other National Organisations (e.g. US IRIS database)
Health and Safety Executive occupational exposure limits.
Expert judgement

Table 1 Sources of Information Used for Setting Environmental Assessment Levels for Releases to Air

Ideally EALs for those substances where there are no existing criteria would be derived direct from toxicological data on the effects of the pollutant on a particular receptor. However, an assessment of this type would be a very substantial undertaking which could only be considered over an extended timescale. One approach to overcoming this problem is to make use of occupational exposure limits which provide an assessment for a specific receptor (i.e. adult human workforce) of the toxicological effects of a pollutant. These values might then be progressively revised as further information and resources allow.

Occupational exposure limits are intended to set a level of exposure based on 8 hours per day, 5 days per week during a normal employment lifetime below which adverse effects are unlikely to arise for the majority of the working population who may be exposed. Occupational limit values may be derived from either actual data on workers or animal toxicity data. In addition, factors such as the ability to achieve or measure the proposed limit may also be taken into consideration. Consequently, the precise basis on which limit values have been set is difficult to determine and a cautious approach needs to be taken in deriving EALs from occupational exposure limits.

In deriving EALs for long-term exposure from occupational limits two factors need to be taken into consideration, the duration of exposure of the general population compared with the workforce and the sensitivity of the group at risk. The weekly exposure of the local population could be up to 168 hours per week (7 × 24 hrs) rather than the 40 hours (5 × 8 hrs) which might be expected for the workforce. Moreover, exposure for the general population may extend to 52 weeks compared with an average working year of 44 weeks. On this basis the minimum safety factor would be 4.96 (i.e. (168/40 × 52/44). In addition, since there may be no recovery period between exposure sessions and exposure could be for a lifetime, a further safety factor of 2 could be introduced giving a total safety factor of 10.

It might also be expected that the general population will contain more sensitive individuals, for example, children, the elderly or those with diseases such as asthma, than workers who are typically between the ages of 16 and 65. In the absence of other information a factor of 10 is normally used to allow for differences between the population mean and the response of sensitive individuals[20]. This is likely to be conservative since, in setting occupational limit values, some allowance will have been made for variation in the sensitivity of the workforce to the pollutant concerned. Combining the safety factors for exposure and sensitivity of the general population gives a long-term air quality standard of 1/100th of the 8-hour occupational exposure limit.

In the UK the Health and Safety Executive distinguish two types of long term occupational exposure limits, occupational exposure standards (OESs) and maximum exposure limits (MELs). MELs are set for chemicals where there is particular concern, for example carcinogens, or doubt over the actual no effect level and for occupational health purposes it is an offence to exceed a MEL. Within the workplace this leads to an emphasis on reducing average levels of exposure of the chemical to ensure that the MEL is not exceeded. In practice this leads to an additional safety margin of up to 5 for chemicals which have MELs over those which have OES values. Effectively, therefore, an additional safety factor of up to 5 is achieved in the workplace by setting an MEL and this factor has been incorporated in determining an EAL for those chemicals listed as having an MEL in HSE Guidance Note EH40/2001[21]. For example a safety factor of 500 (10 × 10 × 5) is used to set the long term EAL for such substances. Where a substance has a maximum exposure limit value then an additional safety factor of 5 can be included on a similar basis to that described for the derivation of long term EALs.

Where no short-term environmental criteria have been identified in the literature a similar approach to their derivation from occupational exposure limits can be adopted to that described above for long-term EALs. However, in this instance it is more appropriate to calculate values based on the short term exposure limits (STELs) set by HSE. Where STELs are not listed then a value of 3 times the 8 hour time weighted average occupational exposure limit may be used.

Since STELs are by definition appropriate for consideration of short-term impacts there is no need for additional safety factors relating to the duration of exposure as suggested for the derivation of long term EALs. Moreover, as STELs already incorporate a limited safety margin for variation in the sensitivity of the workforce an additional factor of 10 is likely to be adequate to account for the increased sensitivity of the general population. However, since many atmospheric dispersion models are only able to produce estimates for time averaging periods in the order of 1 hour it would be convenient for the short term EALS also to be expressed on this basis. Typically ratios between concentrations measured over a 15 minute averaging period and those taken over an hour may be between 1.3 to 2.3. Given this relatively small range and the likely over estimate of the safety factor representing variation in human sensitivity the Environment Agency suggest to adopt a value of 1/10th of the STEL as the short-term EAL.

EA Horizontal Guidance Note H1 utilises EALs as a means of screening out those emissions which are released in such small quantities that they are unlikely to cause a significant impact on the receiving environmental medium; in this case the atmosphere. The significance thresholds are specified as follows:

$PC_{\text{long term}} > 1\%$ of the long term EAL

$PC_{\text{short term}} > 20\%$ of the short term EAL

The EALs for the pollutants considered in the modelling study are summarised in Table 2 below.

Pollutant	Long Term EAL (mg m^{-3})	Short Term EAL (mg m^{-3})	Odour Threshold (mg m^{-3})
Dimethylformamide	300	6,100	6,600
Dichloromethane	700	3,000	3,420
Cyclohexanone	1,020	40,080	83
1,3-butadiene	2.25	1,320	1,100
Acrylonitrile	8.8	264	4,700
Styrene	800	800	160
Tetrachloroethene	3,450	8,000	8,000

Table 2 Environmental Assessment Levels for the Protection of Human Health for the Major VOC Species Released From the Porvair Industrial and Dow Chemical Co. Ltd Sites

The short term EALs are derived primarily from the corresponding HSE short term exposure level (STEL) values that are based on 15 minute averaging periods. Long term EALs are derived from the corresponding HSE 8 hour time weighted average OEL.

Results from dispersion modelling were compared against the EALs in Table 2. Long term EALs were compared against the maximum annual average predicted contribution to ground level concentrations. Short term EALs were compared against maximum 24 hourly average contributions to ground level concentrations

7. Assessment of Potential Impact of VOC Release on Air Quality in the North Lynn Area

In the absence of measured data on ambient concentrations of VOCs, modelling studies were undertaken in order to estimate worst case contributions to ground level concentrations arising from VOC releases from Porvair International Ltd and the Dow Chemical Company Ltd. Details of the modelling strategies are given in APPENDICES 1, 2 and 3.

7.1 Results and Discussion from the ADMS Modelling Study

The ADMS3 model was used to undertake a screening analysis of the worst case contribution to local ground level concentrations of VOCs released from the Porvair International and Dow Chemical Co. industrial sites. Environment Agency guidance on the modelling of odours[22] recommends that an averaging time of 1-hour should be used. Due to the rapid human response to odour, shorter averaging periods such as one or two seconds can be used. It should be noted, however, that a standardised approach based on a shorter duration has not yet been validated. The EA guidance also recommends use of the 98th percentile of a year of hourly means for comparative purposes. Results from the ADMS3 modelling exercise are summarised as annual and 98th percentiles of hourly means in Table 3 and Table 4.

Pollutant	Annual Average (mg m^{-3})	Long Term EAL (mg m^{-3})	Percentage of Long Term EAL (%)	Maximum Hourly Mean (mg m^{-3})	98th Percentile of Hourly Means (mg m^{-3})
Dimethylformamide	39	300	13	690	200
Dichloromethane	6.1	700	0.9	110	31
Cyclohexanone	22	1,020	2.2	390	110
Tetrachloroethene	2.7	3,450	0.08	48	14
1,3-butadiene	0.08	2.25	3.6	1.07	0.4
Styrene	0.12	840	0.01	1.6	0.5
Acrylonitrile	0.02	8.8	0.2	0.3	0.09

Table 3 Worst Case Results from Dispersion Modelling of VOC Releases from the Porvair and Dow Sites

	St Edmunds School		
Pollutant	**Annual Average (mg m^{-3})**	**Percentage of Long Term EAL (%)**	**98th Percentile of Hourly Means (mg m^{-3})**
Dimethylformamide	2.0	0.7	21
Dichloromethane	0.3	0.04	3.3
Cyclohexanone	1.1	0.11	12
Tetrachloroethene	0.14	0.004	1.5
1,3-butadiene	0.01	0.4	0.1
Styrene	0.02	0.0024	0.2
Acrylonitrile	0.003	0.03	0.02
	North Lynn Residential Area		
Dimethylformamide	3.0	1.0	37
Dichloromethane	0.6	0.08	6.0
Cyclohexanone	1.7	0.17	21
Tetrachloroethene	0.2	0.006	2.6
1,3-butadiene	0.05	2.2	0.3
Styrene	0.08	0.01	0.4
Acrylonitrile	0.013	0.1	0.07

Table 4 Worst Case Results from Dispersion Modelling of VOC Releases for the Specific Receptors

It must be borne in mind that the results from this dispersion modelling exercise should be considered as indicative, and should not be considered as an absolute assessment of ground level VOC concentrations that may arise from their release. The modelling was undertaken using the inventory data for 2002. Due to changes in the reporting criteria, some of the 2002 data are shown as "less than" values. In this instance reference is made to the 2001 data.

The uncertainties associated with the results are at their most significant when considering the short term averaging periods. Maximum contribution to ground level concentrations of the pollutants considered were generally within the confines of, or within close proximity of the factory from which the pollutant was released.

7.1.1 Dimethylformamide

The maximum contribution to ground level concentrations from the ADMS3 modelling is estimated to be ~200 µg m^{-3} (~65 ppb), expressed as a 98th percentile of hourly mean, and ~1% of the short term EAL of 6,100 µg m^{-3}. The model predicted value is also below the odour threshold of 6,600 µg m^{-3}.

The location of the maximum hourly average value is within the confines of the industrial estate and results from a westerly wind blowing at 1 m s^{-1}. Under these conditions the pollutants are blown away from the school and local residents, and airborne dispersal reduces pollutant concentrations the further the receptor is away from the source.

In view of the large uncertainties associated with the assumptions made in compiling the model, the significance of the result probably only relates to the fact that it is of the same order of magnitude as the EAL. The maximum estimated process contribution to annual average ground level concentrations was ~40 µg m^{-3} (~13 ppb). This represents ~13% of the long term EAL of 300 µg m^{-3}. The results for the annual average are illustrated graphically in Figure 2.

The results for the specific receptors were about 0.5% of the short term EAL for dimethylformamide, with a value of ~21 µg m^{-3} (~7 ppb) predicted for St Edmunds School and ~37 µg m^{-3} (~12 ppb) for the residential area in Estuary Road, expressed as maximum 98th percentiles of hourly means. The corresponding annual average values were 2 and 3 µg m^{-3} (0.7 and 1 ppb) respectively, which represents a value of ~1% of the long term EAL.

The magnitude of the predicted maximum contributions to ground level concentrations are well below the respective EALs and are below the significance thresholds as described in Section 6.1.

The Environment Agency Pollution Inventory reports that 138 tonne of dimethylformamide was released from the Porvair International site in 2002. In the absence of information on the pattern of release and specific details of how it was released (vented emissions or fugitive release), it is not possible to be precise on how it might disperse within the surrounding community. Nevertheless, despite the associated uncertainties, the results from the modelling suggest that it may be appropriate to undertake a programme of ambient measurement of dimethylformamide in the vicinity of the Porvair International site and the surrounding area.

There may also be merit in undertaking more detailed modelling of the release of DMF from the Porvair International site. As much as two thirds of the DMF release is associated with ventilation of the building and involves a large volume, low concentration situation. The remainder of the DMF, plus the cyclohexanone, are released from a 20 metre stack on site.

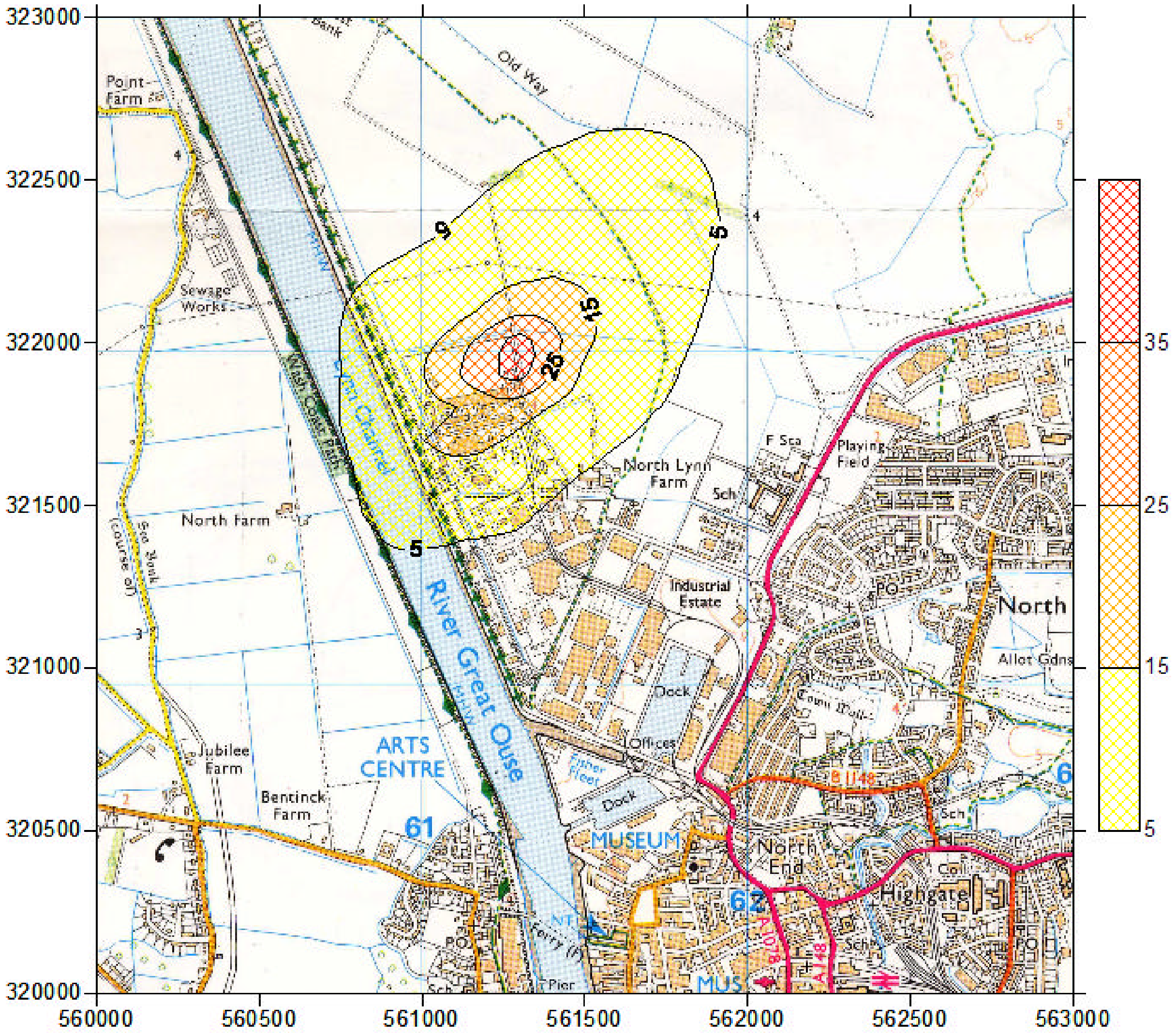


Figure 2 **Predicted Annual Hourly Average Contribution to Ground Level Concentrations of Dimethylformamide**

7.1.2 Cyclohexanone

The maximum predicted 98th percentile of hourly mean contributions to ground level concentrations of cyclohexanone was ~110 µg m^{-3} (~36 ppb) which is ~0.3% of the short term EAL of 40,080 µg m^{-3} (980 ppb). The model predicted value is also above the odour threshold of 83 µg m^{-3} (20 ppb). The corresponding annual average contribution to ground level concentrations of cyclohexanone was ~22 µg m^{-3} (7 ppb), which represents ~2% of the long term EAL of 1,020 µg m^{-3} (330 ppb).

At the specific receptors, the predicted contribution to ground level concentrations of cyclohexanone was ~12 and ~21 µg m^{-3} (~3 and ~5 ppb) respectively at St Edmunds School and the residential area in Estuary Road, expressed as a 98th percentile of hourly means. The respective annual average contributions to ground level concentrations of cyclohexanone were ~1 and ~2 µg m^{-3} (0.3 and 0.7 ppb), or ~0.1 and ~0.2% of the long term EAL.

7.1.3 Dichloromethane

The results for dichloromethane gave an estimated 98th percentile of hourly mean contributions to ground level concentration of about ~31 µg m^{-3} (~11 ppb). This is ~1% of the short term EAL of 3,000 µg m^{-3} (~840 ppb), and well below the odour threshold of 3,420 µg m^{-3} (~960 ppb). The World Health Organisation recommends a guideline value for dichloromethane of 3,000 µg m^{-3} (~850 ppb) expressed as a daily average.

The corresponding annual average contribution to ground level concentrations of dichloromethane was ~6 µg m^{-3} (~2 ppb), which represents ~1% of the long term EAL. The results for the annual average predictions are illustrated graphically in Figure 3.

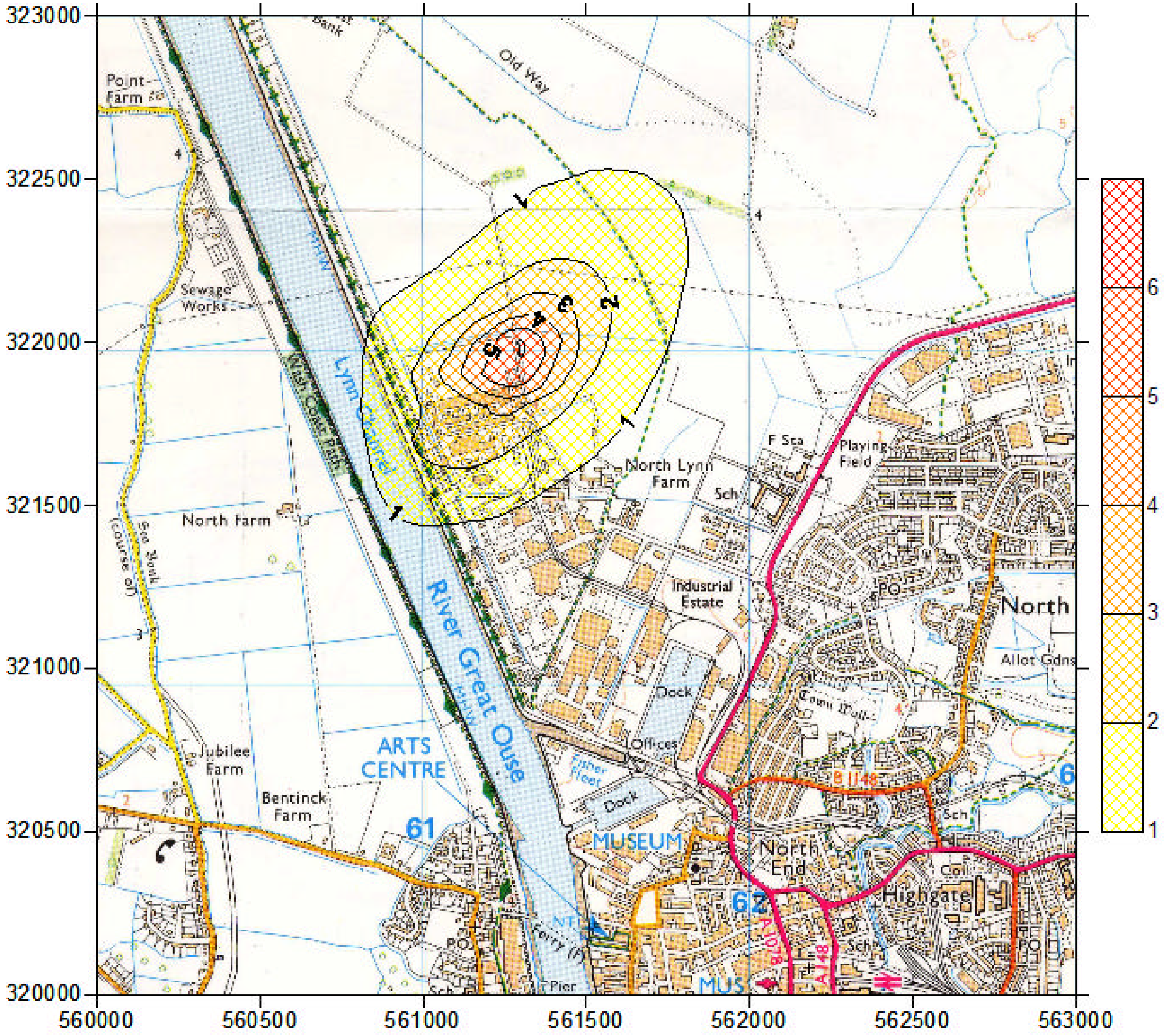


Figure 3 **Predicted Annual Hourly Average Contribution to Ground Level Concentrations of Dichloromethane**

At the specific receptors, the predicted contribution to ground level concentrations (expressed as a 98th percentile of hourly mean values) of dichloromethane was ~3 µg m^{-3} (~1 ppb) at St Edmunds School and ~6 µg m^{-3} (~2 ppb) at the residential area in Estuary Road. The corresponding annual average contributions to ground level concentrations of dichloromethane were ~0.3 and ~0.6 µg m^{-3} (0.1 and 0.2 ppb), representing ~0.1% of the long term EAL.

7.1.4 1,3-Butadiene

The 98th percentile of hourly mean contributions to ground level concentrations of 1,3-butadiene was estimated to be ~0.4 µg m^{-3}, which is about 0.03% of the short term EAL in Technical Guidance Note H1. However, there is a statutory air quality standard for 1,3-butadiene of 2.25 µg m^{-3}, expressed as an annual average value. The model result for the annual average contribution to ground level concentrations of 1,3-butadiene was ~0.08 µg m^{-3}, which is ~4% of the air quality standard.

At St Edmunds School and the residential area in Estuary Road, the predicted contribution to ground level concentrations of 1,3-butadiene was ~0.1 and 0.3 µg m^{-3} respectively (~0.05 and ~0.15 ppb), expressed as 98th percentile of hourly means. The corresponding annual average contributions to ground level concentrations of 1,3-butadiene were ~0.01 and 0.05 µg m^{-3} (0.005 and 0.025 ppb), which represents ~0.4% and ~2% respectively of the long term EAL.

7.1.5 Styrene

The 98th percentile of hourly mean contributions to ground level concentrations of styrene was predicted to be ~0.5 µg m^{-3} (~0.07 ppb), which is <1% of the short term EAL, and well below the odour threshold of 83 µg m^{-3}. The corresponding annual average contribution to ground level was ~0.12 µg m^{-3} (~0.03 ppb), which represents ~0.01% of the long term EAL. The World Health Organisation recommends an air quality guideline value for styrene of 260 µg m^{-3} (~60 ppb) expressed as a weekly average. Accordingly, the model estimate represents a small percentage of the guideline value.

At St Edmunds School and the residential area in Estuary Road, the predicted contribution to ground level concentrations of styrene was ~0.2 and ~0.4 µg m^{-3} (~0.05 and ~0.1 ppb) respectively, expressed as maximum 24 hourly mean values. The corresponding annual average contributions to ground level concentrations of styrene were ~0.02 and ~0.08 µg m^{-3} (0.005 and 0.2 ppb), which represent ~0.03% and 0.01% of the long term EAL.

7.1.6 Acrylonitrile

The 98th percentile of hourly mean contributions to ground level concentrations of acrylonitrile was predicted to be ~0.09 µg m^{-3} (~0.06 ppb) which is <0.1% of the short term EAL, and well below the odour threshold of 4,700 µg m^{-3}. The corresponding maximum annual average contribution to ground level concentrations of acrylonitrile was ~0.02 µg m^{-3} (~0.01 ppb), which represents <0.1% of the long term EAL.

At St Edmunds School and the residential area in Estuary Road, the predicted contribution to ground level concentrations of acrylonitrile was ~0.02 and ~0.07 µg m^{-3} (0.01 and 0.04 ppb) respectively, expressed as a 98th percentile of hourly means. The corresponding annual average contributions to ground level concentrations of acrylonitrile were ~0.003 and ~0.01 µg m^{-3} (~0.0002 and 0.002 ppb).

7.1.7 Tetrachloroethene

The 98th percentile of hourly mean contributions to ground level concentrations of tetrachloroethene was predicted to be ~14 µg m^{-3} (~2 ppb), which is less than ~0.2% of the short term EAL, and well within the odour threshold of 8,000 µg m^{-3}. The corresponding maximum annual average contribution to ground level concentrations of tetrachloroethene was ~3 µg m^{-3} (~0.4 ppb), which is ~0.1% of the long term EAL. World Health Organisation recommends a guideline value of 250 µg m^{-3} (~36 ppb) for tetrachloroethene expressed as an annual average. Accordingly, the maximum value predicted by the modelling exercise represents ~0.1% of the WHO guideline value.

At St Edmunds School and the residential area in Estuary Road, the predicted contribution to ground level concentrations of tetrachloroethene was ~1.5 and ~2 µg m^{-3} (~0.2 and ~0.3 ppb) respectively, expressed as 98th percentile of hourly means. The corresponding annual average contributions to ground level concentrations of tetrachloroethene were ~0.2 µg m^{-3} (0.03 ppb).

7.2 Modelling Conclusions and Consideration of the Need for VOC Monitoring

The results from the ADMS3 modelling of VOC releases from the Porvair International and Dow Chemical Co. Ltd industrial sites give an indication of those species that might be significant in terms of their potential impact on air quality within the surrounding community.

Of the VOC species considered, dimethylformamide is probably the most significant in terms of its magnitude and its estimated impact on air quality. Using the modelling results as a crude indicator of significance in terms of the potential impact on local air quality, there may be a case for a measurement programme that would attempt to quantify ambient concentrations of dimethylformamide, cyclohexanone and possibly 1,3-butadiene. More detailed modelling may also help to identify areas of concern in relation to exposure to these pollutants.

8. Analytical Techniques for Ambient VOCs

The diverse properties of organic pollutants such as VOCs, means that there is no single standard method applicable to their identification and measurement in ambient air. Methodologies tend to be classified in relation to instrumental and passive methods, and the measurement of total hydrocarbons (THC) and speciated measurement for specific compounds.

8.1 Instrumental Methods

The principal methods for measurement of VOCs in ambient air are summarised below in Table 5.

Technique	Applications	Comments
Flame Ionisation Detector	Continuous measurement of total hydrocarbons and/or non-methane hydrocarbons in the field.	Identification of unknown organics not absolute. Response can vary for different mixtures. Reduced response to organic compounds containing hetero-atoms e.g. O, N or Cl.
PID analyser	Continuous measurement of total hydrocarbons and/or non-methane hydrocarbons in the field.	Identification of unknown organics not absolute. Also responds to ammonia and reduced S species. Response factors vary for mixtures. High sensitivity for certain hydrocarbons.
GC-FID, GC-PID	Batch or semi-continuous separation and analysis of speciated hydrocarbons collected by a sampling device, such as sorbent tube or cryogenic trap. A field or laboratory method.	Identification of unknown organics not absolute (characterised by retention times). Co–eluting substances can lead to interference.
GC-MS	Batch or semi–continuous separation and analysis of speciated hydrocarbons collected by a sampling device, such as sorbent tube or cryogenic trap. Mainly a laboratory method.	Can identify and quantify individual species. Spectra can be complex. Field analysers under development but not yet a routine method.
NDIR	Continuous approx. measurement of specific hydrocarbons. Indicative only. Limited sensitivity, not suitable for trace organics at ppb levels.	Identification of unknown organics not absolute. Potential interferences from other IR absorbing compounds and water.
FTIR	Continuous measurement of specific hydrocarbons.	Improved sensitivity, suitable for trace organics at ppb levels. Much less subject to interferences than other forms of IR analysis. Field analysers under development but not yet a routine method.
Photoacoustic IR	Continuous measurement of specific hydrocarbons.	Identification of unknown organics not absolute. More specific and less subject to interference than NDIR. Not yet in widespread use.

Technique	Applications	Comments
Open-path FTIR	Remote continuous method using long path–length FTIR absorption spectroscopy. Concentration of VOCs measured between the source and detector.	Identification of unknown organics not absolute. Remote method allowing distance averaged measurements of many individual VOCs simultaneously, but with no spatial resolution. Ideal for site boundary 'fence-line' monitoring. Some limitations due to size, weight and expense.

Table 5 Instrumental Methods for Determination of VOCs in the Ambient Air

8.1.1 Mass Spectrometry

Mass spectrometry's high sensitivity makes it well suited for analysing small-size organic and inorganic samples, producing a large amount of information for identification and structural determinations. MS is particularly useful for mixtures and is frequently linked with GC to give both separation and identification. In air pollution analysis, MS is most often used for the laboratory analysis of organics collected by sorptive sampling methods. Automated field systems exist and some portable mass spectrometers for pollution monitoring in the field are under development, although their use is not widespread.

8.1.2 Chromatography

Chromatography is the generic term given to the separation of a mixture of compounds by their partition between two immiscible heterogeneous phases. The main chromatographic methods of relevance to air pollution analysis are gas chromatography (GC) and liquid chromatography. The time taken for each component in a mixture to pass through (elute from) the chromatographic column and produce a response at the detector is known as the retention time. Compounds are identified by their retention times (absolute or relative to an internal standard), and are therefore subject to varying degrees of uncertainty.

Absolute identification using GC is not possible using retention times alone because of: possible coincidence of retention times for different compounds; difficulty in precisely controlling the experimental conditions; and the possibility of interactions between components in a mixture causing changes in retention values.

8.1.2.1 Gas Chromatography

In air pollution analysis, gas chromatography is often used in the laboratory to quantify compounds that have been collected cryogenically or on sorbent tubes. However, compact, portable GC-FID and GC-PID instruments are now available for making measurements directly in the field, and provide a useful first step in surveying an area to identify pollution hot spots. It is a characteristic of chromatographic methods that they are essentially batch analysis techniques with discrete analysis cycles, but automatic site-based systems can take sequential samples, e.g. every 30 minutes, to enable semi-continuous monitoring to be carried out. For example, in the UK Automatic Hydrocarbon Network, C_2 to C_8 hydrocarbons in ambient air are collected in a cryogenic trap and then thermally desorbed into the chromatograph (GC-FID) at half-hourly intervals.

Although at present, gas chromatography–mass spectroscopy (GC-MS) systems are commonly found in the laboratory, automated field systems have been developed for speciated VOC monitoring around industrial plant. However, their application is not commonplace.

8.2 Passive Techniques

For higher molecular weight hydrocarbons ($>C_6$), adsorption onto solid sorbents followed by thermal desorption with GC-MS or GC-FID, is widely used. Several different adsorbents are in common use, e.g. Tenax-TA, Tenax-GC, Tenax-GR, Carbotrap, Chromosorb, activated charcoal, etc. For active sampling, typical flow rates through the sorbent tubes are 50 to 200 ml min^{-1} for 20 to 80 minutes, but this can vary considerably according to the application.

Passive diffusion-tube samplers can also used for measuring down to low concentrations of hydrocarbons, provided the uptake rate of the particular adsorbent/tube system has been evaluated for the species of interest.

9. Practical Options for Measurement of VOCs in Ambient Air

There are two main approaches to the measurement of hydrocarbons: first, determining the concentrations of the total hydrocarbon concentrations; or, secondly, measuring individual hydrocarbon species.

9.1 Total Hydrocarbons

The main continuous instrumental method for measuring total hydrocarbons is the flame ionisation detector (FID) continuous analyser. An FID analyser provides a continuous response which is approximately linear for hydrocarbons, but gives a decreased response for carbon atoms bonded to hetero-atoms (e.g. O, N or Cl). Photo-ionisation detector (PID) continuous analysers are suitable for measuring a wide range of volatile organic compounds, although the response of a PID is much more compound-specific than that of an FID. The benefit of the PID is its high sensitivity for certain hydrocarbons.

Both types of instrument are usually calibrated using a methane compressed gas standard, and the resulting measurements of ambient concentrations of total hydrocarbons are reported as ppm methane-equivalent. In order to facilitate comparisons of total hydrocarbon and specific hydrocarbon concentrations, the latter are commonly reported as ppm C, derived by multiplying the concentration in ppm v/v by the number of carbon atoms in the molecule.

9.2 Speciated Hydrocarbons

Generally, speciated hydrocarbons are analysed by gas chromatography coupled with an appropriate detector stage, e.g. FID, PID, MS. Where the determinands are not known in advance and identification as well as quantification of the hydrocarbons is required, then GC-MS is the method of choice. At ambient levels, it is usually necessary to pre-concentrate the hydrocarbons before analysis and this is usually done by sampling onto a suitable sorbent medium such as charcoal or a synthetic polymer sorbent (by either active pumped sampling or by diffusion sampling), by the use of a cryogenic trap, or by collection in evacuated stainless-steel canisters with later cryogenic pre-concentration.

For the low molecular weight hydrocarbons (e.g. C_2-C_5), grab sampling in an impermeable container (e.g. evacuated PTFE bags or stainless-steel canisters) or cryogenic trapping are preferred because of their high volatility. Pre–filters (potassium permanganate crystal or silica wool plug) may be used to remove ozone, which would otherwise react with certain hydrocarbons such as alkenes. For measuring very low hydrocarbon concentrations in the atmosphere, large volumes must be sampled. Once the sample has been collected, the most common approaches for analysis are GC-MS and GC-FID. A draft international standard ISO/DIS 14965 has been produced for the measurement of non-methane organic compounds by cryogenic pre-concentration and FID analysis.

Automatic semi-continuous analysis of speciated hydrocarbons in air samples is possible. Some commercially available GC systems using cryogenic traps have microprocessor-controlled sampling, operation, peak identification, data processing and communication with external devices. They may be configured for automatic analysis of organics such as benzene, toluene, xylenes, styrene, 1,3-butadiene, vinyl chloride, ethene oxide and dimethyl sulphide. The main drawback with these automatic systems is that they need to be supplied with liquid nitrogen, which itself can cause practical difficulties. Other systems use Peltier coolers or solid sorbent pre-concentrator columns to avoid these problems.

There are also small, easily transportable GCs on the market that allow occasional direct measurements in the field to be carried out. Some truly portable GC-FID or GC-PID systems are available for separating and analysing a selection of pre-targeted compounds such as benzene, toluene, 1,3-butadiene and alkanes. Although these instruments are popular for workplace monitoring, the lower detection limits extend down to the low ppb level expected in ambient monitoring. This type of instrument provides a useful tool for undertaking a preliminary survey of VOC concentrations within an area. The information can then be used to formulate a more robust measurement programme using more precise methodologies.

Continuous measurements of speciated hydrocarbons have been made remotely using open-path FTIR, but this technique is not yet widespread in the UK. A more common remote method is differential optical absorption spectroscopy (DOAS), which allows distance–averaged measurements to be made with high sensitivity but with no spatial resolution. Popular applications for this technique are site boundary 'fence-line' monitoring, rooftop monitoring to measure background air quality, street-level monitoring of air quality along roads, and airport monitoring. DOAS systems are more expensive than a single fixed–point analyser but can measure many determinands simultaneously.

9.3 Practical Methodologies for VOCs of Specific Interest to this Study

9.3.1 1,3-butadiene

This compound is routinely monitored as part of the DEFRA's Hydrocarbon Network of sites using the semi-continuous GC method as described previously. Manual sampling of 1,3-butadiene is difficult because its high reactivity leads to sample instability when collected on common sorbents such as Tenax. Cryogenic trapping is preferred but the use of two charcoal sorbent tubes in series followed by GC-FID has been successful (NIOSH method 1024).

9.3.2 Halogenated Organic Compounds

An ISO working group (ISO/TC 147/SC 2/WG 12) is considering a standard method for analysis of halogenated hydrocarbons and pesticides. Current approaches to analysis are centred on gas chromatography, with either FID, PID, MS or electron capture detection (ECD). Many chlorocarbons such as trichloromethane (Freon-11), dichlorodifluoromethane (Freon-12), chloroform and methyl chloroform (1,1,1-trichloroethane) can be simply and accurately measured by direct injection of ambient air into a GC with ECD.

Most manual methods of sampling halogenated hydrocarbons, fluorocarbons and chlorofluorocarbons involve sampling on a solid sorbent, e.g. Tenax GC, activated carbon, XAD-2 resin, or polyurethane foam plugs. Most methods use active sampling but diffusive charcoal samplers can be employed. The compounds are desorbed thermally or by solvent extraction (depending on the sorbent type) before analysis.

Automatically cycling GC systems for unattended operation in air quality monitoring networks use cryogenic trapping to provide a concentrated sample for analysis. Portable GC-FID or GC-PID systems can separate and quantify a selection of pre-targeted halogenated hydrocarbons down to the low ppb level expected in ambient monitoring.

9.4 New Developments in Gas Chromatography

Recent developments in analytical instrumentation have resulted in the refinement of chromatographic techniques to increase resolution at the concentrations experienced typically in the ambient air. Capillary gas chromatography systems are available for the measurement of C_2 to C_5, and C_6 to C_{10} hydrocarbons that accomplish the pre-concentration of the VOC components without the need for cryogenics. Reference analytical application methods are available for most of the VOC species of concern to the situation in North Lynn. Minimum Limit of Detection for VOCs varies according to the species concerned, but for certain species, measurements at concentrations as low as 100 parts per trillion are claimed possible.

10. Suggestions for a Programme of VOC Monitoring

There are two main issues to be resolved in relation to the concerns over VOC release from industrial processes in the North Lynn area and their potential impact on health of the local communities. The first is to identify unambiguously the major VOC species present in the ambient air in the North Lynn area. The second issue relates to quantifying, with a reasonable degree of confidence, the concentration of those VOCs present in the ambient air in the North Lynn area. This information is required by health specialists to determine whether the reported symptoms are consistent with the pollutants identified and their measured concentrations.

Mass spectrometry is the only definitive method for identifying substances by virtue of its ability to differentiate by mass between individual molecular species. Accordingly, it is recommended that an initial survey is carried out using mass spectrometric methods in order to identify the most significant VOCs that are present in the ambient air in the North Lynn area. The application of mass spectrometry using field-based instruments for measurement of airborne pollutants is feasible but prone to substantial technical difficulties. As an alternative approach, it is recommended that samples of VOCs in the ambient air are absorbed onto suitable adsorbents (charcoal in the case of dimethylformamide) and analysed by combined gas chromatography and mass spectrometry (GC-MS) under laboratory conditions by an accredited analytical company. This technique can be carried out either as a diffusive technique, which would give long term average data (monthly averages) or using pumped samplers that could provide short term average data (hourly, 8 hourly, daily etc).

A phased approach to sampling onto sorbent materials is recommended. The first is to undertake an initial diffusion tube survey at specific locations for one month in order to identify definitively, using GC-MS, the most significant VOC species present in the ambient air. Diffusive sampling would provide a semi-quantitative assessment of the significance of the VOC species present in the ambient air in the North Lynn area. Diffusion tubes would be deployed at a number of locations around the industrial estates to provide good directional coverage and to take account of the variability of wind direction within the area.

With this initial information, a targeted programme of measurement could then be undertaken using pumped sampling onto sorbent tubes at selected locations within North Lynn over a period of one week. It is suggested that monitoring should be undertaken at St Edmunds School and at a residential location in Estuary Road, along with other locations identified from the diffusive sampling survey. Both locations were included in the modelling exercise and results indicated that ambient concentrations of dimethylformamide and 1,3-butadiene might be a significant proportion of their respective environmental assessment levels at these locations.

It is also recommended that in conjunction with the pumped sampling programme that a survey of ambient VOC concentrations in the North Lynn area is carried out simultaneously using portable measurement equipment. With the natural variability of the prevailing winds, the concentration of airborne pollutants may vary considerably at a particular location. Using portable instruments it is possible to move the sampling system to maintain position within an air flow that may be contaminated with pollutants released from a particular source. The portable instruments will give an indication of the short term variability in VOC concentrations at specific locations.

For this type of application it is likely that gas chromatography (GC) may be best suited for the measurement of VOCs such as dimethylformamide and 1,3-butadiene. Although identification of substances is less precise than by mass spectrometry, portable GC systems offer the possibility of real time measurement of VOCs at ppb levels in the ambient air. The results from the portable GC can be verified for accuracy in identification of species by comparison with the mass spectra of the samples collected by the pumped samplers. The results from a survey using portable instruments would also assist in identifying appropriate locations for any longer term measurement programme that may be required.

The results from the proposed monitoring programmes should provide reliable information on which the North Lynn Area Group, King’s Lynn BC and the Environment Agency can decide on the requirements for a more intensive and possibly extended measurement programme for VOCs in the North Lynn area. This would necessitate the establishment of a semi-permanent installation, probably based on gas chromatography, at a suitable location within the North Lynn area.

11. Conclusions

EMC Environment Engineering Ltd was contracted by North Lynn Area Group which is made up from representatives from King's Lynn and West Norfolk Borough Council, Environment Agency, Norfolk Health Authority, Health and Safety Executive, Local Industry and Local Residents to undertake a desktop study of air quality in the King’s Lynn area. There is concern within the North Lynn area that releases of certain VOCs from nearby industrial operations may be adversely affecting the health of sections of the local community.

EMC Environment Engineering Ltd has reviewed the available data on emissions of VOCs from industrial processes within the North Lynn area and commented on their potential impact on local air quality. The study has identified several issues that may warrant further investigation, however, it is the responsibility of the Air Quality Sub Group to make recommendations for further action on the basis of the results and conclusions presented here.

Particular emphasis was given in the study to identifying the major industrial sources of VOC emissions in the North Lynn area and to estimating their likely impact on local air quality. The following conclusions have been drawn from the study:

1. Information supplied by King’s Lynn BC and the Environment Agency shows that there are appreciable releases of certain VOC species from industrial processes in the North Lynn area of the town.

2. Emissions of VOCs from all of the sites considered in this study are within their respective prescribed limits as defined in their IPC (Environment Agency) or LAAPC (Kings Lynn BC) Authorisations.

3. Information from the Environment Agency’s Pollution Inventory indicates that the VOC with the greatest annual release is dimethylformamide, of which 138 tonne was released during 2002 from the Porvair International Ltd site (AK3169).

4. Porvair International Ltd is also responsible for other appreciable annual releases of VOCs in the North Lynn area with ~70 tonne of cyclohexanone, ~22 tonne of dichloromethane, and ~10 tonne of tetrachloroethene. Examination of the historical data shows a significant downward trend in emissions of all major species over the past three years, apart from tetrachloroethene which has remained relatively constant.

5. Releases of VOCs from the IPC Authorised processes operated by the Dow Chemical Company are at a lower level than those from Porvair International Ltd. Nevertheless, emissions of 1,3-butadiene, acrylonitrile, styrene and butene represent appreciable quantities, which may have a measurable impact on local air quality.

6. Of the smaller industrial processes within the North Lynn area that are outside the IPC regulatory framework, Williams Refrigeration is responsible for appreciable releases of VOCs, particularly dichloromethane and trichloroethylene.

7. The potential impact of VOC releases on air quality within the area is related primarily to the magnitude of the release, whether or not it is released in a controlled manner from a stack or chimney, or whether it is an uncontrolled, fugitive release. Of all of the specific VOCs identified in the Environment Agency Pollution Inventory data, dimethylformamide is probably the most important in terms of its potential impact on local air quality.

8. The results from screening analyses (Table 3 and Table 4) of the dispersal of dimethylformamide from the Porvair International Ltd site suggest that the impact on local air quality might warrant further investigation. The magnitude of the predicted maximum contribution to ground level concentrations is well below respective EALs, but represents an appreciable proportion of the

EAL and exceeds the long term significance threshold as described in Section 6.1. Despite the lack of refinement in the modelling procedures utilised, as a precautionary measure, consideration should be given to undertaking a programme of measurement of dimethylformamide in the ambient air in vicinity of the Porvair International site. More detailed modelling may also assist in identification of locations where exposure to pollutants may be a cause for concern.

9. The air quality standard for 1,3-butadiene is low (2.25 $\mu g\ m^{-3}$), and the release of this pollutant from the Dow site in Estuary Road may have a measurable impact on local air quality. However, screening methodologies carried out in conjunction with the Environment Agency during the Stage 2 Review concluded that there was not a significant risk of exceeding the 2003 Objective Value. No measurements of ambient concentrations of 1,3-butadiene have been undertaken to date by King's Lynn BC. It may be appropriate to undertake measurements to quantify the impact of this release on air quality and to confirm the Stage 2 Review conclusion.

10. The potential impact of VOC emissions on air quality in the vicinity of St Edmunds School and the residential area in Estuary Road was low in all cases, and represented less than 1% of the EAL apart from the case for 1,3-butadiene. The predicted annual average value of 0.05 $\mu g\ m^{-3}$ for 1,3-butadiene represents ~2% of the long term EAL.

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APPENDIX 1 Modelling of the Potential Contribution of Process Releases to Ground Level Concentrations of VOCs in the North Lynn Area

E1 Screening

Environment Agency Technical Guidance Note E1[23] and IPPC Horizontal Guidance Note H1[24], give guidance on a methodology for estimating short and long term contributions of process emissions to ground level pollutant concentrations. The methodology is based on the following formula:

$$\mathbf{PC_{air} = GLC \times RR}$$

Where:

PC = predicted concentration (µg m^{-3})
RR = Release Rate (g s^{-1})
GLC = maximum average ground level concentration for unit mass release rate (µg m^{-3} per g s^{-1}) based on annual average for long term releases, and hourly average for short term releases.

Effective Height of Release (Metres)	Ground Level Concentration for Unit Mass Emission Rate (µg m^{-3} per g s^{-1})	
	Annual Average	**Maximum Hourly Average**
0	60 (At 100 m from stack)	4070 (At 100m from Stack)
10	15	450
20	2.7	200
30	0.9	81
50	0.27	27

Table 6 Factors to be Used in Estimating Ground Level Concentration

The values of the long term factors relate to Pasquill Stability Class D (neutral) meteorological conditions for 60% of the time. No allowance is made for thermal or momentum plume rise effects. For the short term factors, Pasquill Stability Class B (moderately unstable) meteorological conditions are assumed.

Using the data from the Environment Agency Pollution Inventory, the following pollutant release rates have been calculated assuming that there is a constant release over the complete year. No information was available from the Environment Agency relating to specific emissions release data, nor on the occurrence of transient pollutant emission excursions that may contribute to odour incidents and the incidence of health effects. This may be an oversimplification of the situation at the various sites. However, the absence of detailed information on the pattern of VOC release precludes a more detailed analysis.

Annual Release (tonne)		Pollutant	Release Rate (g s^{-1})	
Porvair Int.	**Dow**		**Porvair Int.**	**Dow**
138	-	**Dimethylformamide**	4.38	-
77.2	-	**Cyclohexanone**	2.45	-
21.5	0.895*	**Dichloromethane**	0.68	0.03
9.6	-	**Tetrachloroethene**	0.30	-
-	0.6	**Styrene**	-	0.018
-	0.569*	**1,3-butadiene**	-	0.013
-	0.1**	**Acrylonitrile**	-	0.003
-	10	**Butene**	-	0.32

Table 7 Release Rates for VOCs from Porvair International and Dow Chemical Company Ltd

Notes: * Data for 2001. Data reported for 2002 as <1000 kg.

** Data for 2001. No data reported for 2002.

The process buildings at Porvair International and Dow Chemical Company are assumed to be 20 metres tall. Using the factors in Table 6 the following estimates of ground level VOC concentrations have been derived:

Pollutant	**Release Rate ($g\ s^{-1}$)**	**Long Term**		**Short Term**	
		Conc. ($\mu g\ m^{-3}$)	**EAL ($\mu g\ m^{-3}$)**	**Conc. ($\mu g\ m^{-3}$)**	**EAL ($\mu g\ m^{-3}$)**
Dimethylformamide	4.38	12	300	876	6,100
Cyclohexanone	2.45	7	1,020	490	40,080
Dichloromethane	0.68	2	700	136	3,000
Tetrachloroethene	0.30	0.8	3,450	60	8,000

Table 8 **Estimated Ground Level Concentrations Arising From Release of VOCs From Porvair International Ltd**

Pollutant	**Release Rate (g s-1)**	**Long Term**		**Short Term**	
		Conc. ($\mu g\ m^{-3}$)	**EAL ($\mu g\ m^{-3}$)**	**Conc. ($\mu g\ m^{-3}$)**	**EAL ($\mu g\ m^{-3}$)**
Dichloromethane	0.03	0.05	700	6	3,000
Styrene	0.018	0.05	840	4	160
1,3-butadiene	0.013	0.04	2.25	3	1,100
Acrylonitrile	0.003	0.008	700	0.6	4,700
Butene	0.32	0.9	-	64	-

Table 9 **Estimated Ground Level Concentrations Arising From Release of VOCs From Dow Chemical Company Ltd**

As can be seen, the results from the above E1 Screening analysis are all well within their respective environmental assessment levels. However, in view of the assumptions relating to the calculations of the release rates, the results in Table 8 and Table 9 may underestimate the potential impact of VOC release on local air quality.

The most significant result relates to dimethylformamide where the long term value represents about one tenth of the EAL and the short term value is about one third of the corresponding EAL.

APPENDIX 2 LAQM TG4(00) Methodology for 1,3-butadiene

DEFRA's Technical Guidance Note TG4(00) gives an improved methodology for estimating the potential impact on air quality of pollutant releases from industrial process sites. Two nomograms have been prepared which estimate the emission rate (in tonnes per annum) which would produce a maximum running annual mean ground level concentration of 0.225 µg m^{-3} (0.1 ppb), equivalent to 10% of the air quality objective for 1,3-butadiene.

The nomogram uses the effective stack height. This can be assumed to be equal to the actual (physical) stack height unless:

The height of release is greater than 3 m above the building on which it sits, but less than 2.5 times the height of the tallest adjacent building. In this case the effective stack height can be calculated from the following formula:

$$\mathbf{U_{eff} = 1 \cdot 66(U_{act} - 1)}$$

where:

U_{eff} is the effective stack height; and
U_{act} is the actual (physical) stack height

King's Lynn BC undertook an assessment of releases of 1,3-butadiene from the Dow Chemicals Ltd site using the TG4(00) methodology. Their assessment was carried out on the basis that the nearest sensitive receptor was 330 metres away, and concluded that for 1,3-butadiene, an annual release of more than 600 kg h^{-1} was required to produce a ground level concentration that would be considered significant.

The Pollution Inventory data for 2000 show that 408 kg of 1,3-butadiene were released from the Dow site. Therefore, the screening methodology suggests that emissions of 1,3-butadiene are unlikely to result in significant ground level concentrations.

It is not possible to comment on the significance of the releases of other VOCs from industrial sites in the North Lynn area as nomograms for these species are not available.

APPENDIX 3 Atmospheric Dispersion Modelling of Potential Impact of VOC Release on Local Air Quality in the North Lynn Area

The only definitive means of quantifying the impact of process emissions on local air quality is to undertake a programme of environmental monitoring around the site in question. As an alternative, atmospheric dispersion modelling provides a means of estimating potential impacts with a reasonable degree of confidence. The dispersal of pollutants released into the atmosphere is modelled in relation to a number of key parameters in order to calculate an estimate of the contribution to ground level pollutant concentrations arising from the release.

On the basis of the pollutant emissions inventory data obtained from the Environment Agency's website, an atmospheric dispersion model was developed to examine the potential impact on local air quality of VOC releases from the industrial sites identified in Section 2. In the absence of detailed information on the release characteristics, and the temporal variation in release rates, a screening model was developed in order to provide an indication of possible VOC ground level concentrations that may arise from releases at Porvair and Dow.

In view of the gross assumptions made in relation to the release characteristics of the pollutants and their mode of release, the results from this dispersion modelling exercise should be considered as indicative only.

Model Parameters

Plume Height

Chimneys and stacks are used to disperse exhaust gases to the atmosphere, and are designed to give acceptable ground level concentrations both locally and further afield. The principal parameters affecting the rate of dispersion are stack height, gas exit velocity (or efflux velocity) and gas temperature. The latter two determine the effective increased height of the gas plume, resulting from momentum and buoyancy.

Computer Model Selection

Guidance on the use of dispersion models in the UK is given in Guidance Note, LAQM.TG3(00)[25], issued originally by the Department of Environment Transport and The Regions (DETR). A range of different models are available for modelling the impact of pollutant emissions to atmosphere on local air quality. Those used routinely in the UK for this sort of application include US EPA models such as AERMOD, and the ADMS models developed in the UK by Cambridge Environmental Research Consultants (CERC)[26].

Modelling procedures are generally classified as Gaussian, numerical, statistical and physical. They can be applied at different levels of sophistication. The first simple level consists of generally, relatively simple estimation techniques that provide "worst case" estimates of the air quality impact of a specific source. These are "screening techniques" or "screening models". Satisfactory screening results avoid the need for further detailed modelling for those sources that clearly will not cause unacceptable ground level concentrations of pollutants. The second more complex level provides more accurate concentration estimates and involves analytical techniques which consider detailed treatment of physical and chemical atmospheric processes and require more detailed and precise input data relating to meteorological conditions and local topography.

The computer programme selected for this application was Version 3 of the ADMS model developed by Cambridge Environmental Research Consultants Ltd. The model is described as a "skewed Gaussian model" which can be used to assess ambient pollutant concentrations arising from a wide variety of emissions sources associated with an industrial source. It can be used for initial screening or more refined determination of ground level pollutant concentrations on either a short term basis (up to 24 hour averages) or longer term (monthly, quarterly or annual averages).

The ADMS model incorporates a more rigorous treatment of the interaction between a plume and the boundary layer than other models such as the US-EPA's ISC models. In ADMS 3 the boundary layer is characterised by the boundary layer height and the Monin-Obukhov length (L_{MO}) and not, as in the case of US-EPA methodologies, by a Pasquill-Gifford stability category. The use of the Monin-Obukhov length enables the variation in boundary layer properties with height to be included in the calculations, providing a potentially more-realistic treatment of plume dispersion under convective conditions. The Monin-Obukhov length is defined as:

$$L_{MO} = \frac{-u_*^3}{\kappa\, gF_{\theta_0} \,/\, \left(\rho\, c_p T_0\right)}$$

Where, u_* is the friction velocity; κ is von Karman's constant (0.4); $F_{\theta 0}$ the surface sensible heat flux; T_0 the near surface temperature; ρ the density and c_p the specific heat capacity of the gas.

Input Data

Plant Details

The ADMS3 model requires that the source of emissions is defined in terms of dimensions, location and physical characteristics of temperature and velocity. The modelling exercise has been carried out to assess the potential impact on local air quality due to releases of VOCs from the various factories identified in Section 2.

Detailed information was not available on the release characteristics of the various factories. Accordingly, in order to give an indication of the potential contribution to ground level concentrations of the various VOC species, each factory was treated as an area source. ADMS3 requires that the release rates are defined in units of $g.m^{-2}s^{-1}$. Accordingly the annual release rate given in the Environment Agency pollution inventory was divided by the estimated area of the factory concerned. Releases from both the Porvair and Dow industrial sites were considered in the screening model.

Gross assumptions have been made that each factory occupies a rectangular "footprint" and that the annual release is uniform across the total surface area of the factory. The modelling results should only be considered as indicative in order to give an estimate of the potential significance of contributions to ground level concentrations. Table 10 presents the parameters used in the modelling studies.

Table 10 Modelled Characteristics of the Factories Associated with VOC Release

	Height	Area of Buildings	Temperature
Porvair	20 metres	18,000 m^2	100 °C
Dow	20 metres	47,300 m^2	100 °C

Pollutant Emissions

The model was developed to assess the impact on local air quality of emissions of VOCs from the Porvair and Dow sites. Data on discharges of VOCs were derived from the Environment Agency's pollutant emissions inventory data and are summarised in Table 11.

Table 11 Pollutant Release Characteristics from the VOC Emission Points

Pollutant	Mass release Rate (g m^{-2} s^{-1})	
	Porvair	**Dow**
Dimethylformamide	0.000243	0.0
Cyclohexanone	0.000136	0.0
Dichloromethane	0.000038	0.000000604
Tetrachloroethene	0.000017	0.0

Pollutant	**Mass release Rate (g m^{-2} s^{-1})**	
Styrene	0.0	0.000000402
1,3-butadiene	0.0	0.000000274
Acrylonitrile	0.0	0.000000067

Meteorological Data

When modelling plume dispersion, the following meteorological data are required as a minimum:

wind speed
stability conditions
wind direction
mixing height

For the purposes of this screening exercise, an annual dataset of hourly averaged meteorological data from the MetOffice's monitoring station at Wyton, Cambridgeshire were utilised. In view of the uncertainties associated with the pollutant release characteristics and their mode of release from the factories in North Lynn, it was considered that no significant benefit would result from the use of data from the station at Marham, which is closer geographically to King's Lynn. Furthermore, the Marham data is not as extensive as the Wyton data. It was concluded that the Wyton data would provide a more rigorous basis for determining the potential worst case impact of process emissions on local air quality than with the Marham data. The windrose for the Wyton dataset is shown below.

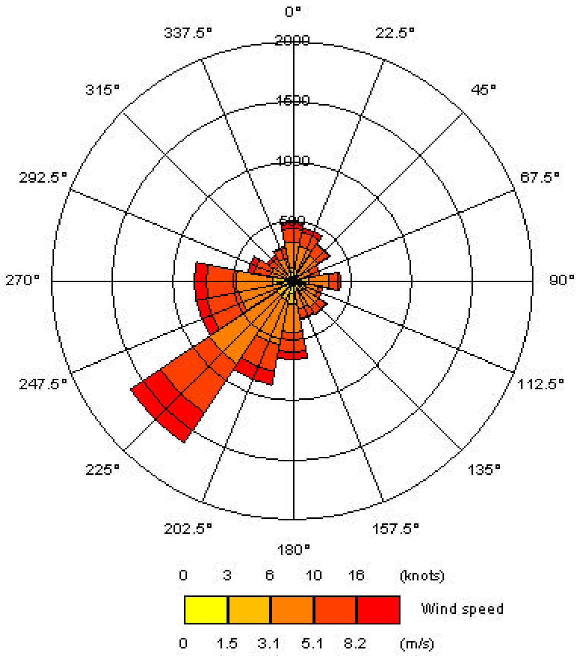

Figure 4 Windrose for the MetOffice Station at Wyton

As can be seen, the winds are predominantly from the southwest, the prevailing wind direction for this part of the UK. Both St Edmunds School and the North Lynn residential area are predominantly to the south east of the Porvair and Dow industrial sites and therefore on the majority of instances would not be expected to be affected directly by airborne pollutants arising from these sites.

Local Environmental Conditions

Local environmental conditions describe the factors that might influence the dispersion process (such as nearby structures, sharply rising terrain etc.) and also describe the locations at which pollutant concentrations are to be predicted. These include:

Nearby Buildings and Structures

If the stack is located on the top of a building, or adjacent to a tall building, then the size of these buildings may need to be considered. As a general guide, building downwash problems (where emissions are caught in the turbulent wake caused by wind blowing around the building) may occur if the stack height is less than 2½ times the height of the building upon which it sits. Adjacent buildings may need to be taken into account if they are within about 5 stack heights of the point of release. To take account of local building effects, models generally require information related to the dimensions and location of the structures with respect to the stack.

No information was available on building dimensions or nearby structures, accordingly, effects of buildings or nearby structures were not considered in this modelling study.

Surface Roughness

It is sometimes necessary to define a term, which describes the degree of ground turbulence caused by the passage of winds across surface structures, also called the surface roughness. The degree of ground turbulence is much greater in urban areas (due to the presence of tall buildings) than in rural areas (which contain smaller obstacles at the surface). The dispersion model may require the user to select “urban” or “rural” conditions, or to specify a “surface roughness length” according to defined criteria. Calculations of dispersion, which take account of the greater aerodynamic roughness of the surface structures in urban areas, tend to predict higher concentrations closer to the stack than calculations under equivalent conditions, which assume typical rural roughness.

For the purpose of this model a surface roughness factor of 1 was chosen, characteristic of cities and woodlands.

Complex Terrain

The presence of steep hills in the vicinity of the stack may affect the dispersion of pollutants. During more stable conditions, an elevated plume may impact upon a nearby hillside, resulting in much higher ground level concentrations than would occur over flat terrain. The more sophisticated models can take account of these terrain effects, and require the input of contour heights in the immediate area surrounding the stack. Terrain effects are unlikely to be significant where the hills have a slope of less than about 10%.

As the area around King’s Lynn is relatively flat terrain modelling was disregarded.

Receptor Locations

It is necessary to define the locations at which ground level concentrations are to be calculated by the model. In selecting receptor locations, it is general practice to identify the nearest, sensitive locations to the chimney stack, such as residential housing, hospitals etc. Many models allow the user to specify a 'grid' of receptor locations. However, when setting up a receptor grid it is important to ensure that there are sufficient receptor points to able to predict the magnitude and location of the maximum concentration. If the grid of receptor points is too widely spaced, the maximum concentration may be missed.

For this modelling exercise a receptor grid covering an area 3 x 3 kilometres with 961 receptor points was set up in order to assess the potential impact of VOC emissions on the surrounding communities. In addition, specific receptor locations corresponding to St Edmunds School and the North Lynn residential area were also included.

Modelling Assumptions

In order to carry out the modelling study it has been necessary to make several assumptions. Some of these have been described above, however a comprehensive list follows:

1. A screening analysis was carried out in order to give an indication of potential contributions to ground level concentrations of VOC releases from the Porvair and Dow industrial sites.
2. Pollutant discharge rates were calculated from data in the Environment Agency's Pollutant Inventory.
3. No consideration was given to the effects of adjacent buildings or terrain effects in the modelling procedures.
4. Hourly averaged meteorological data for Wyton, Northamptonshire were used in the modelling exercise to give a more realistic estimate of the natural variability of meteorological conditions within the area.
5. Modelling scenarios were developed to estimate the contribution of emissions of VOCs from the Porvair International Ltd and Dow Chemical Company sites to ambient concentrations of VOCs based on Environment Agency emissions inventory data.

Results and Discussion

The results from the ADMS modelling are discussed in Section 7.

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