Cambridge Environmental Research Consultants

Dispersion modelling assessment of emissions of VOCs, Essar Tranmere Oil Terminal

Draft report

Prepared for
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CERC

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Contents

1 Summary

Cambridge Environmental Research Consultants Ltd (CERC) was commissioned by Essar Oil (UK) Limited (Essar Oil) to carry out dispersion modelling of emissions to air of volatile organic compounds (VOCs) at a ship loading facility at Tranmere on the Wirral.

A Vapour Recovery Unit will recover VOCs from displaced tanker ullage and the remaining VOCs will be emitted to air via a vent stack. Two cases were modelled, each representing a different composition: E10 Base Oil Blend; and MoGas.

A dispersion modelling assessment of the emissions was carried out using the ADMS model (version 6.0.0.1). Essar Oil provided all site, stack and emissions data.

For both the E10 Base Oil Blend and MoGas scenarios, maximum annual and hourly average offsite concentrations of all hydrocarbons with relevant EALs are screened out, as they are less than 1% and 10% of the respective EALs. Concentrations at the modelled receptors are even lower, 0.1 % or less of the EALs.

2 Introduction

Cambridge Environmental Research Consultants Ltd (CERC) was commissioned by Essar Oil (UK) Limited (Essar Oil) to carry out dispersion modelling emissions to air of volatile organic compounds (VOCs) at a ship loading facility at Tranmere on the Wirral.

A Vapour Recovery Unit will recover VOCs from displaced tanker ullage and the remaining VOCs will be emitted to air via a vent stack. Two cases were modelled, each representing a different composition: E10 Base Oil Blend; and MoGas.

A dispersion modelling assessment of the emissions was carried out using the ADMS model (version 6.0.0.1). Essar Oil provided all site, stack and emissions data.

The model inputs and the results of the dispersion modelling are described in this report. Section 3 presents the air quality standards with which the modelled results are compared. Details of the site location and surrounding area are given in Section 0, including identified sensitive receptors and background concentrations for the area. Model input data, including stack emissions, are detailed in Section 5. The meteorological data input to the modelling are described in Section 6.

Section 7 presents the maximum offsite concentrations, and a discussion of the implications of the modelling results is provided in Section 7.2.1.

Finally, a description of the ADMS model used in the assessment is given in Appendix A.

3 Air quality standards

Table 3.1 shows the long-term and short-term Environmental Assessment Levels (EALs) for butane.

Table 3.1: Environmental Assessment Levels (EALs) for butane (µg/m^3)

Substance	Limit value	Reference period
Butane	181,000	1 hour mean (short-term)
	14,500	annual mean (long-term)

Impacts of propane, pentane, butene and pentene are also under assessment. Although no official EALs exist for these four hydrocarbons, Essar Oil has derived EALs for pentane, butane and pentene, which were approved for use by the Environment Agency. These EALs are set out in Table 3.2.

Table 3.2: Derived Environmental Assessment Levels (EALs) (µg/m^3)

Substance	Long-term (8-hr)	Short-term (15-min)
Pentane	180,000 [1]	-
Butene	As butane	As butane
Pentene	As pentane	-

No EALs were found for propane, but it is understood that this hydrocarbon has even lower toxicity than those included above.

[1] Derived as 10% of the Workplace Exposure Limit

4 Assessment area

4.1 Site location and surrounding area

Essar Tranmere Oil Terminal is located on the west side of the River Mersey, on the Wirral Peninsula. The towns of Birkenhead and Bebington are situated to the north and south of the terminal, respectively. The vent stack will be located in the south east of the terminal, by the ship loading facility.

The location of the oil terminal, and the location of the vent stack within the site, are shown in **Error! Reference source not found.**.

Figure 4.2 shows a more detailed plan with the site boundary marked on it.

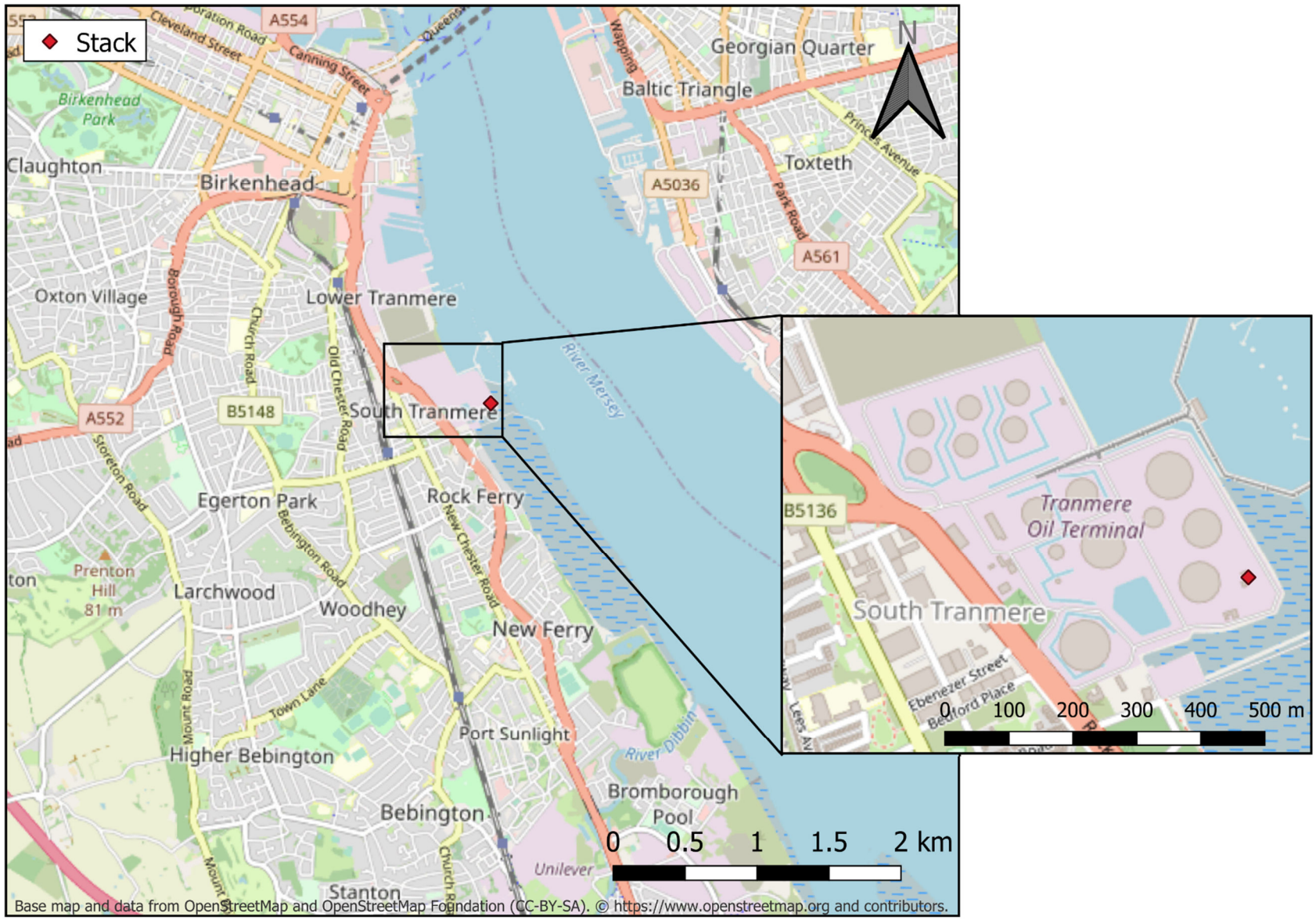

Figure 4.1: Locations of site and vent stack

4.2 Sensitive receptors

Model output was generated over an output grid extending 2 km by 2 km, centred on the vent stack, with a 20 m resolution, capturing the maximum predicted concentrations across the modelled area. Model output was also generated at locations of specific sensitive receptors. The locations of these receptors are described in Table 4.1 and shown in Figure 4.2. All sensitive receptors were modelled at ground level.

Table 4.1: Sensitive human health receptors

Id	Name	Type	Location (X, Y)
1	Rock Ferry Primary	School	332980, 386852
2	Rock Park	Residential	333474, 386725
3	Mersey Road	Residential	333256, 386815
4	Well Lane Primary	School	332361, 387015
5	Evergreen Lodge Care Centre	Care home	333246, 386581
6	Union Street	Residential	332632, 387397

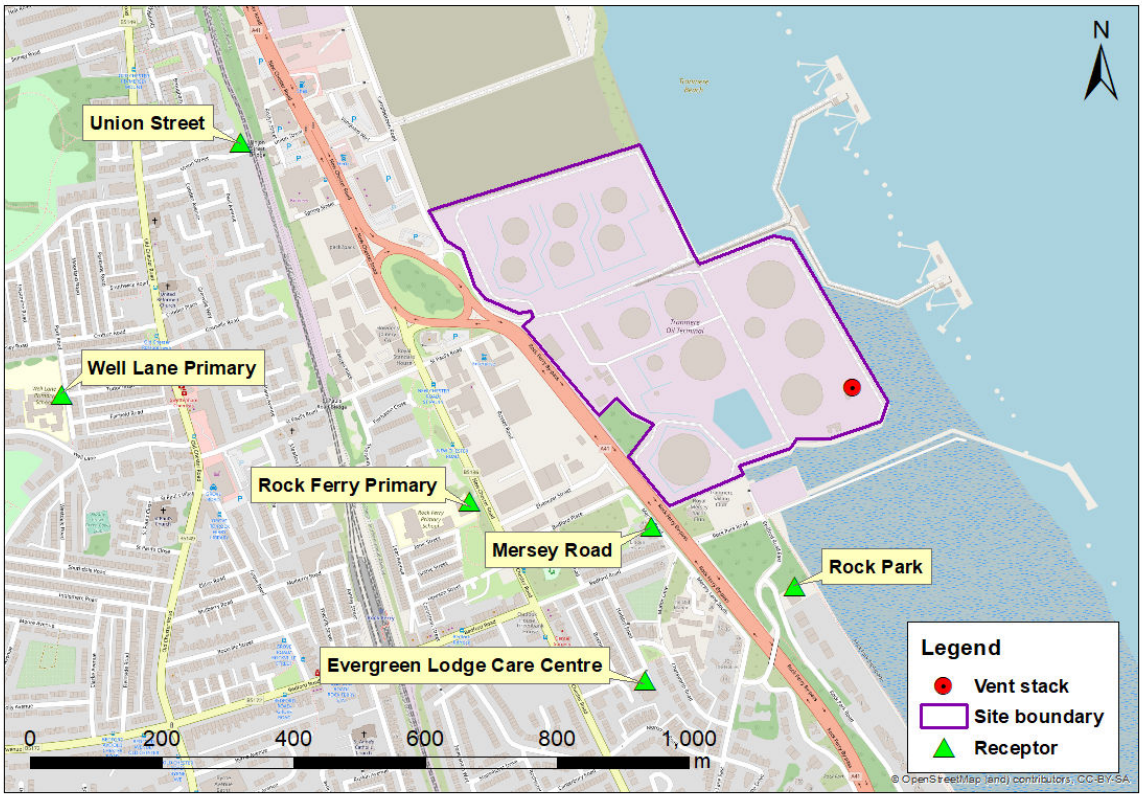

Figure 4.2: Location of sensitive receptors

5 Modelled data

5.1 Modelled stack and emissions

This report considers emissions of hydrocarbon VOCs from the vent stack. The location of the modelled stack is shown in **Error! Reference source not found.**.

The emissions will actually be released at a velocity of 9.3 m/s at an angle of 45° upwards from the horizontal. However, so as to be able to take building downwash effects into account, the vent stack was modelled as a point source (vertical release), using only the vertical component of the efflux velocity.

Table 5.1 presents the modelled stack data and Table 5.2 shows modelled emissions data associated with the MoGas and E10 Base Oil Blend, respectively. In each case, the vent stack emissions were assumed to be continuous throughout the year, which is a conservative approach.

The emission release temperature follows the ambient temperature from the meteorological data file for each hour, with an applied 30 °C upper and 10 °C lower temperature limit. This was used to reflect the fact that the temperature of the emission is likely to vary approximately in line with the ambient temperature, but is unlikely to fluctuate more than 10 °C beyond the assumed loading temperature of 20 °C.

Table 5.1: Modelled stack parameters

OSGB Location		Height (m)	Diameter (m)	Velocity (m/s)
X	Y			
333562	387026	12	0.25	6.6

Table 5.2: Modelled emission rates (g/s)

Substance	MoGas scenario	E10 scenario
Butane	1.35	1.03
Butene	0.56	0.76
Pentane	1.55	1.48
Pentene	0.80	0.93
Propane	-	0.06

5.2 Model setup

A surface roughness length is used in the model to characterise the surrounding area in terms of the effects it will have on wind speed and turbulence, which are key components of the modelling. A surface roughness value of 0.3 metres was used for the modelled area, which represents the land use around the site. A surface roughness value of 0.2 metres was used for Liverpool Airport meteorological station. See Section 6 for further information regarding the meteorological data used in the modelling.

The surrounding area is generally flat, and so the effects of terrain on dispersion were considered negligible and not taken into account in the modelling.

Buildings that are relatively close to the modelled stack and higher than one third of the stack height can have an effect on dispersion, by disturbing wind flows and increasing turbulence. Two carbon bed absorber vessels are located adjacent to the vent stack. These are likely to impact on dispersion from the stack so were included in the modelling. Parameters for both vessels are presented in Table 5.3 and the relative locations of stack and buildings are shown on Figure 5.1.

Table 5.3: Modelled carbon bed absorber vessels

Building	Shape	Height (m)	Diameter (m)	OSGB Location (m)	
				X	Y
Carbon bed absorber 1	Circular	9	2.8	333559.9	387023.3
Carbon bed absorber 2	Circular	9	2.8	333563.8	387025.6

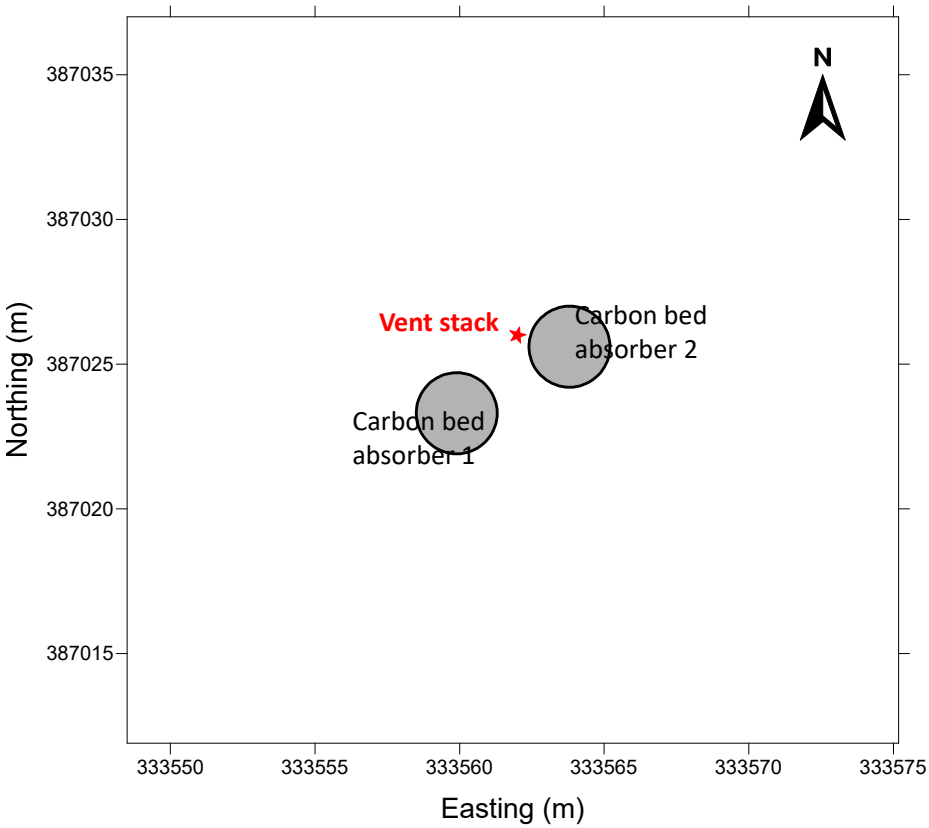

Figure 5.1: Modelled stack and carbon bed absorber vessels

6 Meteorological data

Modelling was carried out using hourly sequential meteorological data obtained from Liverpool Airport for the five years 2016 to 2020 inclusive. Liverpool Airport is located approximately 10 km south-east of the vent stack.

The hours of meteorological data used in the analysis exclude hours of calm, hours of variable wind direction and unavailable data, for example due to issues with the instrumentation. A summary of the data used is given in Table 6.1. The ADMS meteorological pre-processor, written by the Met Office, uses the meteorological data to calculate the parameters required by the model.

Figure 6.1 shows wind roses for Liverpool Airport, giving the frequency of occurrence of wind from different directions for a number of wind speed ranges, for the five years 2016 to 2020.

Table 6.1: Summary of meteorological data used

Year	Percentage used	Parameter	Minimum	Maximum	Mean
2016	98.0	Temperature (°C)	-3.0	30.0	10.8
		Wind speed (m/s)	0	17.5	4.5
		Cloud cover (oktas)	0	8	3.6
2017	97.9	Temperature (°C)	-3.0	28.0	11.2
		Wind speed (m/s)	0	22.7	4.8
		Cloud cover (oktas)	0	8	4.2
2018	95.8	Temperature (°C)	-5.0	30.0	11.2
		Wind speed (m/s)	0	22.1	4.6
		Cloud cover (oktas)	0	8	3.9
2019	97.4	Temperature (°C)	-4.0	31.0	11.1
		Wind speed (m/s)	0	18.0	4.6
		Cloud cover (oktas)	0	8	3.8
2020	98.2	Temperature (°C)	-1.0	30.0	11.5
		Wind speed (m/s)	0	16.5	4.9
		Cloud cover (oktas)	0	8	4.0

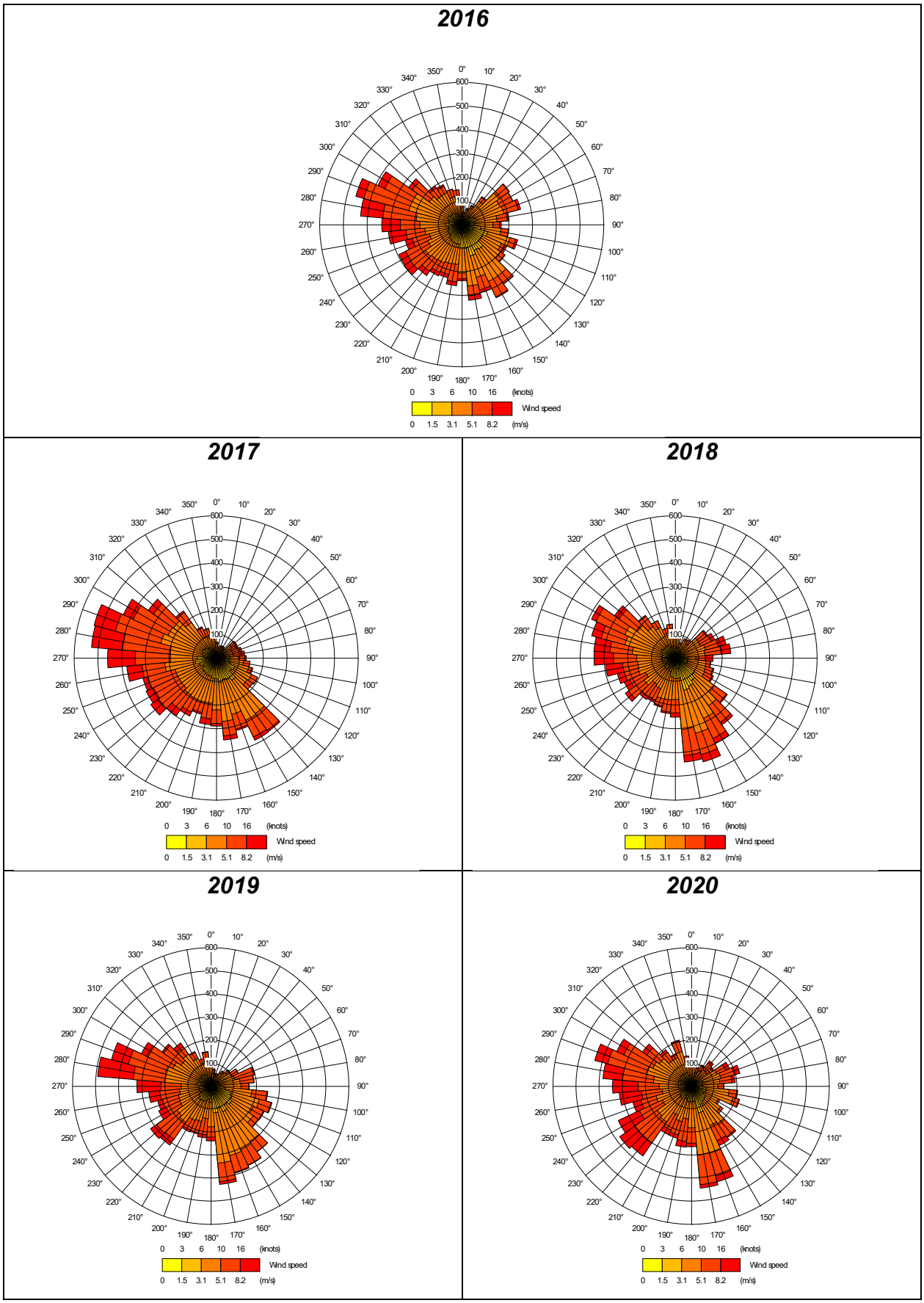

Figure 6.1: Wind roses for Liverpool Airport

7 Results

The significance of the released emissions was assessed by comparing the Process Contribution (PC) of each hydrocarbon to the relevant air quality standards, where available.

For long-term objectives, the Environment Agency considers the release to be insignificant if the PC is less than 1% of the air quality standard.[2] For short-term objectives, including percentiles, the Agency considers the release to be insignificant if the PC is less than 10% of the air quality standard. Where a release is insignificant, the pollutant is screened out and no further assessment of levels of that pollutant undertaken.

Where a release is significant, the Predicted Environmental Concentration (PEC) is calculated by taking the background concentration of the pollutant into account. For these hydrocarbons, the background concentration is assumed to be negligible, and so the PC is equal to the PEC.

All maximum concentrations represent the maximum offsite concentrations; that is, concentrations within the site boundary were excluded.

[2] https://www.gov.uk/guidance/air-emissions-risk-assessment-for-your-environmental-permit

7.1 E10 Base Oil Blend scenario

7.1.1 Butane

Error! Reference source not found. and **Error! Reference source not found.** show the maximum predicted long- and short-term offsite concentrations of butane, respectively, for the E10 Base Oil Blend scenario, calculated using meteorological data for the five years 2016 to 2020.

Table 7.1: Maximum predicted offsite annual average concentrations of butane (µg/m^3), E10 scenario

Year	EAL	EAL value	PC = PEC	Max. PC % of objective	Screened out?	Location	
						X	Y
2016	LT	14,500	23	0.2	Yes	333620	387005
2017			27	0.2		333620	387005
2018			21	0.1		333620	387005
2019			22	0.2		333620	387005
2020			21	0.1		333620	387005

Table 7.2: Maximum predicted offsite hourly average concentrations of butane (µg/m^3), E10 scenario

Year	EAL	EAL value	PC = PEC	Max. PC % of objective	Screened out?	Location	
						X	Y
2016	ST	181,000	683	0.4	Yes	333600	387045
2017			657	0.5		333580	387065
2018			625	0.5		333580	387065
2019			571	0.3		333600	387045
2020			638	0.5		333580	387065

Maximum annual and hourly average offsite butane concentrations are screened out, as they are less than 1% and 10% of the respective EALs.

As the maximum offsite concentrations are so low, concentrations at the modelled receptors are not presented; they are 0.1 % or less of the EALs.

7.1.2 Butene

Table 7.3 to Table 7.4 show the maximum predicted long- and short-term offsite concentrations of butene, respectively, for the E10 Base Oil Blend scenario, calculated using meteorological data for the five years 2016 to 2020.

Table 7.3: Maximum predicted offsite annual average concentrations of butene (µg/m^3), E10 scenario

Year	EAL	EAL value	PC = PEC	Max. PC % of objective	Screened out?	Location	
						X	Y
2016	LT	14,500	17	0.1	Yes	333620	387005
2017			20	0.1		333620	387005
2018			16	0.1		333620	387005
2019			16	0.1		333620	387005
2020			15	0.1		333620	387005

Table 7.4: Maximum predicted offsite hourly average concentrations of butene (µg/m^3), E10 scenario

Year	EAL	EAL value	PC = PEC	Max. PC % of objective	Screened out?	Location	
						X	Y
2016	ST	181,000	504	0.3	Yes	333600	387045
2017			485	0.3		333580	387065
2018			461	0.3		333580	387065
2019			421	0.2		333600	387045
2020			471	0.3		333580	387065

Maximum annual and hourly average offsite butene concentrations are screened out, as they are less than 1% and 10% of the respective EALs.

As the maximum offsite concentrations are so low, concentrations at the modelled receptors are not presented; they are 0.1 % or less of the EALs.

7.1.3 Pentane

Table 7.5 shows the maximum predicted long-term offsite concentrations of pentane, for the E10 Base Oil Blend scenario, calculated using meteorological data for the five years 2016 to 2020.

Table 7.5: Maximum predicted offsite annual average concentrations of pentane (µg/m^3), E10 scenario

Year	EAL	EAL value	PC = PEC	Max. PC % of objective	Screened out?	Location	
						X	Y
2016	LT	180,000	34	< 0.1	Yes	333620	387005
2017			39	< 0.1		333620	387005
2018			30	< 0.1		333620	387005
2019			32	< 0.1		333620	387005
2020			30	< 0.1		333620	387005

Maximum annual average offsite pentane concentrations are screened out, as they are less than 1% of the long-term EAL.

As the maximum offsite concentrations are so low, concentrations at the modelled receptors are not presented; they are 0.1 % or less of the EAL.

7.1.4 Pentene

Table 7.6 shows the maximum predicted long-term offsite concentrations of pentene, for the E10 Base Oil Blend scenario, calculated using meteorological data for the five years 2016 to 2020.

Table 7.6: Maximum predicted offsite annual average concentrations of pentene (µg/m^3), E10 scenario

Year	EAL	EAL value	PC = PEC	Max. PC % of objective	Screened out?	Location	
						X	Y
2016	LT	180,000	21	< 0.1	Yes	333620	387005
2017			24	< 0.1		333620	387005
2018			19	< 0.1		333620	387005
2019			20	< 0.1		333620	387005
2020			19	< 0.1		333620	387005

Maximum annual average offsite pentene concentrations are screened out, as they are less than 1% of the long-term EAL.

As the maximum offsite concentrations are so low, concentrations at the modelled receptors are not presented; they are 0.1 % or less of the EAL.

7.1.5 Propane

Table 7.7 show the maximum predicted long-term offsite concentrations of propane, for the E10 Base Oil Blend scenario, calculated using meteorological data for the five years 2016 to 2020.

Note that there are no EALs for propane, which has low toxicity.

Table 7.7: Maximum predicted offsite annual average concentrations of propane (µg/m^3), E10 scenario

Year	PC = PEC	Location	
		X	Y
2016	1	333620	387005
2017	2	333620	387005
2018	1	333620	387005
2019	1	333620	387005
2020	1	333620	387005

7.2 MoGas scenario

7.2.1 Butane

Table 7.8 and Table 7.9 show the maximum predicted long- and short-term offsite concentrations of butane, respectively, for the MoGas scenario, calculated using meteorological data for the five years 2016 to 2020.

Table 7.8: Maximum predicted offsite annual average concentrations of butane (µg/m^3), MoGas scenario

Year	EAL	EAL value	PC = PEC	Max. PC % of objective	Screened out?	Location	
						X	Y
2016	LT	14,500	31	0.2	Yes	333620	387005
2017			35	0.2		333620	387005
2018			28	0.2		333620	387005
2019			29	0.2		333620	387005
2020			27	0.2		333620	387005

Table 7.9: Maximum predicted offsite hourly average concentrations of butane (µg/m^3), MoGas scenario

Year	EAL	EAL value	PC = PEC	Max. PC % of objective	Screened out?	Location	
						X	Y
2016	ST	181,000	896	0.5	Yes	333600	387045
2017			861	0.5		333580	387065
2018			819	0.5		333580	387065
2019			748	0.4		333600	387045
2020			837	0.5		333580	387065

Maximum annual and hourly average offsite butane concentrations are screened out, as they are less than 1% and 10% of the respective EALs.

As the maximum offsite concentrations are so low, concentrations at the modelled receptors are not presented; they are 0.1 % or less of the EALs.

7.2.2 Butene

Table 7.10 and Table 7.11 show the maximum predicted long- and short-term offsite concentrations of butene, respectively, for the MoGas scenario, calculated using meteorological data for the five years 2016 to 2020.

Table 7.10: Maximum predicted offsite annual average concentrations of butene (µg/m^3), MoGas scenario

Year	EAL	EAL value	PC = PEC	Max. PC % of objective	Screened out?	Location	
						X	Y
2016	LT	14,500	13	< 0.1	Yes	333620	387005
2017			15	0.1		333620	387005
2018			12	< 0.1		333620	387005
2019			12	< 0.1		333620	387005
2020			11	< 0.1		333620	387005

Table 7.11: Maximum predicted offsite hourly average concentrations of butene (µg/m^3), MoGas scenario

Year	EAL	EAL value	PC = PEC	Max. PC % of objective	Screened out?	Location	
						X	Y
2016	ST	181,000	372	0.2	Yes	333600	387045
2017			357	0.2		333580	387065
2018			340	0.2		333580	387065
2019			310	0.2		333600	387045
2020			347	0.2		333580	387065

Maximum annual and hourly average offsite butene concentrations are screened out, as they are less than 1% and 10% of the respective EALs.

As the maximum offsite concentrations are so low, concentrations at the modelled receptors are not presented; they are 0.1 % or less of the EALs.

7.2.3 Pentane

Table 7.12 shows the maximum predicted long-term offsite concentrations of pentane, for the MoGas scenario, calculated using meteorological data for the five years 2016 to 2020.

Table 7.12: Maximum predicted offsite annual average concentrations of pentane (µg/m^3), MoGas scenario

Year	EAL	EAL value	PC = PEC	Max. PC % of objective	Screened out?	Location	
						X	Y
2016	LT	180,000	35	< 0.1	Yes	333620	387005
2017			41	< 0.1		333620	387005
2018			32	< 0.1		333620	387005
2019			33	< 0.1		333620	387005
2020			31	< 0.1		333620	387005

Maximum annual average offsite pentane concentrations are screened out, as they are less than 1% of the long-term EAL.

As the maximum offsite concentrations are so low, concentrations at the modelled receptors are not presented; they are 0.1 % or less of the EAL.

7.2.4 Pentene

Table 7.13 shows the maximum predicted long-term offsite concentrations of pentene, for the MoGas scenario, calculated using meteorological data for the five years 2016 to 2020.

Table 7.13: Maximum predicted offsite annual average concentrations of pentene (µg/m^3), MoGas scenario

Year	EAL	EAL value	PC = PEC	Max. PC % of objective	Screened out?	Location	
						X	Y
2016	LT	180,000	18	< 0.1	Yes	333620	387005
2017			21	< 0.1		333620	387005
2018			16	< 0.1		333620	387005
2019			17	< 0.1		333620	387005
2020			16	< 0.1		333620	387005

Maximum annual average offsite pentene concentrations are screened out, as they are less than 1% of the long-term EAL.

As the maximum offsite concentrations are so low, concentrations at the modelled receptors are not presented; they are 0.1 % or less of the EAL.

8 Discussion

A Vapour Recovery Unit will recover VOCs from displaced tanker ullage and the remaining VOCs will be emitted to air via a vent stack. Two cases were modelled, each representing a different composition: E10 Base Oil Blend; and MoGas.

For both the E10 Base Oil Blend and MoGas scenarios, maximum annual and hourly average offsite concentrations of all hydrocarbons with relevant EALs are screened out, as they are less than 1% and 10% of the respective EALs.

Concentrations at the modelled receptors are even lower, 0.1 % or less of the EALs.

Appendix A: Summary of ADMS 6

ADMS, the **A**tmospheric **D**ispersion **M**odelling **S**ystem[3], has been developed to make use of the most up-to-date understanding of the airflow and turbulence behaviour in the lower levels of the atmosphere in an easy-to-use computer modelling system for the dispersion of atmospheric emissions. This allows the impact of emissions from industrial and other facilities to be thoroughly investigated as part of an environmental assessment or for other regulatory purposes. The model is supported on Windows 11 and Windows 10 environments.

ADMS's original sponsors included the Environment Agency, the Health and Safety Executive (HSE) and successor power companies of the CEGB (Central Electricity Generating Board), whilst the Met Office and University of Surrey contributed to its development. The model is now used for regulatory and other purposes in many countries across the world.

The following is a summary of the capabilities and validation of ADMS 6. More details can be found on the CERC web site at www.cerc.co.uk.

The core model calculates the average concentration arising from an emission for a given meteorological condition (for example, wind speed and direction), taking account of plume rise and stack downwash where required. The emission may be released from a single source or from a number of sources. In addition, ADMS is able to:

- calculate long-term concentration statistics, typically for a period of one year, for direct comparison with air quality standards and objectives;
- take into account the often very significant effects that a nearby building can have on the dispersion of emissions;
- model the chemical conversions that occur in the atmosphere between nitric oxide (NO), nitrogen dioxide (NO_2) and ozone (O_3);
- include background concentrations in concentration statistics;
- allow for the effects of complex terrain and changes in surface roughness on wind speed and direction, and on the levels of turbulence in the atmosphere;
- determine the quantities of an emission deposited to the ground by both dry and wet deposition processes;
- include the decay of radioactive emissions and determine the gamma dose at a location received from passing material;
- report the extent to which a moist plume will be visible;
- model sources over the sea, such as oil platforms, using special calculations of surface roughness and heat fluxes;
- output temperature, relative and/or specific humidity, as well as exceedences of temperature and/or humidity thresholds and simultaneous exceedences of temperature and humidity threshold values;
- output concentrations in units of ou_e for odour studies;
- model the effect of a coastline by accounting for the development of an internal convective layer during sea breeze events;

[3] Carruthers DJ, Holroyd RJ, Hunt JCR, Weng W-S, Robins AG, Apsley DD, Thompson DJ and Smith FB, **1994**: UK-ADMS: A new approach to modelling dispersion in the earth's atmospheric boundary layer. J. of Wind Engineering and Industrial Aerodynamics, vol. 52, pp. 139-153, DOI: 10.1016/0167-6105(94)90044-2.

- calculate concentrations and deposition fluxes due to an instantaneous or finite duration release (puffs);
- model short-term fluctuations in concentration due to atmospheric turbulence, particularly important for the modelling of odours and concentrations for averaging times less than one hour;
- model the effect of building density on near-surface wind and turbulence profiles (urban canopy); and
- model the effect of wind turbines on plume dispersion.

More details of some of these processes are given below, along with a summary of data comparisons that have been used to validate the model.

Dispersion Modelling

ADMS uses boundary layer similarity profiles in which the boundary layer structure is characterised by the height of the boundary layer and the Monin-Obukhov length, a length scale dependent on the friction velocity and the heat flux at the ground. This has significant advantages over earlier methods in which the dispersion parameters did not vary with height within the boundary layer.

In stable and neutral conditions, dispersion is represented by a Gaussian distribution. In convective conditions, the vertical distribution takes account of the skewed structure of the vertical component of turbulence. This is necessary to reflect the fact that, under convective conditions, rising air is typically of limited spatial extent but is balanced by descending air extending over a much larger area. This leads to higher ground-level concentrations than would be given by a simple Gaussian representation.

The formulation of ADMS means that, for a given meteorological condition, as well as determining average concentrations, the model is also able to provide statistical information on concentration fluctuations. This can be particularly important in applications, for example, determining whether or not a dispersing material exceeds flammability or odour detection thresholds.

Emissions

Buoyant emissions, and those with vertical momentum, rise in the atmosphere after emission. This movement, which is referred to as *plume rise*, also results in additional dilution and can result in the emission penetrating the top of the atmospheric boundary layer and being lost from the local area. These effects are included in the modelling using an integral solution of the conservation equations for the plume's mass, momentum and heat. The possibility of entrainment behind the stack, known as *downwash*, which can lower the effective height of the emission, is also included in the calculation.

ADMS can also model emissions represented as:
- lines – for linear sources;
- areas – to represent situations where a source can best be represented as uniformly spread over an area, such as evaporation from an open tank;
- volumes – to represent situations where a source can best be represented as uniformly spread throughout a volume, such as fugitive emissions from a factory complex; and

- jets – to represent situations where emissions are not emitted vertically upwards.

Presentation of Results

For most situations ADMS is used to model the fate of emissions for a large number of different meteorological conditions. Typically, meteorological data are input for every hour during a year or for a set of conditions representing all those occurring at a given location. ADMS uses these individual results to calculate statistics for the whole data set. These are usually average values, including rolling averages, percentiles and the number of hours for which specified concentration thresholds are exceeded. This allows concentrations to be calculated for direct comparison with air quality limits, guidelines and objectives, in whatever form they are specified.

Results can be presented as numerical values at specified locations. In addition, by calculating concentrations over a grid of locations, results can be presented graphically as concentration contours or isopleths. This can be done using an integrated Mapper, which can also be used to visualise, add and edit sources, buildings and output points. The model also links to other software packages, such as Surfer, ArcGIS and MapInfo GIS.

Complex Effects - Buildings

A building or similar large obstruction can affect dispersion in three ways:

1. It deflects the wind flow and therefore the route followed by dispersing material;
2. This deflection increases levels of turbulence, possibly enhancing dispersion; and
3. Material can become entrained in a highly turbulent, recirculating flow region or cavity on the downwind side of the building.

The third effect is of particular importance because it can bring relatively concentrated material down to ground-level near to a source. From experience, this occurs to a significant extent in more than 95% of studies for industrial facilities.

The buildings effects module in ADMS has been developed using extensive published data from scale-model studies in wind-tunnels, CFD modelling and field experiments on the dispersion of pollution from sources near large structures. It has the following stages:

(i) A complex of buildings is reduced to a single wind-aligned rectangular block with the height of the dominant building and representative streamwise and crosswind lengths.

(ii) The disturbed flow field consists of a recirculating flow region in the lee of the building with a diminishing turbulent wake downwind, as shown in Figure A1.

(iii) Concentrations of the entrained part of the plume are uniform within the well-mixed recirculating flow region and based upon the fraction of the release that is entrained.

(iv) Concentrations further downwind in the main wake are the sum of those from two plumes: a ground level plume from the recirculating flow region and an elevated plume from the non-entrained remainder. The turbulent wake reduces plume height and increases turbulent spread.

(v) If the source is directly upwind of the building, the plume will be split into up to three plumes going around and over the building. These plumes are then used in the calculation of the fraction entrained into the cavity and represent the elevated plume for the non-entrained contribution in the main wake

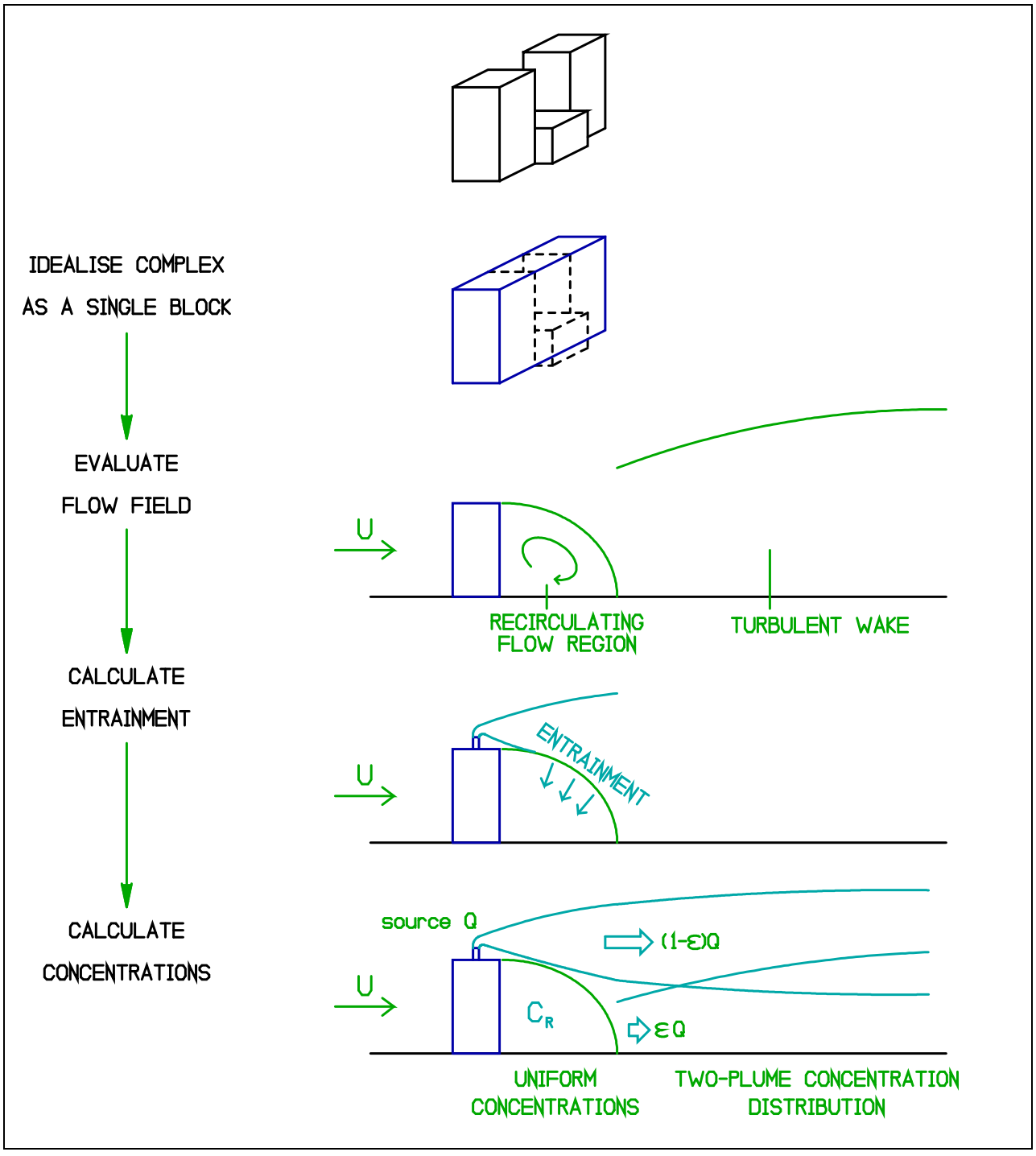

Figure A1: Stages in the modelling of building effects

Complex Effects – NO_x Chemistry

Nitrogen oxides (NO_x) emitted from combustion processes are typically only 5% to 10% nitrogen dioxide (NO_2), with the remainder as nitric oxide (NO). After emission, the NO combines with the ozone (O_3) present in the atmosphere to increase the proportion of NO_2. The key features of the two processes involved can be represented by:

(1) $NO + O_3 \rightarrow NO_2$; and
(2) $NO_2 + h\nu \rightarrow NO + O_3$,

where the role played by oxygen (O and O_2) has been omitted for clarity and $h\nu$ represents ultra violet radiation. Both of these reactions, which can proceed relatively rapidly, are modelled by ADMS, which only allows the second reaction to occur in daylight. A third reaction $2NO + O_2 \rightarrow 2NO_2$ is also included, though this will not have significant impact on NO and NO_2 concentrations unless the initial NO concentration is sufficiently high and the reaction takes place over a long period of time. Other reactions that involve O_3 and NO_2, such as those with Volatile Organic Compounds (VOCs), have not been included because their reaction times are significantly longer. They would not have any significant effect on concentrations arising from specific industrial emissions.

Complex Effects – Terrain and Roughness

Complex terrain can have a significant impact on wind-flow and consequently on the fate of dispersing material. Primarily, terrain can deflect the wind and therefore change the route taken by dispersing material. Terrain can also increase the levels of turbulence in the atmosphere, resulting in increased dilution of material. This is of particular significance during stable conditions, under which a sharp change with height can exist between flows deflected over hills and those deflected around hills or through valleys. The height of dispersing material is therefore important in determining the route it takes. In addition, areas of reverse flow, similar in form and effect to those occurring adjacent to buildings, can occur on the downwind side of a hill.

Changes in the surface roughness can also change the vertical structure of the boundary layer, affecting both the mean wind and levels of turbulence.

The ADMS Complex Terrain Module models these effects using the wind-flow model FLOWSTAR. This model uses linearised analytical solutions of the momentum and continuity equations, and includes the effects of stratification on the flow. The model is most accurate for hills of moderate slope and can typically be used for gradients up to about 1:2 but may not be reliable close to isolated slopes or escarpments with higher gradients or more generally if large parts of the modelling domain have slopes greater than 1:2. The terrain height is specified at up to 770,000 points that are interpolated by the model onto a regular grid of up to 512 by 512 points. The best results are achieved if the specified data points are regularly spaced. FLOWSTAR has been extensively tested with laboratory and field data.

Regions of reverse flow are treated by assuming that any emissions into the region are uniformly mixed within it. Material then disperses away from the region as if it were a virtual point source. Material emitted elsewhere is not able to enter reverse flow regions.

Deposition

Material in a plume that is close to the ground can be lost to the ground by dry deposition. This process is included in ADMS by using a gravitational settling velocity (which affects particles) and a deposition velocity based on aerodynamic, sub-layer and surface-layer resistance values (which affects gases and particles). The concentration profile within a dispersing plume is then adjusted to take account of the losses at the surface. Dry and wet deposition parameters can be varied spatially, to take into account changes in land use across the modelled area.

Wet deposition is included via a washout coefficient to control the quantity of material incorporated into rain. In addition, for SO_2 and HCl emitted from point sources, the 'Falling Drop' model is available, which includes the kinetics of the uptake of gases, as well as the thermodynamics and chemistry of the dissolution of gases in raindrops.

Radioactivity

For radioactive releases ADMS calculates the transformations within the plume of one isotope into another by radioactive decay. ADMS can also determine the gamma dose received at a location from a dispersing plume.

Visible Plumes

For moist emissions ADMS determines the section of the plume where the liquid water content is sufficient for the plume to be visible. This allows statistics of the frequency and lengths of visible plumes to be calculated.

Data Comparisons – Model Validation

The individual components of ADMS, for example the Buildings Module, have been developed using published scientific data and each component extensively tested to ensure that it provides reliable results. In addition, a very large number of studies have been performed on the accuracy of ADMS for point source emissions.

Among other validation studies, ADMS output has been compared with three flat terrain data sets known as Kincaid, Indianapolis and Prairie Grass, which are available from the US Modellers Data Archive. Each of these datasets has been generally accepted as containing enough measurements of sufficient quality for meaningful validation.

Further details of ADMS and model validation, including a full list of references, are available from the CERC web site at www.cerc.co.uk.