ABERDEEN
CITY COUNCIL

Aberdeen Harbour Local Air Quality Study

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Executive Summary

AECOM were commissioned by Aberdeen City Council to undertake a study of local air quality impacts due to shipping in Aberdeen Harbour. Air quality adjacent to the main roads in the vicinity of the harbour area is known to be poor, predominantly due, it has been assumed, to road traffic. Previous studies have indicated that, whilst ship emissions are unlikely to be the cause of breaches of the air quality objectives, they are likely to contribute to total pollutant concentrations near the harbour.

A detailed dispersion modelling study was undertaken to determine the local air quality impacts due to emissions from ships at berth and manoeuvring in the harbour. The results were compared with monitored concentrations.

The assessment considered emissions from ships using the ten berths closest to the City Centre Air Quality Management Area, at Jamiesons, Trinity and Regent Quays, and the Northlink ferry terminal. Detailed information regarding the number of calls, duration spent at each of the ten modelled berths, and the engine power capacities was used for each ship. The emission rates were determined from published factors, which were annualised according to the actual activity of each ship in 2010.

The greatest local air quality impacts were predicted to occur to the north of the berths around Virginia Street, and to the south and south-east within the dock area, whereas smaller impacts were predicted to occur on Market Street, which was partly due to the meteorology and the dispersion effects of the nearby tall buildings.

Emissions of nitrogen oxides from shipping were predicted to contribute a maximum of approximately 6.6 $\mu g/m^3$ to the annual mean nitrogen dioxide (NO_2) concentration at a location of relevent exposure(16% of the annual mean objective), whilst emissions of fine particulate matter (PM_{10}) were predicted to contribute a maximum of approximately 2.2 $\mu g/m^3$ to the annual mean concentration (6% of the annual mean objective). Generally, the impacts were predicted to be less than approximately 5% of the total ambient NO_2 and PM_{10} concentrations. Therefore, whilst emissions from shipping are not likely to cause an exceedence of the annual mean air quality objectives, they do contribute to existing exceedences in specific areas near the harbour.

Table of Contents

1 Introduction

AECOM were commissioned by Aberdeen City Council to undertake a study of air quality impacts due to shipping in Aberdeen Harbour. Air quality adjacent to the main roads in the vicinity of the harbour area is known to be poor, predominantly due, it has been assumed, to road traffic.; previous local air quality Council reports have indicated that, whilst ship emissions are unlikely to be the cause of breaches of the air quality objectives, they are likely to contribute to the total pollutant concentrations near the harbour. This study considers emissions from ships using the berths closest to the city centre. The results from the study were compared with air quality monitoring undertaken by the Council, and recent detailed modelling of road traffic emissions.

Measure 6.4 of the City's 2011 Air Quality Action Plan is to investigate initiatives to improve air quality in the environs of the harbour.

1.1 Aberdeen Low Emission Zone

Aberdeen City Council are currently investigating the feasibility of a Low Emission Zone (LEZ). It is likely that any such LEZ would take the form of an area or zone within which road vehicles that do not meet certain emissions based criteria would not be permitted to enter. The Council's air quality action plan (ACC, 2011) identified a LEZ as potentially one of the most successful measures to improve air quality. The LEZ feasibility work has so far not considered the contribution of shipping emissions to the city's air quality problem in any great detail, but it is recognised that if an LEZ were to be implemented with a focus on road vehicles, a clearer understanding of the contribution of shipping to the city's air quality problem is required, and whether appropriate measures to reduce the contribution should be proposed.

1.2 Aberdeen Harbour

The harbour in Aberdeen is located close to the city centre. The berths located closest to residential properties and the city centre are directly adjacent to a major thoroughfare through the city (Market Street), and adjacent to the new Union Square retail complex.

The harbour provides berths and services for three main types of vessel; oil tenders, fishing, and ro-ro (roll-on, roll-off) ferries. The berths closest to the city centre are all used by oil tenders, whilst the ferry terminal is further to the east, and fishing vessels mainly use a separate basin to the south.

Emissions from shipping arise due to ships manoeuvring in the harbour, and from hotelling, when the main engines are generally inactive and auxiliary engines provide a base load for heating, lighting, etc. There are also emissions to air associated with various other vehicles and dock-side equipment, such as loading cranes.

Aberdeen is considered to be relatively unique in the UK with regard to the proximity of a busy harbour to the City Centre, and particularly to an AQMA, as ports and harbours in the UK with similar high levels of ship movements are typically more remote from the city centres. However, shipping is recognised in the Local Air Quality Management (LAQM) regime as a potential significant air pollutant source. For example, emissions from Portsmouth harbour, which is one of the largest in the UK, are predicted to contribute a 'significant' proportion of the total NO_X in the City (PCC, 2009).

1.2.1 The Spatial Scope of the Study

This study has assessed the local air quality impacts due to emissions from the oil tender berths closest to the city centre at Jamiesons, Trinity and Regent Quays, and from the Northlink ferry berth, which is approximately 150 m further to the east away from the city centre.

The berths that were assessed were specifically chosen due to their proximity to locations of relevant exposure, such as residential properties, and the city centre AQMA, which is exposed to significant emissions from road vehicles.

There are several basins and berthing areas in Aberdeen harbour, which are used by different types of ship, including fishing vessels and those associated with the oil industry. These other berths were not assessed as they are further from the AQMA, and are generally not near areas of relevant public exposure. The only other berths that were considered to have potentially significant local air quality impacts are Commercial Quay and Albert Quay. These quays are relatively close to the Market Street AQMA, although the nearest berth locations within this area are approximately 100 m east of Market Street.

Therefore, whilst all of the berths will contribute to the total emissions from the harbour, only those included in this study are considered to be significant with regard to local air quality impacts.

1.3 Report Layout

The following structure is used in this report:

- Summary of legislation and guidance
- Summary of existing air quality
- Assessment methodology
- Results and discussion
- Conclusions
- Appendices, with detailed model inputs and results

2 Legislation and Guidance

2.1 Local Air Quality Management Policy Context

2.1.1 Overview of Recent Air Quality Legislation and Policy

The provisions of Part IV of the Environment Act 1995 (Environment Act Part IV, 1995) establish a national framework for air quality management, which requires all local authorities in England, Scotland and Wales to conduct local air quality reviews. Section 82(1) of the Act requires these reviews to include an assessment of the current air quality in the area and the predicted air quality in future years. Should the reviews indicate that the standards prescribed in the Air Quality Strategy (HMSO, 2007) will not be met, the local authority is required to designate an Air Quality Management Area (AQMA). Action must then be taken at a local level to ensure that air quality in the area improves.

2.1.2 The Air Quality Strategy

The Air Quality Strategy identifies several ambient air pollutants that have the potential to cause harm to human health. These pollutants are associated with local air quality problems, with the exception of ozone, which is recognised as being a regional problem.

The Air Quality Strategy set standards for the pollutants that are associated with local air quality. These objectives aim to reduce the health impacts of the pollutants to negligible levels. The most important pollutants with regard to road traffic are nitrogen dioxide (NO_2) and fine particulate matter, produced during the combustion of fuel. For shipping, sulphur dioxide (SO_2) has also been recognised to be a pollutant of concern, although the sulphur content of the fuel has been reduced significantly over the past decade.

2.1.3 LAQM Regime

The Local Air Quality Management (LAQM) regime in the UK is focussed on identifying and reducing concentrations of NO_2 and PM_{10}. These are the main pollutants associated with road traffic emissions, and are the main cause of exceedences of the air quality objective limits in densely populated urban areas. However, the regime recognises the importance of emissions from non-road sources, such as shipping.

Emissions from road traffic are generally decreasing, despite increases in the total number of vehicles, due to increasingly stringent emission limits as discussed below in Section 2.2. However, controls on shipping emissions are regulated in Europe and internationally though different regulations, and the year-on-year changes are generally independent of local and national regulations, as discussed in Section 2.3.

2.2 Pollutants of Concern

2.2.1 Nitrogen Dioxide

The Government and the Devolved Administrations adopted two Air Quality Objectives for nitrogen dioxide (NO_2) which were to be achieved by the end of 2005. In 2010,, mandatory EU air quality limit values on pollutant concentrations were to apply in the UK, however the UK Government has applied for derogation. The EU limit values for NO_2 are the same as the national objectives (HMSO, 2007):

- An annual mean concentration of 40 µg/m^3; and
- An hourly mean concentration of 200 µg/m^3, to be exceeded no more than 18 times per year.

In practice, meeting the annual mean objective has been and is expected to be considerably more demanding than achieving the 1-hour objective. The annual mean objective of 40 µg/m^3 is currently widely exceeded at roadside sites throughout the UK, with exceedences also reported at urban background locations in major conurbations. Exceedences are associated almost exclusively with road emissions.

There is considerable year-to-year variation in the number of exceedences of the hourly objective, driven by meteorological conditions which give rise to winter episodes of poor dispersion and summer oxidant episodes. Analysis of the relationship between 1-hour and annual mean NO_2 concentrations at roadside and kerbside monitoring sites indicate that exceedences of the 1-hour objective are unlikely where the annual mean is below 60 µg/m^3 (AEA, 2008).

NO_2 and nitric oxide (NO) are both oxides of nitrogen, and are collectively referred to as NO_X. All combustion processes produce NO_X emissions, largely in the form of NO, which is then converted to NO_2, mainly as a result of its reaction with ozone in the atmosphere. Therefore the ratio of NO_2 to NO is primarily dependent on the concentration of ozone and the distance from the emission source.

In recent years a trend has been noted whereby roadside NO_2 concentrations have not been falling, or have been increasing, at certain monitoring sites, despite emissions of NO_X falling. The 'direct NO_2' phenomenon is having an increasingly marked effect at many urban locations around the country and must be considered when undertaking modelling studies and in the context of future local air quality strategy. At the end of September 2010 Defra released a brief FAQ (Frequently Asked Question) note on the issue (Defra, 2010), acknowledging that NO_2 concentrations have not fallen as projected over the past 6-8 years, and also published a draft report in March 2011 entitled "Trends in NO_X and NO_2 emissions and ambient measurements in the UK" (Defra, 2011c), which discusses the disparity between modelling and monitoring in detail. Whereas this trend does not directly affect the emissions from shipping, it is generally acknowledged that reductions in the contribution from road emissions alone are unlikely to prevent exceedences of the air quality objectives within existing AQMAs.

2.2.2 Particulate Matter

Particulate matter is composed of a wide range of materials arising from a variety of sources. Particulate matter is typically assessed as total suspended particulates or as a mass size fraction. National objectives and European limit values already apply for the PM_{10} fraction (particles of under 10 µm in diameter) and objectives and limit values will apply for $PM_{2.5}$ (particles of under 2.5 µm in diameter) from 2020 and 2015 respectively.

This assessment considers the annual mean and daily mean air quality standards, as specified in The Air Quality Standards (Scotland) Regulations 2010 (SG, 2010). In Scotland, two objectives have been adopted for PM_{10}, to be achieved from 2010:

- An annual mean concentration of 18 µg/m^3 (gravimetric); and
- A 24-hour mean concentration of 50 µg/m^3 (gravimetric) to be exceeded no more than 7 times per year.

Both short-term and long-term exposure to ambient levels of particulate matter are consistently associated with respiratory and cardiovascular illness and mortality as well as other ill-health effects. Particles of less than 10 µm in diameter have the greatest likelihood of reaching the thoracic region of the respiratory tract.

It is not currently possible to discern a threshold concentration below which there are no effects on the whole population's health. Reviews by WHO and the Committee on the Medical Effects of Air Pollutants (COMEAP, 1998) have suggested exposure to a finer fraction of particles ($PM_{2.5}$, which typically make up around two thirds of PM_{10} emissions and concentrations) give a stronger association with the observed ill health effects, but also warn that there is evidence that the coarse fraction (between PM_{10} – $PM_{2.5}$) also has some effects on health.

Emissions of PM_{10} have decreased considerably since 1970, mainly due to the decline in coal use and the result of legislative and technical control of emissions from both road traffic and industrial sources. Industrial processes and road transport were the main sources of PM_{10} in 2005. In general diesel vehicles emit a greater mass of particulate per vehicle kilometre than petrol-engined vehicles (AEA, 2007). Ships generally use low-grade No.6 fuel oil when at sea (also known as bunker fuel), which has relatively greater emissions of PM_{10} compared to the higher grade fuel used on UK road vehicles. However, higher grade fuel is often used in port to satisfy EU and international emissions regulations (see Section 2.3), with associate benefits to PM_{10} emissions.

2.2.3 Sulphur Dioxide

The main source of Sulphur Dioxide (SO_2) in the United Kingdom is industry, which accounted for more than 87% of emissions in 2004. Domestic sources now only account for <4% of emissions, but can be locally much more significant. Road transport currently accounts for less than 1% of emissions, which can be attributed in the main to the reduced use of fuel oil, and the reduced sulphur content of gas oil and DERV.

The UK government and devolved administrations have adopted three objectives for SO_2:

- A 15-minute mean concentration of 266 µg/m^3, with an objective for the standard not to be exceeded more than 35 times in a year;
- A 1-hour mean objective of 350 µg/m^3, to be exceeded no more than 24 times per year; and
- A 24-hour objective of 125 µg/m^3, to be exceeded no more than 3 times per year.

As a result of this decline in emissions, ambient concentrations have fallen at all monitoring sites. Local exceedences of the objectives (principally the 15-minute mean objective) may occur near to and downwind of industrial premises, in the vicinity of small combustion plant (less than 20 MW) which burn coal or oil, in areas where solid fuels are the predominant form of domestic heating, and in the vicinity of major ports where high-sulphur fuels are burned.

As discussed in Section 2.3, Aberdeen harbour is within the North Sea Sulphur Emission Control Area (SECA), which regulates the amount of sulphur in fuel. Therefore, this pollutant has not been assessed further.

2.3 Shipping Emissions Regulation

Emissions from shipping are regulated independently from other sources. Whilst individual countries or harbours implement local standards, commercial pressure ensures that they are invariably derived from international agreements.

The International Maritime Organisation (IMO) has defined regulations for emissions from ships through the 'International Convention on the Prevention of Pollution from Ships', known as MARPOL 73/78. This convention has been amended by the '1997 Protocol', which includes Annex VI 'Regulations for the Prevention of Air Pollution from Ships' limits for NO_X and sulphur oxides (SO_X) emissions from ship exhausts, and prohibits deliberate emissions of ozone depleting substances.

The 2008 Amendments to Annex VI (in force from July 2010) introduced further fuel quality requirements, Tier II and III NO_X emission standards for new engines, and the requirement for compliance with Tier I NO_X for existing pre-2000 engines. The Tier I and Tier II limits are global, while the Tier III standards apply only in NO_X Emission Control Areas. As shown n Table 1, the limits are related to the rated engine speed, where slower engines are subject to tighter limits, and become progress less stringent up to a fast engine speed of 2000 rpm.

The Annexe VI regulations include limits to the sulphur content of fuel, shown in Table 2, which is directly proportional to emissions. Annex VI regulation limit the sulfur content of fuel oil, which may be used in conjunction with an approved exhaust gas cleaning system or other verifiable, enforceable technological method to reduce SO_X emissions.

PM_{10} is not specifically regulated by Annex VI, although SO_X emissions regulations controlling fuel quality have indirect benefits to the emission of fine particles, through improved combustion efficiency and abatement technology.

From the date of enforcement of an ECA, it s a requirement of EU member states or individual countries (where appropriate) within the area to enforce SO_X or NO_X standards for all ships calling at their ports or transiting the ECA. The NO_X limits in Table 1 are enforced within areas specifically designated as Emission Control Areas (ECA), and SO_X limits in Table 2 are enforced worldwide. The following ECAs have been designated:

- Baltic Sea (SO_X, adopted 1997, entered into force 2005)
- North Sea (SO_X)
- US and Canadian coast (NO_X & SO_X).

Table 1: MARPOL Regulations for the Prevention of Air Pollution from Ships, Annex VI NO_X Emission Limits

Tier	Date	NO_X Limit (g/kWh) (n = rated engine speed, rpm)		
		n < 130	130 < n < 2000	n > 2000
Tier I	2000	17.0	$45 \times n^{-0.2}$	9.8
Tier II	2011	14.4	$44 \times n^{-0.23}$	7.7
Tier III (US and Canadian coast ECA only)	2016	3.4	$9 \times n^{-0.2}$	1.96

Table 2: MARPOL Regulations for the Prevention of Air Pollution from Ships, Annex VI Fuel Sulphur Limits

<table>
<tr><th rowspan="2">Compliance Date</th><th colspan="2">Sulphur Limit in Fuel (% m/m)</th></tr>
<tr><th>SO_X ECA</th><th>Worldwide</th></tr>
<tr><td>2000</td><td>1.5%</td><td rowspan="2">4.5%</td></tr>
<tr><td>2010</td><td rowspan="2">1.0%</td></tr>
<tr><td>2012</td><td rowspan="2">3.5%</td></tr>
<tr><td>2015</td><td rowspan="2">0.1%</td></tr>
<tr><td>2020</td><td>0.5%</td></tr>
</table>

2.3.1 Aberdeen Harbour

Emissions of SO_X are regulated in Aberdeen Harbour in accordance with the North Sea Sulphur Emission Control Area (SECA), which came into force in August 2007.

Emissions of NO_X in Aberdeen Harbour are regulated through the Annex VI regulations in accordance with the EU Tier standards for diesel engines. The North Sea is not designated as an ECA for NO_X, and so whilst the Tier II standards apply, the more stringent Tier III standards do not.

The regulations for emission of SO_X apply to all ships from the enforcement date within the relevant area (either worldwide or within an SECA). However, the emission limits for NO_X are subject to physical controls, and so whilst the Tier I regulations apply to all engines, including those pre-2000, the Tier II regulations (and Tier III where applicable) only apply to ships constructed to ongoing substantial modification or repair after the enforcement date. Therefore, since the average lifespan of a ship in the North Sea fleet is approximately 25 years (Entec, 2010), it is anticipated that a relatively small proportion of the fleet will comply with the strictest emission limits

3 Existing Air Quality

3.1 Local Air Quality Management Reporting

Aberdeen City Council undertakes air quality Review and Assessment in accordance with the Local Air Quality Management regime. The Council has declared several AQMAs, notably one in the city centre near the harbour.

The Council has completed a significant amount of work to identify, and determine the extent of exceedences of the air quality objectives. The Council published an Air Quality Action Plan in 2011, which contains measures to improve air quality through planning controls and traffic regulation. This Plan replaces the 2006 Action Plan.

Emissions from road traffic are considered to be the most significant sources of pollution in the City, although emissions from shipping in the harbour have been assessed previously in the 2004 Detailed Assessment and found to contribute to total pollutant concentrations.

3.1.1 Harbour Emissions

Emissions from the harbour were assessed in the 2004 Detailed Assessment, which determined that emissions of SO_2 and PM_{10} were not significant in the context of ground level pollutant concentrations in the vicinity of the harbour, when compared with road traffic emissions.

The 2004 assessment predicted that emissions of NO_2 from the harbour make a significant contribution to pollutant concentrations at areas surrounding the harbour. Whilst emissions were not predicted to give rise directly to exceedences of the annual mean or hourly NO_2 objectives, emissions from the harbour would contribute to the predicted exceedences of 2005 annual mean objective for NO_2 and also the 2010 annual mean objective for PM_{10} on Market Street and Virginia Street:

- Emissions from the harbour contribute between 3 and 10 $\mu g/m^3$ to the annual mean NO_2 concentrations.
- The predicted annual mean NO_2 concentration attributed to harbour emissions at the areas surrounding Virginia Street and northerly areas of Torry (south of the harbour) were between 5 and 8 $\mu g/m^3$.
- The predicted annual mean NO_2 concentration at Errol Place attributed to harbour emissions was approximately 1 $\mu g/m^3$.
- The maximum hourly NO_2 concentration predicted by the model at the closest receptors ranged from 65 $\mu g/m^3$ at Victoria Road to nearly 130 $\mu g/m^3$ at the closest point on Market Street.
- The maximum predicted hourly NO_2 concentration at Errol Place was around 20 $\mu g/m^3$.

It was recommended that further monitoring should be undertaken in these areas to determine the presence or extent of any exceedence, which was subsequently undertaken with a collocated TEOM and Partisol gravitational sampler at Duthie Quay in Aberdeen Harbour between June and September 2006.

Emissions from the harbour were also assessed by Marr et.al. (2007). This assessment used both ambient and stack sampling, and emissions inventory modelling. The assessment concluded:

- Emissions from road traffic were the predominant source, with concentrations of NO_2 dependent on traffic flow.
- The concentration of PM_{10} was generally very low with no major hotspots.
- The concentration of SO_2 was very low, with monitored concentrations near to the limit of detection, although the harbour was the predominant source of SO_2.
- Whilst the harbour was identified as a significant emission source, the other sources within the City (such as roads) were the most significant contributor to the total pollutant concentrations.

3.1.2 Air Quality Management Areas

Three AQMAs have been declared in Aberdeen for annual mean NO_2 and PM_{10} based on monitoring and modelling work undertaken by ACC, which has revealed that national air quality objectives and statutory European limits are either currently not being met, or are unlikely to be met in these areas. ACC undertakes monitoring of the main local air pollutants associated with urban areas: nitrogen oxides (NO_X; consisting of nitrogen oxide (NO) and nitrogen dioxide (NO_2)) and fine particulate matter (PM_{10}). The air quality problem in Aberdeen is predominantly a result of emissions from road vehicles, as is the case elsewhere in the UK, which is reflected in the locations of the AQMAs:

- City Centre (originally declared in 2001, last amended in 2005; including Union Street, Market Street, Virginia Street, Commerce Street, and parts of Holburn Street, Guild Street and King Street)
- Anderson Drive (declared December 2008, incorporating the whole of Anderson Drive and the area around the Haudagain roundabout); and
- Wellington Road (declared December 2008, from the Queen Elizabeth II Bridge to Balnagask Road)

The City Centre AQMA includes Market Street, which is adjacent to the harbour and potentially subjected to emissions from shipping. Detailed modelling was undertaken in 2010 (ACC, 2010); the modelling predicted continued exceedences of the NO_2 annual mean objective within the City Centre AQMA (adjacent to the harbour), as well as several areas outwith this AQMA. Monitoring data and the recent 2011 Progress Report (ACC, 2011) concluded that exceedences of the NO_2 and hourly annual mean objectives are continuing to occur within and outwith the designated AQMA. Therefore, the following actions are being undertaken:

- The City Centre AQMA for NO_2 will be slighted extended to include Victoria Road to the junction with Sinclair Road, Bridge Street and West North Street to the junction with Littlejohn Street;
- The City Centre AQMA will be amended to include the risk of exceedence of the 1-hour NO_2 objective;
- The Anderson Drive/Haudagan roundabout AQMA will be extended to include Auchmill Road to the junction with Howes Road.

The extent of the City Centre AQMA is shown in Appendix B, Figure 9.

3.1.3 Air Quality Action Plan

Aberdeen City Council published an Air Quality Action Plan (AQAP) in 2006, which was updated and revised in 2011. The AQAP is focussed predominantly on controlling emissions from road vehicles, as this is the major source of pollution in the City as a whole, although the Plan includes Measure 6.4 to investigate initiatives to improve air quality in the environs of the harbour.

A source apportionment study was also undertaken within the AQAP, which included Market Street (see Table 3). The study determined that road traffic contributed approximately 89% of the NO_X and 58% of the PM_{10}, where HGVs were the most significant source of NO_X. Cars and taxis were predicted to contribute the majority of the local PM_{10}, whilst the background sources contributed 42%.

Table 3: Source Apportionment Study from AQAP (ACC, 2011)

Road	Source Contribution	NO_X	PM_{10}	Traffic Source Breakdown			
				Vehicle Type	NO_X	PM_{10}	$PM_{2.5}$
Union St	Background	18%	59%	Car/Taxi	18%	44%	40%
				LGV	6%	15%	15%
				Bus/Coach	65%	34%	37%
	Traffic	82%	41%	OGV1	8%	5%	5%
				OGV2	4%	2%	2%
Wellington Rd	Background	36%	56%	Car/Taxi	14%	35%	31%
				LGV	7%	16%	17%
				Bus/Coach	10%	5%	6%
	Traffic	64%	44%	OGV1	26%	18%	18%
				OGV2	44%	25%	27%
Haudagain Roundabout	Background	8%	52%	Car/Taxi	23%	50%	46%
				LGV	6%	12%	13%
				Bus/Coach	23%	11%	12%
	Traffic	92%	48%	OGV1	21%	13%	13%
				OGV2	27%	14%	15%
Market St	Background	11%	42%	Car/Taxi	13%	35%	32%
				LGV	5%	13%	14%
				Bus/Coach	34%	19%	21%
	Traffic	89%	58%	OGV1	27%	20%	20%
				OGV2	21%	13%	14%

3.2 Monitoring

Aberdeen City Council undertake continuous monitoring at six locations for both NO_2 and PM_{10}, and a further 44 locations using passive NO_2 diffusion tubes.

Continuous monitoring is undertaken on Market Street near the harbour. The monitor was relocated in October 2008 due to the construction of the Union Square retail complex, and concentrations of both measured pollutants decreased substantially in subsequent years, as a consequence of the new location. Monitoring is also undertaken at a ‘background’ location (Errol Place), approximately 1 km to the north.

The Council also undertake monitoring at six sites near the harbour with passive NO_2 diffusions.

The results of this monitoring are provided in Table 4 and 5. The annual mean concentrations of both NO_2 and PM_{10} have exceeded the national air quality objectives at every roadside location, and for every year (with just a few exceptions).

The Council has recently received Defra funding to undertake additional monitoring around the harbour using both passive NO_2 diffusion tubes and automatic Osiris PM_{10} monitoring units. A pair of Osiris units will be collocated for short periods at several of the new diffusion tube sites.

Table 4: Monitored NO_2 Concentrations Near the Harbour

Location	Type	Designation	OS Grid Coordinate		Annual Mean, $\mu g/m^3$ (exceedences of hourly objective in brackets)					
			X	Y	2005	2006	2007	2008	2009	2010
Errol Place	Auto	Background	394397	807392	24	27	23	25	26	21
Market St	Auto	Roadside	394408	805893	55 (6)	55 (19)	62 (39)	73 (94)	-	-
			394560	805677	-	-	-	-	38 (2)	44 (0)
31 Market St	Passive	Roadside	394258	806157	-	54	57	58	55	63
184/192 Market St	Passive	Roadside	394530	805708	-	71	80	75	64	76
40 Union St	Passive	Roadside	394284	806284	-	60	67	62	53	62
Guild St/ Market St	Passive	Roadside	394336	806097	-	50	59	63	53	63
43/45 Union St	Passive	Roadside	394295	806266	-	56	58	60	54	50
26 King St	Passive	Roadside	394449	806453	-	43	45	46	44	38

Note: Market street analyser was relocated in October 2008 due to construction work at the Union Square retail development
No diffusion tube monitoring was reported in 2005 due to very low data capture

Table 5: Monitored PM_{10} Concentrations Near the Harbour

Location	Designation	OS Grid Coordinate		Annual Mean, $\mu g/m^3$ (exceedences of daily objective in brackets)									
		X	Y	2005		2006		2007		2008 [A]		2009	2010
Correction Factor to Gravitational Equivalent [B]				1.3	1.14	1.3	1.14	1.3	1.14	1.3	1.14		
Errol Place	Background	394397	807392	19	17 (4)	20	17 (5)	22	19 (4)	18	16 (2)	15 (4)	13 (1)
Market St	Roadside	394408	805893	52	46 (84)	51	44 (104)	84	74 (116)	80	70 (148)	-	-
		394560	805677	-	-	-	-	-	-	-	-	28 (3)	22 (6)

Note: [A] Market street analyser was relocated in October 2008 due to construction work at the Union Square retail development
[B] The Errol Place and Market Street TEOMs were replaced with FDMS and BAM equipment in 2009 so no gravimetric equivalent factors were applied.

3.3 Background Concentrations

3.3.1 Defra Estimated Values

A large number of small sources of air pollutants exist which individually may not be significant, but collectively, over a large area, need to be considered in modelling studies. These sources area classified as the background contribution.

Background pollutant concentrations can be derived from the Defra UK Air Quality Archive (AQA, 2011 (downloaded in June 2011)), where estimates are available with a spatial resolution of one square kilometre, and disseminated between several source categories. The 1×1 km squares within the model domain were identified, and background concentrations of NO_X, NO_2, PM_{10} and $PM_{2.5}$ were determined according to the technical guidance, LAQM.TG(09) (Defra, 2009a).

The estimated annual mean pollutant concentrations centred on grid-square 394500, 806500 are provided in Table 6 for the model year 2010, and an arbitrary future year of 2015. Concentrations are generally predicted to be lower in the future due to more stringent legislation and improved emissions technology.

Table 6: Defra Estimated Annual Mean Background Pollutant Concentrations, µg/m^3

Pollutant	Year	
	2010	2015
NO_X	42.0	34.1
NO_2	25.0	21.3
PM_{10}	14.8	13.6

3.3.2 Summary of Background Data

The estimated annual mean background concentration for the grid square containing the Errol Place background continuous analyser was compared with the value recorded by the Council in this location (Table 4 and 5). The ratios of estimated / monitored values were approximately 1.2 for NO_2 and 1.1 for PM_{10} for 2010. However, the concentrations recorded in 2010 were relatively low compared to previous years, and the ratio between the monitored and predicted background concentrations is typically closer to 1.

Therefore, since the estimated values are reasonably similar to the monitored values, and it is preferable to use locally recorded background concentrations wherever possible, the concentrations of NO_X/NO_2 and PM_{10} recorded at Errol Place have been used in this study.

4 Assessment Methodology

4.1 Introduction

Detailed dispersion modelling was undertaken to assess the local air quality impact due to emissions from ships manoeuvring in the harbour near to the city centre,

The modelled emissions sources are shown in Appendix B, Figure 9.

The emissions from ships at berth and manoeuvring in the harbour were modelled as stack sources based on berth usage data, fleet composition, engine power capacities and published emission factors.

The following procedure was followed:

- Annual arrival and time spent in the harbour were provided for each ship;
- Emission rates for each ship were estimated based on the engine power capacities;
- The annual mean emissions were calculated by factoring the time in harbour with the emission rate

4.1.1 Study Area

As discussed in Section 1.2.1, this study assess local air quality impacts due to emissions from the ferries berthed at the Northlink Roro berth, and from vessels berthed at the three quays nearest to the city centre; Jamiesons, Trinity and Regent Quays.

These emission sources were included due to their proximity to the AQMA. Emissions from berths further away,such as the Commeical Quay and Albert Quay, were not considered likely to have a significant impact on the AQMA and so were excluded from the study.

The impacts due to emissions from ships outside the study area are discussed in Section 5.5.

4.1.2 Pollutants

The study has predicted the contribution of NO_2 and PM_{10} from shipping using the berths closest to Market Street. These two pollutants are the most significant with regard to local air quality, and specifically with regard to the City Centre AQMA.

SO_2 is also typically associated with shipping, although this has not been assessed as this is not considered to be a significant issue in Aberdeen harbour. As discussed in Section 2.3, the North Sea is a SECA, which significantly limits the levels of SO_2 that are emitted, and sampling and assessment undertaken as part of a scientific study (Marr et.al. 2007) indicates that existing concentrations are very low.

4.2 AERMOD

The emissions from ships in the harbour were modelled as discrete stack sources using the latest version (version 7, using EPA executable 09292) of the US EPA AERMOD dispersion model. AERMOD is a dispersion modelling system that simulates essential atmospheric physical processes and produces refined concentration estimates over a wide range of meteorological conditions and modelling scenarios.

The model also implements a Building Profile Input Program (BPIP) executable, which considers the effects of structures and terrain on dispersion. It also specifically accounts for the building-downwash effect, whereby low pressure on the down-wind side of buildings can effectively increase ground-level concentrations by drawing pollutants down to ground level.

4.3 Meteorology

The meteorological data applied to the model were derived from Dyce Airport, which is approximately 10 km to the north west of the harbour. Although close to the harbour, Dyce is relatively inland, and is unlikely to experience the same coastal effects as the study area (or at least to a lesser degree). However, this is the closest site to the study area that can provide the necessary quality controlled data, and is considered broadly representative of regional meteorological conditions sufficient to satisfy the requirements of this assessment.

The harbour authority record weather conditions at the harbour entrance every few hours. However, these data are not logged for extended periods and are, therefore, unsuitable for use in this study. The Council have now started to collect meteorological data in the vicinity of the harbour, and so it may be possible to gain a better understanding of localised conditions in the near future.

Five years of data, 2005 to 2009, were individually applied to the assessment to determine the annual mean pollutant concentration for each of the five years. The year for which the highest concentrations were predicted were considered to represent a relatively conservative scenario.

The wind rose generated from these data, shown in Appendix A, indicates that wind speed and direction has remained relatively consistent over the past five years, with the prevailing wind for the region from the north west through to the south. Winds from the north east through to the south east are relatively rare. However there are some notable differences between the years; for instance in 2005 there was a particularly notable north westerly component; and in 2009 and 2006 there was a greater proportion of southerly winds than for the other years.

Nevertheless, based on the Dyce met data it is considered that there is a greater likelihood of areas to the east and north of the pollutant sources experiencing the greatest impacts.

4.4 Terrain and Buildings

Digital elevation data with a resolution of 50 m was used to create a Digital Terrain Model (DTM), which was used to determine the relative elevation of the sources, receptors and buildings. Given the topography in the vicinity of the harbour, it was considered important that the model should take this into account. The DTM is indicative of the local topography, although it is relatively coarse and does not include detailed features, such as low-lying vegetation or hedgerows.

Buildings and large structures were drawn into the model manually using detailed mapping and approximate heights. As discussed above in Section 5.1.1, the BPIP executable accounts for the dispersion effects of structures. The 3D environment constructed in the model is illustrated in Appendix B, Figure 7.

4.5 Exhaust Parameters

The ship exhausts were represented by a single emission point to represent the main and auxiliary engine exhausts at each of the nine tender and single ferry berths, as it is not feasible to model the precise exhaust parameters for all the ships that use the berths.

The exhaust parameters used in the model are presented in Table 7, and whilst many vessels use the quays, the parameters are considered to be representative of all the ships in the study.

Table 7: Ship Exhaust Parameters

Parameter	Tender		Ferry		Notes
	Main	Auxiliary	Main	Auxiliary	
Exhaust Diameter, m	0.5	0.25	0.5	0.25	Estimated value based on exhausts from typical marine engines and considered to be conservative with regard to potential LAQ impacts.
Stack No.	1	1	2	2	Assumes one stack for each engine on the tender, but two separate pairs of exhausts for the ferries.
Exhaust height [A], m	18		25		Estimate height based on measured values in Meneses (2004). The stack height will change up to approx 4 m with changing tides, although this was not included in the model.
Efflux Flow rate, m^3/s	2.5	5.0	2.5	5.0	Estimated value based on professional judgement, and based on typical values for large marine diesel engines.
Temperature, °C	400				

4.6 Modelling Emissions

Data were supplied by Aberdeen Harbour Board for all ships using the port in 2010 (see Appendix A, Table 14). Detailed data for ship movements, representing approximately 20% of the total harbour movements, were provided for Regent Quay, Jamiesons Quay, Trinity Quay and the Northlink Roro berth:

- Annual arrivals (calls) to Aberdeen Harbour for every ship during one year (265 ships, making 1649 calls in total);
- Annual time spent at each berth in Aberdeen Harbour for each ship during one year;

The following engine data were compiled from the IHS Fairplay database (IHS, 2011)

- Power output of the prime mover (main engine for each ship) for the majority of ships (approx 75%, 193 ships);
- Power output of the auxiliary engine/generator for approx. 60 of the ships.
- The ships for which data was not available were those that berthed least frequently, and therefore contribute proportionally fewer emissions.

The calls data and engine capacities were used to calculate and adjust emission rates using the published emission factors discussed in Section 4.6.1. A summary of these data are provided in Appendix B, Table 15 and 16.

4.6.1 Emission Rates

Emission rates (mass of pollutant per time) were calculated for each ship based on the rated power capacity of the main and auxiliary engines using published emission factors (mass of pollutant per unit power or fuel use).

The emission factors, measured as g/kwh or g/tonne of fuel, were derived from a literature review. The primary source material was the Quantification of Emissions from Ships Associated with Ship Movements Between Ports in the European Community (Entec, 2002) (prepared on behalf of the European Commission), for ship emissions in Europe including the North Sea area (based primarily on Lloyds Register Engineering Services data). This report has been referenced independently by Environment Canada in 2004, and is also broadly consistent with emission factors for large diesel propulsion engines used in the Levelton 2002 inventory and the Meneses 2004 inventory for Aberdeen harbour. A recent report published by Entec 2010, on behalf of Defra, reviewed the emission inventory further, and published typical emission factors for a range of engine speeds, fuels and activities for 2007.

Therefore in the absence of actual vessel-specific pollutant emissions information, it is considered that the 2002 and 2010 Entec reports provide the most reliable available data. The emission factors used in the report were for medium-speed, diesel-fuelled engines (MSD) using residual oil (RO) for the main (ME) and auxiliary engines (AE). The ratio of power to fuel-use in the 2002 Entec report were used to calculate the emission factors for fuel use for the 2007 power emission factors. The following assumptions were used:

- Auxiliary engines are used when hotelling in-port (hotelling refers to a ship's operations when moored or at anchor, and includes providing electric power for lights, climate control, ventilation and heating for residual fuel).
- Main and auxiliary engines are used when manoeuvring in-port.
- The emissions from manoeuvring were modelled as an area source within the harbour based on number of calls during the year.

The emission factors applied to the model are provided in Table 8. The emission rates were calculated using the appropriate factor and the power capacity of the boiler for each ship. Details of each ship are provided in Appendix B, Table 15 and 16.

Table 8: Emission Factors (used to calculated emission rates)

Activity	Factor, g/kwh		Factor, g/tonne of fuel	
	NO_X	**PM_{10}**	**NO_X**	**PM_{10}**
Main Engine	10.5	2.4	45500	10588
Auxiliary Engine	13.8	0.8	59143	3374

4.6.2 Engine Loading Adjustment Factors

The emission factors were adjusted using published loading factors, based on engine load to simulate slow manoeuvring speeds, and reduced demand whilst berthed. The loading factors that were used are based on data published by Miola, et al (2009) and Entec (2002), and then adjusted further for Aberdeen harbour based on discussion with the Environmental Advisor at the Aberdeen Harbour Board, the Chief Executive of Northlink Ferries and the Senior QHSE Manager at North Star Shipping Ltd.

The following assumptions were applied to the model:

- Auxiliary engines are used whilst hotelling:
    - Auxiliary engines on the tenders operate at a very low-level and North Star Shipping suggested an approximate power demand of 70 kW. These engines were, therefore, modelled at 10% loading, which is equivalent to an average power demand of 106 kW. This value is consistent with the range published by Cooper (2003) of 9-45%, and was considered to be a conservative approach that accounts for any increased emissions during maintenance, and preparing to depart/arrive that are otherwise very difficult to estimate.
    - Auxiliary ferry engines operate at a loading of approximately 500 kW whilst berthed, based on information provided by Northlink Ferries.
- Auxiliary engines are used whilst manoeuvring in port at a higher loading than whilst hotelling;
- Main engines do not operate whilst hotelling, and it was assumed that all ships have auxiliary engines available;
- Main engines are used whilst manoeuvring in port, in addition to the auxiliary engines.

Table 9: Engine Loading Factors

Engine	Loading Factor	
	Hotelling	Manoeuvring
Tender Main Engine	0%	20%
Tender Auxiliary Engine	10%	50%
Ferry Main Engine	0%	20%
Ferry Auxiliary Engine	26%	50%

4.6.3 Berth Usage and Calls

The berths are not in use continually and some are occupied more than others throughout the year and day. Therefore, the following data were used to adjust the annual average emission rates from each berth:

- The annual average hourly (diurnal) profile was calculated to determine the proportional usage (and hence emission period) for each berth during a 24hr period.
- The time that each tender was in each of the nine berths was used to annualise the emission rates (e.g. Ship A uses berth B 4000 hours per year. Therefore, the emission rate is factored by 4000/8760=0.45).
- The number of calls were used to annualise the manoeuvring time for each ship.

4.7 Model Assumptions

As discussed above, model inputs, such as emission rates and adjustment factors, were partly based on local information where it was available. Where it was not possible to use accurate data from Aberdeen Harbour, published data were reviewed. It was necessary to make the following assumptions:

- The '*Shippingefficiency.org GHG Rating Calculation'* suggested that average fuel consumption of 200g per KWh for the main engine of ships of varying sizes and ages was appropriate. The same source also stated fuel consumption figures of 230 g of fuel per KWh for auxiliary engines (generators).
- For those ships that did not have engine power data available (of 265 ships, 72 ships for main driver and 205 ships for auxiliary), a median average annual fuel consumption was calculated and applied. The median value represented a ship coming into port seven times a year and at berth for 123 hours. A median was applied as opposed to a factor, as data was largely complete for the ships visiting Aberdeen most often. Therefore, applying a factor to a fuel consumption figure boosted by ships with large number of arrivals and longer times at berth would not have been representative of the ships for which we do not have data for, the large majority of which spent little time at Aberdeen.

4.8 Conversion of NO_X/NO_2

The emissions of NO_X in the exhaust gases comprise of mainly NO, which is converted to NO_2 in the atmosphere through reaction with ozone, as discussed in Section 2.2.1. The proportion of NO_2 is dependent on several factors including temperate of the gas, duration in the air, and availability of ozone.

Recent Environment Agency guidance published in association with the H1 Horizontal Guidance Note (EA, 2010c) recommends a conversion relationship, whereby 70% of long-term (annual mean) average NO_X concentrations are converted to NO_2 for comparison with the Air Quality Standards objectives for human health. The rate of conversion is considered to be a conservative representation of the total mass of NO_X in the exhaust stream that is converted to NO_2.

Therefore, in accordance with the Environment Agency H1 technical guidance document (EA, 2010b) and supporting documentation published on the EA website (EA, 2010c), it has been assumed that 70% of the NO_X emitted will be converted to NO_2 for predicted annual mean contribution from shipping.

4.9 Receptor Locations

4.9.1 Discrete Receptors

Discrete receptor locations have been selected at representative sensitive locations, such as residential properties. The contribution from the ship emissions to the annual pollutant concentrations at these locations has been predicted.

The contribution from shipping to the annual mean pollutant concentration was also predicted at local air quality monitoring locations, and locations where the 2008 annual mean NO_2 and PM_{10} concentrations were predicted in the 2010 City Centre Further Assessment (ACC, 2010).

The data in Table 10 identifies each of the modelled receptor locations. Seven locations are ACC monitoring locations, with annual mean concentrations available for several years. Five locations were assessed in the 2010 Further Assessment (ACC, 2010) and so 2008 annual mean modelled concentrations were available. The annual mean monitored and modelled concentrations at these twelve locations were compared with the predicted contribution from shipping in the harbour.

The receptor IDs in Table 10 are consistent with the source of the information, whereby 'SR' refers to the receptors in the 2010 Further Assessment, 'ACC' are monitoring locations, and 'H' are new receptors for this study located near the harbour. The locations are shown in Appendix B, Figure 9.

Table 10: Receptor Locations

ID	Location	Type	OS Grid Coordinate		Notes
			X	Y	
SR106	40 Market Street	Residential	394266	806117	Location modelled in 2010 Further Assessment
SR108	35-37 Union Street	Residential	394308	806272	
SR109	1-7 Virginia Street	Residential	394337	806097	
SR116	15-29 Virginia Street	Residential	394522	806285	
SR117	204-208 Market Street	Residential	394535	805699	
ACC9	31 Market St	Diffusion Tube	394258	806157	Council monitoring location
ACC10	184/192 Market St	Diffusion Tube	394530	805708	
ACC12	40 Union St	Diffusion Tube	394284	806284	
ACC16	Guild St/ Market Street	Diffusion Tube	394336	806097	
ACC17	43/45 Union St	Diffusion Tube	394284	806284	
ACC21	26 King Street	Diffusion Tube	394449	806453	
CM	Market Street	Automatic Analyser	394408	805893	
H1	Virginia Street	Residential	394414	806202	New harbour receptor location
H2	Regent Quay	Residential	394497	806167	
H3	Regent Quay	Residential	394686	806193	
H4	Regent Quay	Residential	394430	806157	
H5	Market Street	Commercial	394336	806000	

Note: The automatic analyser on Market Street was relocated in 2008 due to construction work (see Section 3.2), and the high value recorded in 2008 is likely to be a consequence of the disturbance due to the construction works.

4.9.2 Receptor Grid

In addition to the discrete receptors, the annual mean pollutant concentrations were also predicted at a height of 1.5 m above ground-level for a Cartesian grid with 20 m resolution. These results were used to create a contour plot of pollutant concentrations, shown in Appendix B, Figures 6 and 7.

5 Assessment Results

The predicted contributions of NO_2 and PM_{10} from shipping are presented below, and contour plots of the predicted impacts are provided in Appendix B.

The annual mean contribution due to shipping was predicted to be very similar in all five meteorological years, whilst the greatest contributions were predicted to occur in the 2009 conditions. Therefore, these data have been presented in Section 5.1 and 5.2 and the results for all five years are provided in Appendix B.

The predicted contributions from shipping have been compared with monitoring undertaken by the Council for 2009, and the modelled outputs from the City Centre Further Assessment for the year 2008 (ACC, 2010).

5.1 NO_2

The annual mean NO_2 contribution from shipping, and combined with the background concentration (see Section 3.3.2), at each of the receptor locations is shown in Table 11 for the 2009 meteorological conditions. The background contribution includes regional sources, but does not explicitly include localised road sources, and so these modelled values were generally lower than have been recorded by monitoring. The total actual concentration at several receptors has been determined from monitoring and modelling data, and includes all local sources such as roads and shipping.

The predicted annual mean NO_2 concentration due to shipping has been plotted for the meteorological year 2009, for which year the greatest impacts at most of the receptor locations were predicted. This is presented in Appendix C, Figure 6. The effects of meteorology and the surrounding buildings and topography have a substantial effect on dispersion, with the greatest impacts predicted to occur to the north around Virginia Street and to the south and south-east within the dock area. The smallest impacts were predicted to occur on Market Street (receptors CM and H5), which is partly due to the meteorology and the dispersion effects of the tall buildings at the junction of Market Street and Guild Street. However, as noted in Section 4.3, the met data is taken from Dyce Airport, which is further inland and so will not be influenced as much by coastal winds.

The contribution to the annual mean concentration of NO_2 has been predicted at the continuous monitoring station on Market Street, five diffusion tube monitoring locations and at the five receptor locations from the 2010 City Centre Further Assessment (ACC, 2010):

- The shipping contribution plus background is below the annual mean objective of 40 $\mu g/m^3$ at all locations, and the majority of locations are also below 30 $\mu g/m^3$;
- The greatest contribution to the total NO_2 concentration was predicted to occur at the identified receptors on Virginia Street and Regent Quays, with a concentration of 6.6 and 6.3 $\mu g/m^3$, respectively.

The annual mean concentration at all of the monitored and modelled locations already exceeds the objective (except for the continuous monitor on Market Street), and although the emissions from shipping contribute to this situation, they are not considered likely to cause an exceedence directly.

Table 11: Predicted NO_2 Contribution from Shipping

ID	Location	Annual Mean Ship NO_2 Contribution, $\mu g/m^3$	Annual Mean Concentration (Ship contribution plus Background) $\mu g/m^3$	Monitored / Modelled Annual Mean, $\mu g/m^3$ [A]	Annual Mean Ship Contribution as % of Total Monitored / Modelled Concentration
SR106	40 Market St	2.0	28.0	53.9	3.7%
SR108	35-37 Union St	4.0	30.0	58.8	6.8%
SR109	1-7 Virginia St	2.4	28.4	65.4	3.7%
SR116	15-29 Virginia St	4.6	30.6	53.5	8.5%
SR117	204-208 Market St	1.9	27.9	64.5	3.0%
ACC9	31 Market St	2.4	28.4	55	4.4%
ACC10	184/192 Market St	2.0	28.0	64	3.1%
ACC12	40 Union St	3.4	29.4	53	6.4%
ACC16	Guild St/ Market St	2.5	28.5	53	4.8%
ACC17	43/45 Union St	3.4	29.4	54	6.2%
ACC21	26 King St	3.4	29.4	44	7.7%
CM	Market St	2.0	28.0	73 [B]	2.7%
H1	Virginia St	6.6	32.6		
H2	Regent Quay	5.2	31.2		
H3	Regent Quay	3.9	29.9		
H4	Regent Quay	6.3	32.3		
H5	Market Street	1.8	27.8		

Note: [A] Monitored concentrations are provided for the ACC monitoring IDs; modelled concentrations are taken from the City Centre Detailed Assessment report, which did not specifically take account of shipping emissions. [B] Concentratin measured at old location in 2008.

5.2 PM_{10}

The predicted annual mean PM_{10} contribution due to shipping and the concentration including background contribution is provided in Table 12.

The contribution from shipping is generally less than 2 $\mu g/m^3$ (except at H1 Virginia Street and H4 Regent Quay), with the majority of locations also being below 1 $\mu g/m^3$.

- The maximum contribution of 2.2 $\mu g/m^3$ was predicted to occur at Virginia Street (H1);
- The greatest contribution at a receptor assessed in the xxxreport was at 35-37 Union Street, with an impact of 8.2% of the total concentration.

Less monitoring is undertaken for PM_{10} near the harbour than for NO_2. Therefore, fewer comparison are possible. However, the relative contribution of PM_{10} at the comparable locations is similar to the calculated NO_2 contributions of up to approximately 10%.

The contribution from shipping, plus the background contribution is not predicted to cause an exceedence of the annual mean objective for PM_{10}, although many locations do, or are predicted, to exceed the 18 $\mu g/m^3$ annual mean objective.

Table 12: Predicted PM_{10} Contribution from Shipping

ID	Location	Annual Mean Ship PM_{10} Contribution, µg/m^3	Annual Mean Concentration(Ship contribution plus Background), µg/m^3	Total Monitored / Modelled Annual Mean, µg/m^3 [A]	Annual Mean Ship Contribution as % of Total Monitored / Modelled Concentration
SR106	40 Market St	0.7	15.7	16.2	4.0%
SR108	35-37 Union St	1.3	16.3	15.9	8.2%
SR109	1-7 Virginia St	0.8	15.8	18.1	4.3%
SR116	15-29 Virginia St	1.5	16.5	22.3	6.7%
SR117	204-208 Market St	0.6	15.6	24.0	2.6%
ACC9	31 Market St	0.8	15.8		
ACC10	184/192 Market St	0.6	15.6		
ACC12	40 Union St	1.1	16.1		
ACC16	Guild St/ Market St	0.8	15.8		
ACC17	43/45 Union St	1.1	16.1		
ACC21	26 King St	1.1	16.1		
CM	Market St	0.7	15.6	70.0 [B]	1.0%
H1	Virginia St	2.2	17.1		
H2	Regent Quay	1.7	16.7		
H3	Regent Quay	1.3	16.3		
H4	Regent Quay	2.1	17.0		
H5	Market Street	0.6	15.6		

Note: [A] Monitored concentrations are provided for the ACC monitoring IDs; modelled concentrations are taken from the City Centre Detailed Assessment report, which did not specifically take account of shipping emissions. [B] Concentratin measured at old location in 2008.

5.3 Future Impacts

The EU will implement the Tier II emissions regulations for NO_X in 2011, which will apply to all ships constructed, or undergoing significant modification or repair, after the enforcement date. The regulations will implement a limit based on engine speed, whereby engines in the higher speed bracket (>2000 rpm) will be subject to more stringent limits. This is discussed further in as discussed in Section 2.3.

The average Tier II NO_X emission limit for medium speed engines in the 130-2000 rpm bracket will be 8.85 g/kWh, based on an average speed of 1065 rpm. For the purposes of this calculation, it is assumed that the main engines of the tenders are medium speed (based on the average speed within this bracket of 1065 rpm), and the auxiliary engines are high speed (>2000 rpm).

The typical lifecycle of a marine engine is expected to be approximately 25 years (Entec, 2010), and it is anticipated that the fleet proportion compliant with the 2011 Tier II emission factors will increase annually as ships are replaced or repaired. The predicted future NO_X emission rates are shown in Table 13.

The impacts due to emissions from the harbour will decrease proportionally to the predicted decrease in the emission rate. Therefore, it is predicted that the impacts due to shipping may be approximately 10-20% lower in 2025 than in 2011.

However, as discussed above in Section 3.3, background pollutant concentrations are generally predicted to fall due to improved road vehicle and industrial emissions regulations, and are also predicted to decrease much more quickly than the improvements to harbour shipping emissions in Table 13.

Therefore, whilst total pollutant emissions from the harbour will decrease in the future, it is unlikely to keep pace with improvements from other emission sources, resulting in a greater relative contribution from shipping in the future.

Table 13: Adjusted Future Emission Factors

Engine	NO_X, g/kwh (% change from 2011 in brackets)			
	2011	2015	2020	2025
Main Engine	10.5	10.2 (-2.5%)	9.9 (-5.6%)	9.6 (-8.8%)
Auxiliary Engine	13.8	13.0 (-5.7%)	12.0 (-12.9%)	11.0 (-20.1%)

5.4 Limitations and Uncertainty

The modelling was subject to a number of limitations and uncertainties, which are discussed in the relevant sections of Chapter 4. However, some of the uncertainties may be quantified further to determine an overall confidence in the model outputs:

- Emission rates were calculated using the engine capacity for each ship and a factor from published studies:
  - The NO_X emission factors ranged between 10.5-14 g/kWh, equivalent to +/- 25%
  - The PM_{10} emission factors ranged between 0.75-2.4 g/kWh, equivalent to +/- 70%
- The emission rates were annualised based on an engine loading factor whilst hotelling or manoeuvring, which were determined from published studies and from discussion with the operators in Aberdeen harbour. Changing these factors has a direct proportional effect on the emission rates and the predicted impacts:
  - Main engine hotelling factor ranged between 0-1%.
  - Main engine manoeuvring factor was 20%, and is a value consistently stated in the literature.
  - Auxiliary engine hotelling factor ranged between 9-45%, although the modelled values were based on information from the tender and ferry operators.
  - Auxiliary engine manoeuvring factor ranged between 0-50%
- Five years of meteorological data were reviewed to determine the greatest impacts (predicted to occur in 2009 conditions). Whilst the predicted impacts were very similar for the five years, there was variation of up to +/- 26%.
- The conversion of total NO_X to NO_2 was based on Environment Agency guidance whereby 70% of long-term (annual mean) average NO_X concentrations are converted to NO_2 (see Section 4.8). Subjectively, this is likely to be a conservative estimate, and may be substantially lower at 30-50% conversion.
- The height of the stacks was based on photographs and an indicative height published by Mar et.al. (2007). The modelled height was considered to represent the typical height of the ships. However, to quantify the potential variation, the tidal range of 4m may be used to indicate an uncertainty of +/- 22%.

The most significant uncertainties are considered to be the conversion of NO_X to NO_2, which was cautious and likely to overestimate the actual impacts, and the engine loading factors, which can substantially alter the emission rates but were based on local information as far as possible.

Therefore, the overall uncertainty of the model is considered to be within approximately +/- 25-40%.

5.5 Other Harbour Emissions

As discussed above in Section 1.2.1 and 4.1.1, the study assessed emissions from ships near the city centre, as these are considered to be the source of the greatest local air quality impacts. In order to assess emissions from the overall harbour, however, annual ship movements have been reviewed. The annual arrivals data for the harbour is provided in Appendix B, Table 18.

5.5.1 Total Emissions

This study has taken account of statistics for 1665 arrivals, which is equivalent to 3330 movements entering and leaving the harbour, representing approximately 20% of the total calls to the harbour in 2010. The data for the supply vessels berthing at the three quays included in the assessment accounted for approximately 30% of the total for this type of vessel.

It is not appropriate to directly compare the modelled emissions with those from the harbour as whole, as an essential aspect of the model was the inclusion of engine power capacity and engine loading. However, the types of vessel modelled in this assessment represent more than half of the total vessels using the harbour, and so it may be assumed that the vessel emission outputs are broadly representative of the harbour as a whole.

The total modelled emission rate was 2.9 g/s for NO_X and 0.7 g/s for PM_{10} (see Appendix B, Table 15), which is considered to be approximately equivalent to 20% of the total harbour emissions, based on the number of ship movements. Therefore, the total emissions may be approximated to be 14.8 g/s and 3.4 g/s for each pollutant respectively, which is equivalent to annual emissions of approximately 465 tonnes of NO_X and 108 tonnes of PM_{10}, These values can be put into context by comparison with total emissions from Aberdeen City of 3630 tonnes NO_X and 296 tonnes of PM_{10} (in 2009).

5.5.2 Local Air Quality Impacts

It is difficult to make any estimate of the local air quality impacts due to emissions from ships outside the study area. However, as discussed above in Section 4.1.1, due to the distance between relevant exposure and these other emissions points, it is considered that the likely impact is negligible when compared to the berths assessed in this report.

5.6 Summary and Options for Reducing Ship Emissions

This study has indicated that, whilst emissions from shipping are not likely to cause exceedences of the annual mean air quality objectives, they do contribute to existing exceedences, perhaps by up to 9% for NO_2, and 8% for PM_{10}. Most of the measures to improve air quality in the Air Quality Action Plan are associated with vehicle emissions, but it would be desirable to also reduce emissions from shipping, particularly given that emissions from shipping are likely to contribute to a greater proportion of the total concentration of NO_2 in the future compared with now. The magnitude of the predicted impacts are similar to those identified in the 2004 assessment (see Section 3.1.1).

Long-term control options are considered to be the most viable means of controlling emissions from ships in the harbour, although they all have significant drawbacks. The mitigation control options for emissions from shipping are mainly associated with national-level policy controls, such as the EU Tier limits, although many port authorities also implement local controls on fuel-quality and operating procedures. The following mitigation controls are considered to provide the greatest local air quality benefits:

- Emission Control Area (ECA) NO_X/NO_2. The North Sea is currently designated as an emission control area for SO_2 emissions, whereby the fuel used in this area is strictly controlled to control emissions to within designated limits, although it has not been designated for NO_X/NO_2. If it is designated as such, ships operating in this area would be subject to the 2016 Tier III emission limits, which are substantially lower than the Tier II controls. However, this designation would be subject to agreement from the EU countries bordering the North Sea.
- Exhaust abatement. Engineering control technology, such as Selective Catalytic Reduction (SCR), Exhaust Gas Recirculation (EGR) and Dust Particulate Filters (DPF) are becoming more common on new engines as technology becomes cheaper and more reliable. It is also possible to retrofit forms of this technology onto existing engines. However, this may entail substantial initial and ongoing costs to the operators.
- Shore-power. This has been found to substantially reduce, or completely negate, emissions from hotelling ships as the power requirements are satisfied by a connection to the local electricity grid. However, the power demand would be substantial, potentially increasing costs to the operator, and necessitating a new dedicated connection to the grid.

6 Conclusions

6.1 Summary

A detailed dispersion modelling study was undertaken to determine the local air quality impacts due to emissions from ships hotelling and manoeuvring in Aberdeen Harbour. Previous studies had indicated that, whilst emissions of NO_2 were not predicted to give rise directly to exceedences of the annual mean or hourly NO_2 objectives, they were predicted to contribute to potential exceedences of the annual mean objective.

The study specifically considered how the emissions from ships correlated with local air quality monitoring undertaken by the Council, and previous detailed dispersion modelling of road traffic emissions.

The assessment considered emissions from ships using the ten berths closet to the City Centre AQMA; Jamiesons, Trinity and Regent Quays, and the Northlink ferry terminal.

6.2 Conclusions

The study has indicated that:

- The annual mean contribution of PM_{10} was predicted to be significantly lower than NO_2;
- The maximum annual mean contribution due to shipping was predicted to occur near Virginia Street, with an NO_2 concentration of approximately 6.6 $\mu g/m^3$, and PM_{10} of 2.2 $\mu g/m^3$.
- The greatest impacts were predicted to occur to the north of the berths, around Virginia Street and to the south and south-east within the dock area;
- The smallest impacts were predicted to occur on Market Street, which is partly due to the meteorology and the dispersion effects of the nearby tall buildings;
- The emissions of NO_2 from shipping were predicted to contribute a maximum of approximately 9% of the total concentration at Virginia Street;
- The emissions of PM_{10} from shipping was predicted to contribute a maximum of approximately 8% of the total concentration at Union Street;
- The impacts were predicted to be relatively small on Market Street, despite this being adjacent to the harbour, with maximum annual mean NO_2 contribution of 2.0 $\mu g/m^3$ representing approximately 4 % of the total exposure at the old location of the automatic monitoring station; and,

Therefore, whilst emissions from shipping are not likely to cause an exceedence of the annual mean air quality objectives, they do contribute to existing exceedences at several specific areas near the harbour, and to the total regional emissions.

6.3 Recommendations

The modelling indicates impacts do not extend over a very large area, and are mainly constrained to the area around Virginia Street, north of the harbour. In addition, the maximum annual mean contribution to the total concentration of either NO_2 or PM_{10} is predicted to be less than 9%, and generally less than 5%. Therefore, it is considered that road traffic is the main source of emissions near the harbour, and should remain the focus of Air Quality Action Planning.

The opportunities to control emissions from shipping are limited, due to financial constraints, and priority is necessarily given to satisfying international shipping regulations. However, it is predicted that, if the fleet size remains the same, the proportional pollution contribution from shipping is likely to increase in the future. Therefore, mitigation controls should be discussed with the harbour and fleet operators to identify whether there are any long-term opportunities to introduce better controls in the future.

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Appendices

Appendix A: Meteorological Data

Figure 1: Dyce Windrose, 2005

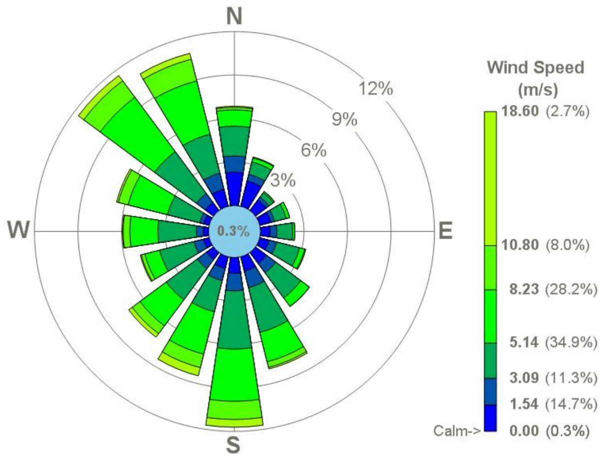


Figure 2: Dyce Windrose, 2006

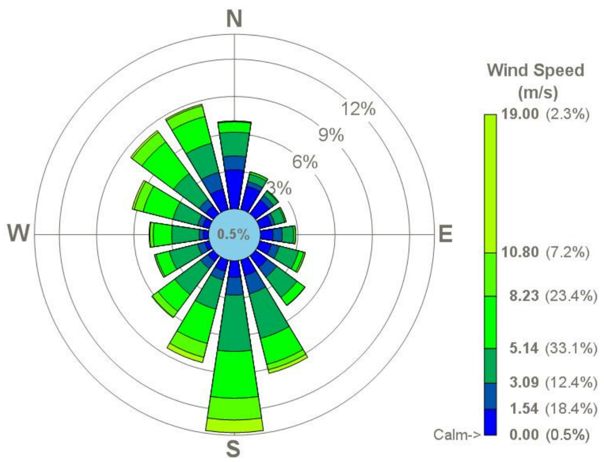


Figure 3: Dyce Windrose, 2007

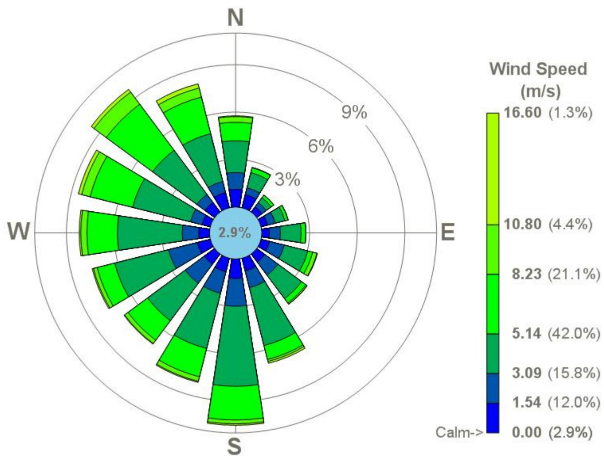


Figure 4: Dyce Windrose, 2008

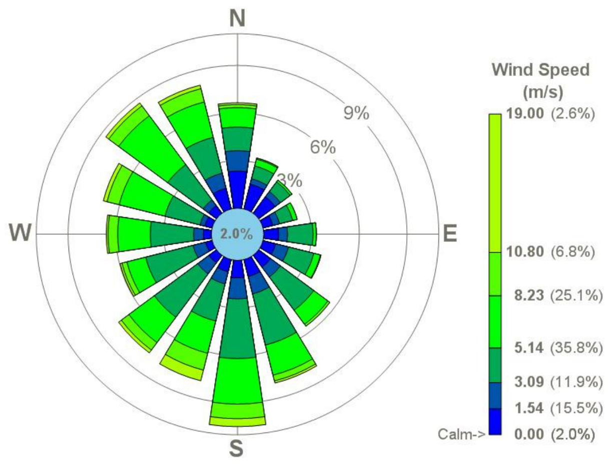


Figure 5: Dyce Windrose, 2009

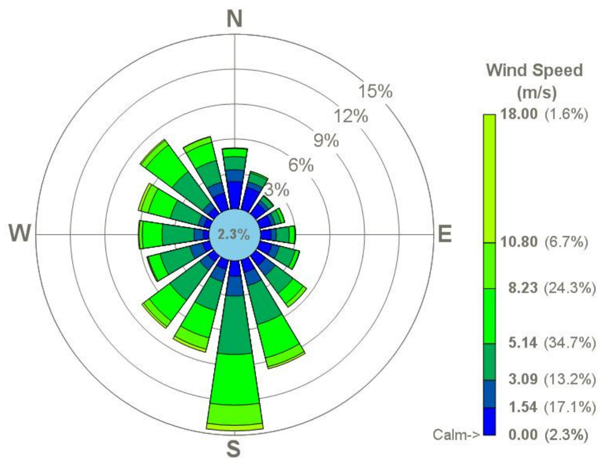
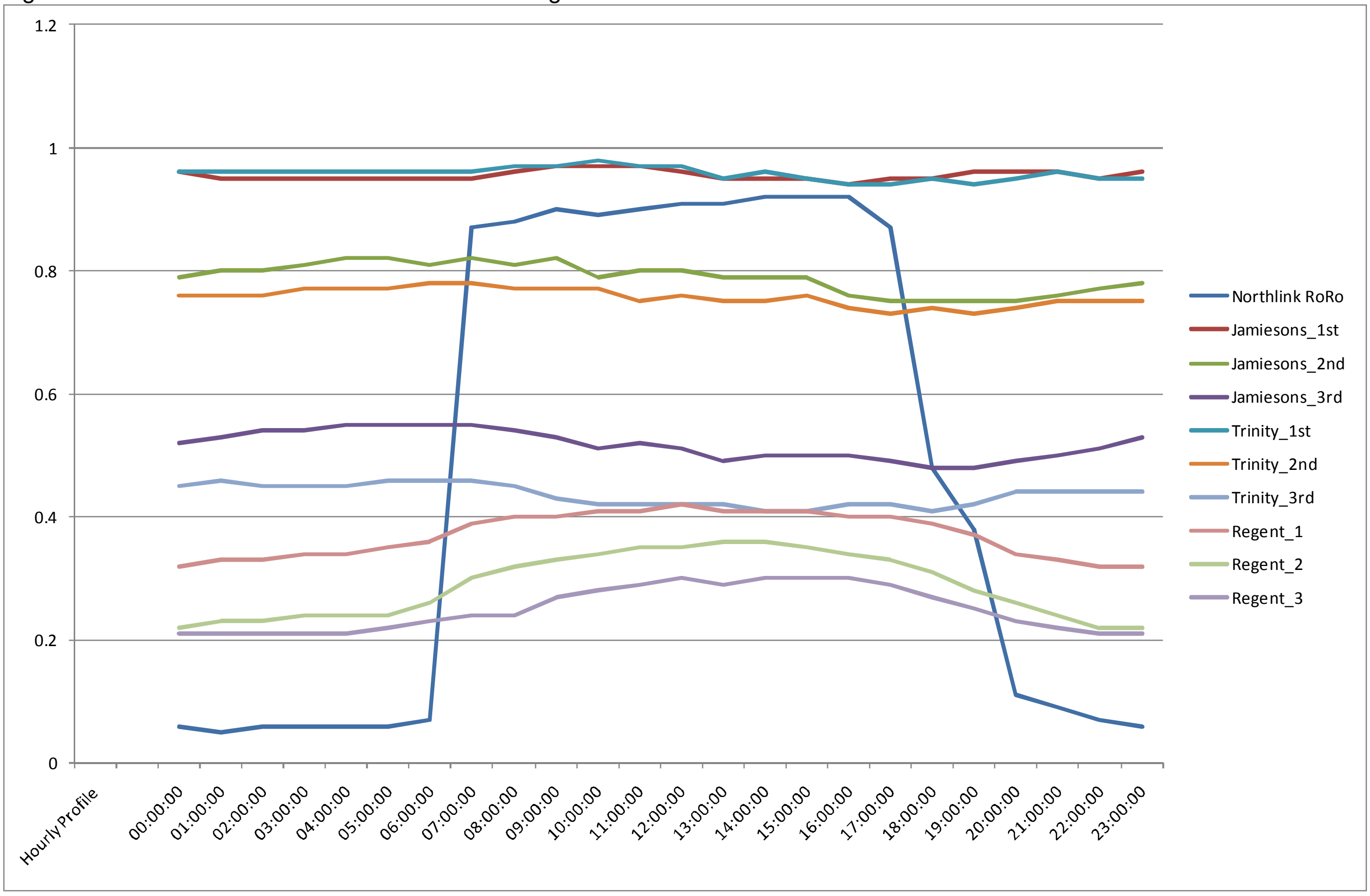


Table 14: Meteorological Statistics, 2009

Mean speed (m/s)	Wind Direction (from)												
	346 - 15	16 - 45	46 - 75	76 - 105	106 - 135	136 - 165	166 - 195	196 – 225	226 - 255	256 - 285	286 - 315	316 - 345	Total (%)
0 to 2	5.1	2.0	1.1	1.2	1.2	1.4	1.5	0.8	0.7	0.6	0.7	1.4	**18%**
2 to 4	2.8	0.7	1.2	1.8	2.4	2.9	3.5	2.5	3.2	2.2	1.2	1.9	**26%**
4 to 6	1.4	0.8	0.7	1.2	1.9	2.6	3.9	2.7	3.2	2.7	3.7	3.0	**28%**
6 to 8	1.1	0.1	0.2	0.1	0.6	1.3	2.6	2.0	1.2	1.8	3.2	2.6	**17%**
8 to 10	0.3	0.1	0.0	0.0	0.1	0.4	1.4	1.1	0.5	0.8	1.2	1.4	**7%**
10 to 12	0.2	0.0	0.0	0.0	0.0	0.1	0.7	0.5	0.2	0.3	0.3	0.4	**3%**
over 12	0.1	0.0	0.0	0.0	0.0	0.0	0.4	0.5	0.2	0.1	0.2	0.2	**2%**
Total (%)	**11%**	**4%**	**3%**	**4%**	**6%**	**9%**	**14%**	**10%**	**9%**	**9%**	**10%**	**11%**	**-**

Appendix B: Ship and Berth Data

Figure 6: Annual Mean Diurnal Profile for Berth Usage



Note: The Northlink ferry (Roro) operates during the day and is occupied less frequently during the night
The Jamieson and Trinity quays are nearest to the City and are used more frequently than the Regent quays

Table 15: Annual Average Auxiliary Engine Emissions, g/s

	Northlink RoRo	Jamiesons_ 1st	Jamiesons_ 2nd	Jamiesons_ 3rd	Trinity_ 1st	Trinity_2 nd	Trinity_3 rd	Regent _1	Regent _2	Regent _3
NO_X / g/s	0.68 [A]	0.48	0.41	0.25	0.45	0.35	0.22	0.05	0.04	0.04
PM_{10} / g/s	0.08 [A]	0.11	0.09	0.06	0.10	0.08	0.05	0.01	0.01	0.01

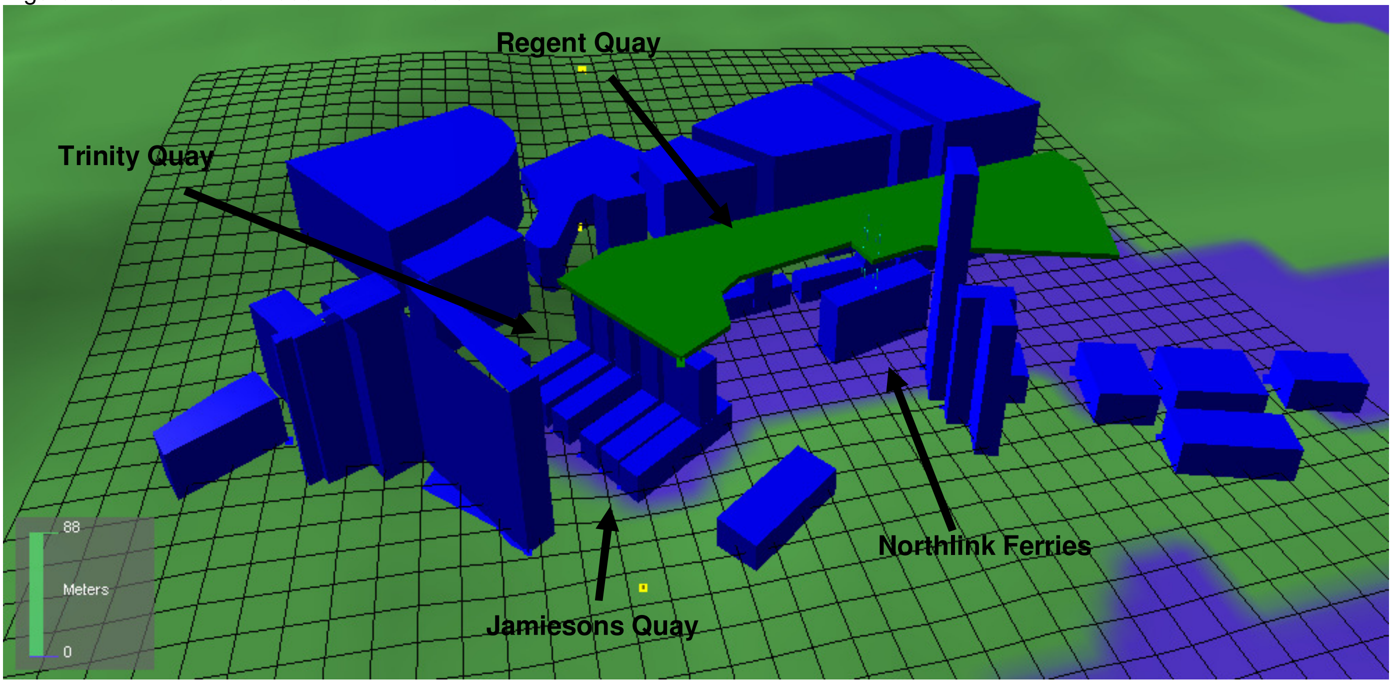
Note: [A] Northlink ferries Modelled with two stack locations

Table 16: Manoeuvring Emission Rates

Pollutant	Emission Rate	Emission Area	Emission Rate per Unit Area
	g/s	m^2	$g/s/m^2$
NO_X / g/s	0.235	35,000	6.7×10^{-6}
PM_{10} / g/s	0.054		1.5×10^{-6}

Note: Modelled as diffuse area source within harbour combining emission from auxiliary and main engines

Figure 7: 3D AERMOD Model Environment



Note: Vertical axis are exaggerated by 400% for presentation purposes
Blue structures represent buildings and ship superstructures
Dark green polygon represents the area source from ships manoeuvring in the harbour

Figure 8: Map of Harbour and Study Area

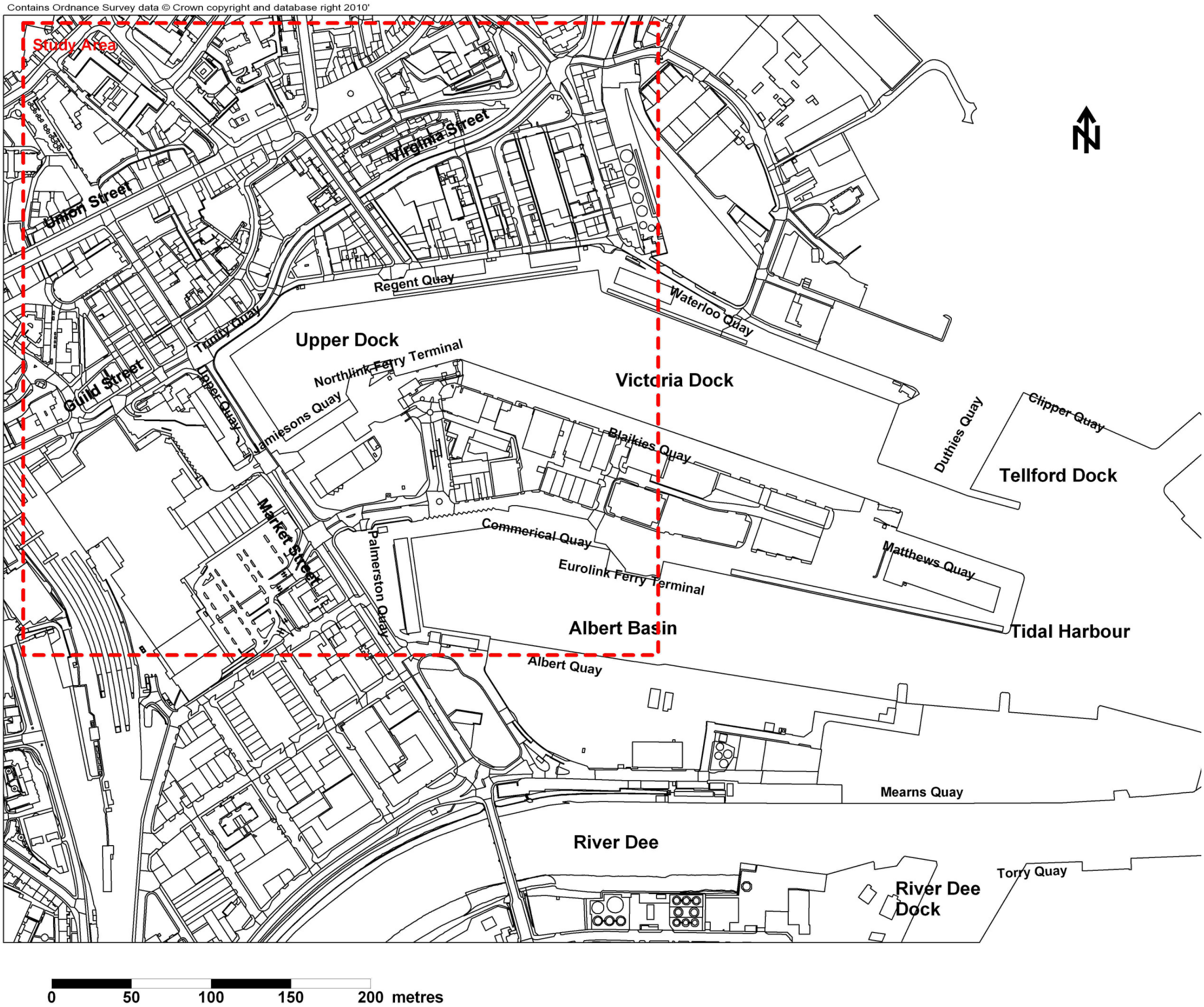


Figure 9: AQMA, Source and Receptor Locations

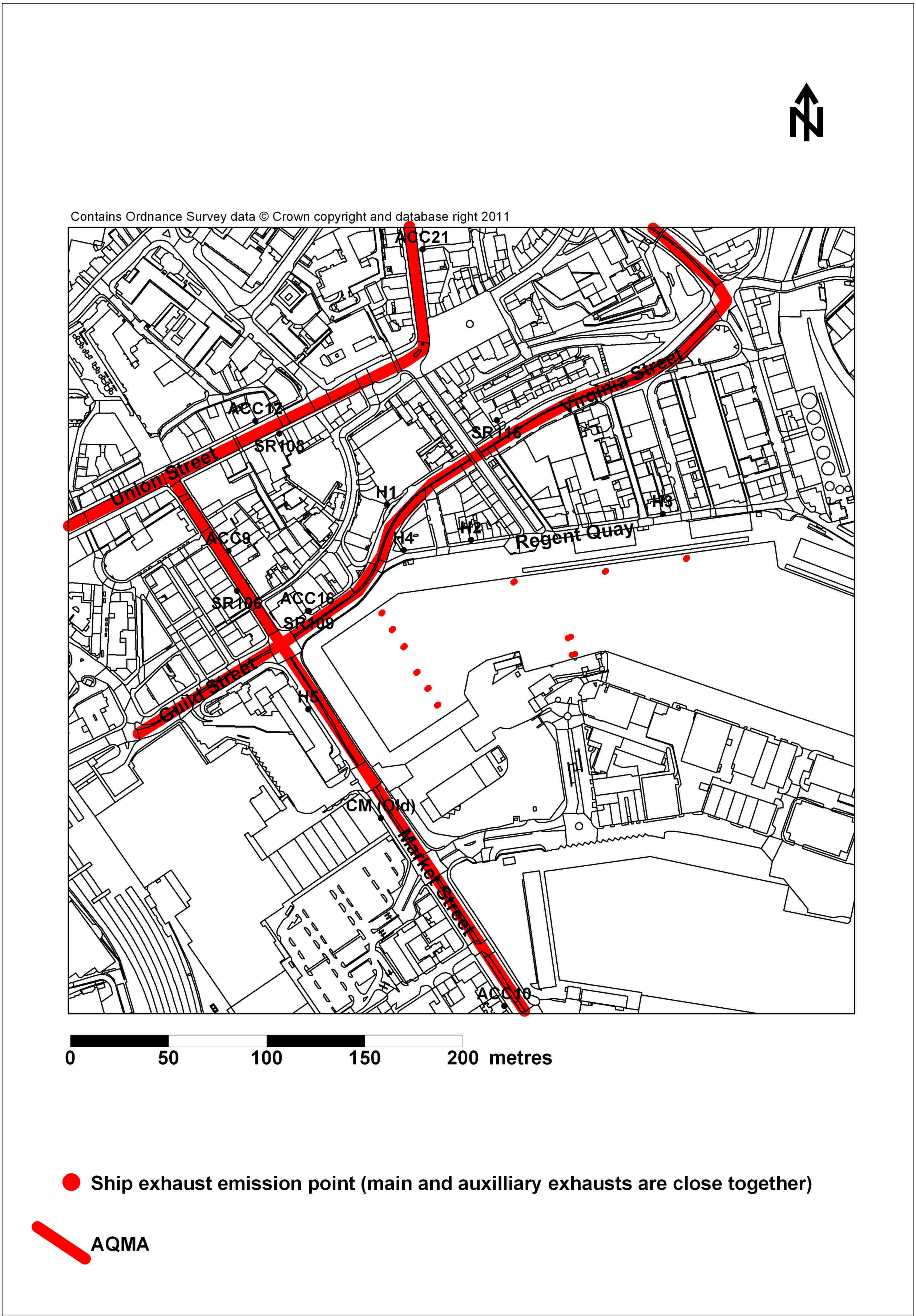


Table 17: Ship Engine Capacities and Berth Usage (in order of decreasing berthed time)

Ship Name	Main Power	Aux Power	Number of hours at berth per year									
	kW [A]		Northlink	Jamiesons			Trinity			Regent		
				1	2	3	1	2	3	1	2	3
HROSSEY	21600	1880	2163	0	0	0	0	0	0	0	3.50	0
HJALTLAND	21600	1880	2020	0	0	0	0	0	0	0	0	0
UOS ENDEAVOUR	10200	1470	0	165	266	232	559	221	127	0	0	0
MAERSK LOGGER	17280	1064	0	436	129	30	723	94	117	0	0	0
VOS PRINCE	8828	880	0	458	254	134	135	293	16	0	0	0
OCEAN MAINPORT	5884	652	0	126	498	166	101	130	125	0	0	0
SEA PANTHER	13246	2000	0	356	201	125	93	73	111	0	0	0
UOS LIBERTY	10200	1470	0	247	330	126	21	73	158	0	0	0
NSO FORTUNE	4502	1256	0	255	150	0	421	31	91	0	0	0
SBS CIRRUS	8828	2090	0	758	80	20	63	21	0	0	0	0
OLYMPIC PEGASUS	34560	2800	0	76	241	185	123	102	141	0	0	6
HIGHLAND VALOUR	24000	2670	0	120	168	0	168	187	161	0	0	0
TOISA DARING	18000	1790	0	142	414	134	0	88	0	0	0	0
SKANDI OLYMPIA	11392	1060	0	760	0	0	0	0	0	0	0	0
HIGHLAND COURAGE	20400	2670	0	23	104	180	242	143	60	0	0	0
HAVILA SATURN	24000	2020	0	72	238	0	87	313	15	3	0	3
FAR GRIMSHADER	4502	1256	0	50	88	105	264	209	3	0	0	0
TOISA SONATA	12000	1720	0	55	71	23	278	147	93	0	0	0
MAERSK TRADER	17340	3780	0	335	69	21	51	38	93	0	0	45.50
NORMAND MASTER	17280	2800	0	68	102	104	178	85	79	0	0	1.50
HAVILA FORTRESS	9840	2330	0	245	0	43	239	13	68	0	0	0
SUCHANDRA	10200	2400	0	178	276	0	11	70	60	0	0	0
RIG EXPRESS	6288	577	0	131	41	165	130	115	0	0	0	0
OLYMPIC OCTOPUS	23976	2000	0	566	0	0	0	0	0	0	0	0
HAVILA FORTUNE	10144	1060	0	286	0	0	136	56	47	0	0	0
SEA LYNX	22480	3270	0	169	65	63	30	119	62	1	0	0
TOISA INTREPID	9840	2290	0	78	191	76	86	40	33	0	0	0
HIGHLAND ENDURANCE	20400	2761	0	3	98	146	22	163	37	0	1	0
BALDER VIKING	27200	2640	0	111	0	0	209	119	27	0	0	0
TOISA INDEPENDENT	10800	1060	0	0	145	105	178	0	31	0	0	0
ENERGY GIRL	4414	1560	0	0	0	0	0	346	98	0	0	0
TOISA CORAL	7800	2030	0	88	270	41	0	42	0	0	0	0
F. D. RELIABLE	4971	1800	0	16	59	142	50	104	67	0	0	0
VIDAR VIKING	13440	2640	0	16	151	51	27	45	146	0	0	0
SUBHADRA	10200	2400	0	20	25	69	236	53	16	0	0	0
OLYMPIC POSEIDON	21200	1920	0	0	14	138	125	73	37	0	0	0
VOS DON	3820	655	0	0	0	0	0	0	0	382	4.50	0
EDDA SPRINT	9712	2370	0	88	4	0	188	93	0	0	0	6
SKANDI CARLA	20240	1470	0	354	0	0	0	0	0	24.50	0	0
TOISA SERENADE	12000	2000	0	49	44	0	211	0	72	0	0	0
MAERSK TENDER	17340	2060	0	0	263	39	0	0	54	0	0	0
E. R. GEORGINA	5916	530	0	0	1	27	149	163	9	0	0	1

Ship Name	Main Power	Aux Power	Number of hours at berth per year									
	kW [A]		Northlink	Jamiesons			Trinity			Regent		
				1	2	3	1	2	3	1	2	3
MALAVIYA SEVEN	14120	1800	0	37	54	30	128	61	39	0	0	0
SKANDI FALCON	9712	2210	0	13	19	0	191	28	94	0	0	0
SEA COUGAR	22120	1125	0	0	119	43	106	49	26	0	0	0
MAERSK LIFTER	34560	1064	0	0	0	0	193	127	0	0	0	0
E. R. ATHINA	5916	530	0	0	98	29	57	127	0	0	0	0
TOISA VIGILANT	8976	2130	0	0	0	0	31	0	208	0	62.50	5
TOISA CREST	7800	2030	0	279	0	0	0	0	0	0	0	0
MAERSK FEEDER	10600	2330	0	0	69	13	71	67	52	0	0	0
GRAMPIAN TALISKER	7920	2010	0	150	0	0	121	0	0	0	0	0
HIGHLAND PRIDE	9712	2210	0	0	96	17	37	104	17	0	0	0
HIGHLAND STAR	9712	2210	0	0	132	39	18	45	36	0	0	0
FAR SCOTIA	8020	1810	0	16	118	134	0	0	0	0	0	0
MAERSK LANCER	34560	1064	0	0	0	0	31	223	14	0	0	0
BOA FORTUNE	4850	1500	0	0	5	38	168	0	0	46	0	0
SARTOR	3090	652	0	30	110	100	0	2	11	0	0	0
SKANDI FOULA	12240	1814	0	6	0	0	214	25	7	0	0	0
NORTHERN QUEEN	5120	164	0	0	96	0	0	117	37	0	0	0
NORMAND MARINER	17284	2800	0	47	61	90	50	0	0	0	0	0
ACADIAN SEA	4856	1680	0	11	0	94	0	98	41	0	0	0
POWER EXPRESS	4916	407	0	0	0	0	243	0	0	0	0	0
F. D. INCREDIBLE	5580	1800	0	0	25	174	0	0	40	0	0	0
SEA BEAR	22080	1800	0	0	0	0	103	99	0	0	0	23.50
EDDA FRENDE	15360	1800	0	54	77	21	21	0	36	0	0	0
MAERSK LEADER	34560	3780	0	5	51	28	0	125	0	0	0	0
MALAVIYA THIRTY	6816	1810	0	0	107	22	7	72	0	0	0	0
ODIN VIKING			0	0	93	18	0	30	66	0	0	0
MAERSK FIGHTER	5300	884	0	52	59	7	49	33	0	0	0	0
E. R. NARVIK			0	0	0	89	77	28	4	0	0	0
OCEAN ENDEAVOUR	2984	498	0	0	0	0	0	0	0	79	116.50	0
FAME			0	0	0	0	0	0	0	0	0	193.50
FUGRO SEARCHER			0	0	0	0	0	0	0	19	25	148.50
SKANDI MARSTEIN	5880	981	0	58	17	44	21	39	13	0	0	0
HIGHLAND CITADEL			0	25	30	0	61	52	21	0	0	0
VOS SIREN	1866	311	0	0	0	0	0	0	0	145.50	33	7.50
SCOTIA			0	0	0	0	0	0	0	133	50.50	0
VOS WARRIOR	1472	246	0	0	0	0	0	0	0	45.50	137.50	0
HIGHLAND PRINCE			0	11	28	0	9	112	21	0	0	0
OCEAN SURF	588	98	0	91	15	54	0	0	20	0	0	0
ROCKWATER 1			0	0	0	0	0	0	0	0	175.50	0
HIGHLAND EAGLE	3408	568	0	0	0	172	0	0	0	0	0	0
MALAVIYA NINETEEN	4016	670	0	0	56	17	0	49	16	27.50	0	0
MAERSK ADVANCER	17280	3780	0	0	36	0	19	63	45	0	0	0

Ship Name	Main Power	Aux Power	Number of hours at berth per year									
	kW [A]		Northlink	Jamiesons			Trinity			Regent		
				1	2	3	1	2	3	1	2	3
VOS SERVER	1678	280	0	0	0	0	0	0	0	37.50	82	40.50
SIEM EMERALD			0	0	0	18	0	77	63	0	0	0
SBS TORRENT	4060	677	0	66	58	8	0	23	0	0	0	0
GEOBAY			0	0	0	0	0	0	0	0	0	149
TROMS POLLUX			0	146	0	0	0	0	0	0	0	0
MAERSK FORWARDER	5300	884	0	0	0	0	77	46	18	0	0	0.50
BOURBON ORCA			0	0	0	66	0	51	24	0	0	0
HAVILA AURORA	5164	861	0	0	33	0	26	0	82	0	0	0
VOS EXPLORER	2404	401	0	0	0	0	0	0	0	119	21.50	0
VOS FIGHTER	4120	687	0	0	0	0	0	0	0	139	0	0
SKANDI CALEDONIA	6120	1021	0	0	9	59	1	26	43	0	0	0
ALLIANCE			0	0	0	0	0	0	0	25.50	0.50	110
VOLSTAD VIKING			0	0	0	0	0	20	116	0	0	0
HIGHLAND PRESTIGE	7600	1268	0	0	22	40	47	0	18	0	0	3
GRAMPIAN EXPLORER	4010	669	0	0	0	0	98	31	0	0	0	0
VOS ENDEAVOUR	3138	523	0	0	0	0	0	0	0	84.50	28.50	15
SKANDI BUCHAN	6120	1021	0	123	0	0	0	0	0	0	0	0
VOS MULL	1850	309	0	0	0	0	0	0	0	83.50	27	12.50
VOS SUPPLIER	4532	756	0	0	0	0	0	0	0	80	12.50	26
VOS PILOT	3000	500	0	0	0	0	0	0	0	25	43.50	49.50
NORMAND SKARVEN			0	0	0	0	13	102	0	1.50	0	0
BB TROLL			0	0	0	0	100	0	16	0	0	0
TOISA VALIANT	4488	749	0	116	0	0	0	0	0	0	0	0
ENEA			0	0	0	13	73	5	16	0	0	3
MARTY QUIST TIDE			0	0	0	36	0	68	6	0	0	0
SEA WOLF 1	11240	1875	0	0	0	68	0	0	27	0	12.50	0
FAR STRIDER	4920	821	0	0	0	28	79	0	0	0	0	0
VOS RUNNER	1324	221	0	0	0	0	0	0	0	89.50	10	7
VOS SCOUT	1250	209	0	0	0	0	0	0	0	24.50	78	3
SBS TYPHOON	3450	575	0	0	0	0	0	49	56	0	0	0
DINA MERKUR			0	0	0	0	74	12	18	0	0	0
PACIFIC BLADE			0	23	0	0	3	59	19	0	0	0
DEA CLIPPER			0	0	0	0	0	0	0	39	61	0
OCEAN CLEVER	5178	864	0	0	0	0	0	0	0	48	6.50	40
EDDA FRAM	7680	1281	0	0	0	21	50	0	22	0	0	0
UP ESMERALDA			0	90	0	0	0	0	0	0	0	0
ISLAND EMPRESS	4640	774	0	0	0	0	0	89	0	0	0	0
OCEAN SEARCHER	296	49	0	0	0	0	0	0	0	52	4.50	32.50
VOS PATROL	1866	311	0	0	0	0	0	0	0	45.50	27	15
VOS DEE	1472	246	0	0	0	0	0	0	0	47.50	30	7.50
MAERSK LASER	17280		0	0	0	0	83	0	0	0	0	0
VOS NORTHWIND	1628	272	0	0	0	0	0	0	0	0	62	20.50

Ship Name	Main Power	Aux Power	Number of hours at berth per year									
	kW [A]		Northlink	Jamiesons			Trinity			Regent		
				1	2	3	1	2	3	1	2	3
KOMMANDOR STUART	1765	294	0	0	0	0	0	0	0	68	0	12.50
TRIDENS			0	0	0	0	0	0	0	20.50	59	0
SEA TROUT	3956	660	0	0	29	44	0	3	3	0	0	0
OCEAN NESS	4000	667	0	0	0	0	0	0	0	18	30	29.50
FUGRO MERIDIAN	1942	324	0	0	0	0	0	0	0	0	44	33
GRAMPIAN HUNTER	1570	262	0	0	0	0	0	0	0	52.50	24.50	0
SEA TIGER	2648	442	0	0	0	10	0	44	23	0	0	0
VOS PROTECTOR	1838	307	0	0	0	0	0	0	0	17.50	16	43.50
FUGRO DISCOVERY	2638	440	0	0	0	0	0	0	0	0	26.50	49.50
VOS MARINER	1692	282	0	0	0	0	0	0	0	0	23	53
VOS RAASAY	3118	520	0	0	0	0	0	0	0	32	37.50	6
KENNY TIDE			0	0	0	0	0	75	0	0	0	0
VOS PREMIER	2958	493	0	0	0	0	0	22	53	0	0	0
VOS PROSPECTOR	3138	523	0	0	0	0	0	0	0	4.50	30.50	38
VOS SAILOR	1250	209	0	0	0	0	0	0	0	29	37.50	6
KOMMANDOR SUBSEA	2790	465	0	0	0	0	0	0	0	35	36.50	0
GRAMPIAN PRIDE	1008	168	0	0	0	0	0	0	0	9.50	50	11.50
BIBBY TOPAZ	11520	1922	0	0	0	0	0	0	0	0	21.50	49
VOS VICTORY	1432	239	0	0	0	0	0	0	0	19	35.50	16
HUGIN EXPLORER			0	0	0	0	0	0	0	70	0	0
OCEAN RESEARCHER	1940	324	0	0	0	0	0	0	0	18.50	43	8
VOS VEDETTE	1103	184	0	0	0	0	0	0	0	20.50	9	39
MAERSK FINDER	5300	884	0	0	0	51	0	0	16	0	0	0
VOS PROVIDER	4800	801	0	0	0	0	0	0	0	19	27.50	20.50
VOS ENDURANCE	336	56	0	0	0	0	0	0	0	66.50	0	0
GRAMPIAN COURAGEOUS	1520	254	0	0	0	0	0	0	0	38.50	26	0
GRAMPIAN ENDURANCE	5940	991	0	0	0	0	0	0	0	35.50	17.50	11.50
FAR SUPERIOR	4504	751	0	0	0	0	0	59	4	0	0	0
OCEAN SWAN	1177	196	0	0	0	0	0	0	0	35	0	28
VOS CHALLENGER			0	0	0	0	0	0	0	38	20	3.50
VOS LISMORE	1488	248	0	0	0	0	0	0	0	41.50	19.50	0
GRAMPIAN CONTENDER	1520	254	0	0	0	0	0	0	0	23.50	18	19
VOS PIONEER	3138	523	0	0	0	0	0	0	0	4.50	24.50	31.50
VOS SEARCHER			0	0	0	0	0	0	0	27.50	32.50	0
VOS GUARDIAN	1432	239	0	0	0	0	0	0	0	26.50	16	17
GRAMPIAN PROTECTOR	1570	262	0	0	0	0	0	0	0	0	9.50	49.50
E. R. BERGEN			0	0	47	0	0	0	11	0	0	0
VIKING DYNAMIC			0	0	0	0	52	5	0	0	0	0
VOS MASTER	5340	891	0	0	0	0	0	0	0	12	44.50	0
ESPERANZA		0	0	0	0	0	0	0	0	53	0	0
OCEAN OBSERVER	3920	654	0	0	0	0	0	0	0	53	0	0
VOS SEEKER	3138	523	0	0	0	0	0	0	0	25	22	5

Ship Name	Main Power	Aux Power	Number of hours at berth per year									
	kW [A]		Northlink	Jamiesons			Trinity			Regent		
				1	2	3	1	2	3	1	2	3
EDDA FRIGG	7060	1178	0	6	16	0	0	0	20	0	9	0
BRUDANES			0	0	0	0	0	0	0	6.50	20.50	23
OCEAN SPIRIT	4502	751	0	0	0	49	0	0	0	0	0	0
FS FLAMANT			0	0	0	0	0	0	0	48	0	0
GRAMPIAN HAVEN	956	159	0	0	0	0	0	0	0	11.50	3.50	33
GRAMPIAN FALCON	956	159	0	0	0	0	0	0	0	23.50	9	14.50
SKANDI ADMIRAL	15876	3780	0	0	0	0	0	47	0	0	0	0
GRAMPIAN OSPREY	2354	393	0	0	0	0	0	0	0	35.50	6	5
GRAMPIAN CAVALIER	1292	216	0	0	0	0	0	0	0	40	0	6
OMS RESOLUTION			0	0	0	0	0	0	0	0	21	25
FAR SERVICE	2640	440	0	0	0	0	45	0	0	0	0	0
OCEAN SPRITE	3090	515	0	0	0	0	0	0	0	5.50	38	0
BRAVO SUPPORTER			0	0	0	0	0	0	0	36	6	0
HMCL SEEKER			0	0	0	0	0	0	0	20.50	21.50	0
SEA HALIBUT	4010	669	0	0	21	0	0	21	0	0	0	0
OCEAN SWIFT			0	0	0	0	0	0	0	25.50	14.50	0
ASSO VENTICINQUE			0	0	0	16	0	23	0	0	0	0
PFS SUPPLIER			0	0	39	0	0	0	0	0	0	0
VOS VOYAGER	3138	523	0	0	0	0	0	0	0	23.50	0	15
GRAMPIAN PRINCE	5120	854	0	0	0	0	0	0	0	0	29	9
HDMS TRITON			0	0	0	0	0	0	0	0	37.50	0
VOS RANGER	1714	286	0	0	0	0	0	0	0	0	17	20.50
VOS SUPPORTER	1714	286	0	0	0	0	0	0	0	0	17	20.50
SKANDI RONA	6120	1021	0	9	11	0	0	17	0	0	0	0
LORD NELSON			0	0	0	0	0	0	0	36.50	0	0
GRAMPIAN FRONTIER	6200	1034	0	0	0	0	0	0	0	0	0	34.50
BIBBY SAPPHIRE	8820	1471	0	0	0	0	0	0	0	0	0	32
GRAMPIAN RANGER	1810	302	0	0	0	0	0	0	0	12	0	20
SEAWELL			0	0	0	0	0	0	0	0	0	32
VOS TIREE	1850	309	0	0	0	0	0	0	0	0	7	24.50
GRAMPIAN HIGHLANDER	3090	515	0	0	0	0	0	0	0	0	26.50	4.50
SEA EXPLORER	6472	1080	0	0	0	0	0	0	0	0	30.50	0
GRAMPIAN CALGARY	1292	216	0	0	0	0	0	0	0	5	23	0
VOS INNOVATOR	2404	401	0	0	0	0	0	0	0	8.50	14	5
VOS ISLAY	2800	467	0	0	0	0	0	0	0	17	10.50	0
ESVAGT SIGMA			0	0	0	0	0	0	0	0	27	0
GREATSHIP DHRITI			0	4	0	23	0	0	0	0	0	0
HIGHLAND BUGLER			0	0	0	0	0	0	0	14	0	13
OCEANIC CHALLENGER			0	0	0	0	0	0	0	0	0	27
OCEAN SPEY	4000	667	0	0	0	0	0	0	0	0	15.50	11
FS PEGASUS			0	0	0	0	0	7	19	0	0	0
MINNA			0	0	0	0	0	0	0	0	0	24.50

Ship Name	Main Power	Aux Power	Number of hours at berth per year									
	kW [A]		Northlink	Jamiesons			Trinity			Regent		
				1	2	3	1	2	3	1	2	3
SKANDI INSPECTOR	3530	589	0	0	0	0	0	0	0	24.50	0	0
FPV JURA			0	0	0	0	0	0	0	0	0	23.50
OCEAN WEST	1368	228	0	0	0	0	0	0	0	9	2	12
OCEAN SUN	423	71	0	0	0	0	0	0	0	0	5	17.50
TOR VIKING II			0	0	0	0	0	0	0	0	0	22.50
VOS TRAVELLER	1325	221	0	0	0	0	0	0	0	0	22	0
GRAMPIAN VENTURE	956	159	0	0	0	0	0	0	0	21.50	0	0
VOS OCEAN	1678	280	0	0	0	0	0	0	0	0	21.50	0
IXPLORER			0	0	0	0	0	0	0	0	13.50	7
HARMONY II			0	0	0	0	0	0	0	20	0	0
OCEAN SEEKER	2354	393	0	0	0	0	0	0	0	6.50	11	0
ISLAND CHAMPION	5916	987	0	0	0	0	0	0	0	0	0	17
OOSTERSCHELDE			0	0	0	0	0	0	0	17	0	0
OLYMPIC PRINCESS			0	0	0	0	0	0	0	0	0	16
GRAMPIAN DEFENDER	1810	302	0	0	0	0	0	0	0	0	8.50	6.50
ATLANTIC GUARDIAN			0	0	0	0	0	0	0	0	14	0
GRAMPIAN CONQUEROR	1520	254	0	0	0	0	0	0	0	0	14	0
VOS CONQUEST	1472	246	0	0	0	0	0	0	0	0	12.50	0
GRAMPIAN CORINTHIAN	1292	216	0	0	0	0	0	0	0	0	12	0
MAERSK DISPATCHER	13440	2242	0	0	0	12	0	0	0	0	0	0
HAVILA VENUS	10200	1701	0	0	0	0	0	0	0	0	0	11
EEMS			0	0	0	0	0	0	0	0	0	10
POLE STAR			0	0	0	0	0	0	0	0	10	0
VOS COMMANDER	4532	756	0	0	0	0	0	0	0	0	10	0
CLARE			6	0	0	0	0	0	0	0	0	3.50
DEEP CYGNUS			0	0	0	0	0	0	0	0	1	8.50
MAERSK TRACER	8670	1446	0	0	0	0	0	0	0	0	0	8.50
VOS DEFENDER	1978	330	0	0	0	0	0	0	0	0	0	8.50
KL ARENDALFJORD			0	0	0	8	0	0	0	0	0	0
MAERSK DETECTOR	13440	2242	0	0	0	3	5	0	0	0	0	0
GRAMPIAN ORCADES	1570	262	0	0	0	0	0	0	0	0	7.50	0
PRINCE ALBERT II			0	0	0	0	0	0	0	0	0	7
GRAMPIAN CITADEL	1292	216	0	0	0	0	0	0	0	0	0	6.50
GRAMPIAN COMMANDER	1520	254	0	0	0	0	0	0	0	0	0	6.50
SILVER FJORD			0	0	0	0	0	0	0	0	0	6.50
VOS SENTINEL	1654	276	0	0	0	0	0	0	0	0	6.50	0
GRAMPIAN SURVEYOR	7200	1201	0	0	0	0	0	0	6	0	0	0
HAMNAVOE			6	0	0	0	0	0	0	0	0	0
ISLAND CHIEFTAIN	5916	987	0	0	0	0	0	0	0	0	0	6
GRAMPIAN PIONEER	1008	168	0	0	0	0	0	0	0	0	5.50	0
MAGGIE M M.B.E.			0	0	0	0	0	0	0	5.50	0	0
GRAMPIAN CONFIDENCE	1292	216	0	0	0	0	0	0	0	5	0	0

Ship Name	Main Power	Aux Power	Number of hours at berth per year									
	kW [A]		Northlink	Jamiesons			Trinity			Regent		
				1	2	3	1	2	3	1	2	3
GRAMPIAN SPRITE	956	159	0	0	0	0	0	0	0	0	5	0
VOS IONA	3090	515	0	0	0	0	0	0	0	4.50	0	0
BEAUCEPHALUS			0	0	0	0	0	0	4	0	0	0
GRAMPIAN CORSAIR	1292	216	0	0	0	0	0	0	0	0	4	0
MALAVIYA TWENTY	4010	669	0	0	0	0	0	0	0	0	0	3.50
VIKLAND			0	0	0	0	0	0	0	0	0	3.50
TAURUS			0	0	0	0	0	0	0	0	0	3
GANN			0	0	0	0	0	0	0	0	0	2.50
2 JS OF LONDON			0	0	0	0	0	0	0	0	0	2
ALK EXPLORER			0	0	0	0	0	0	0	0	2	0
ENERGY SWAN			0	0	0	0	0	0	0	0	2	0
HILDASAY			0	0	0	0	0	0	0	0	0	2
BOY GORDON			0	0	0	0	0	0	0	0.50	0	0

Note: [A] Where accurate information was not available for a ship engine, it was estimated based on the average size for the fleet. Accurate information was available for ships that were berthed for the longest period and made the most calls.

Table 18: Total Ship Movements for Aberdeen Harbour, 2010

VESSEL TYPE	CATEGORY	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
Refined Oil Tanker	Cargo	73	58	59	68	67	68	63	61	80	62	66	62	*787*
Misc Commercial Vessel	Cargo	6	24	28	26	36	12	20	60	48	62	22	14	*358*
Bulk Cargo Vessel	Cargo	4	4	4	8	6	4	8	7	5	6	4	4	*64*
General Cargo Vessel	Cargo	40	52	47	62	56	63	51	42	66	64	42	54	*639*
Chemical Tanker	Cargo	6	12	8	16	10	10	14	8	4	9	6	2	*105*
Refridgerated Vessel	Cargo	0	0	0	0	0	0	0	0	2	0	0	0	*2*
Container Vessel	Cargo	15	17	17	18	18	17	18	19	18	19	17	13	*206*
Cruise	Cruise	0	0	0	0	6	8	2	0	0	0	0	0	*16*
Ro/Ro Vessel	Ferries	73	74	85	74	85	81	90	87	102	92	84	72	*999*
Ferry	Ferries	28	25	30	26	32	30	31	36	31	29	31	25	*354*
Sto/Ro	Ferries	2	0	0	0	0	0	0	0	0	0	0	0	*2*
Purse Netter	Fishing	2	4	10	2	2	0	0	2	0	0	2	4	*28*
Seiner	Fishing	74	62	53	75	85	81	109	121	123	85	82	71	*1021*
Side Trawler	Fishing	15	15	16	17	16	22	25	13	11	28	17	15	*210*
Beamer	Fishing	25	20	7	1	27	90	78	50	18	10	18	18	*362*
Stern Trawler	Fishing	0	4	6	9	22	21	18	5	5	4	0	2	*96*
Ocean Tug	Miscellaneous	2	0	4	3	1	0	0	0	1	2	2	2	*17*
Exhibition Vessel	Miscellaneous	0	0	0	0	0	0	0	0	0	0	0	2	*2*
Fishery Protection Vessel	Miscellaneous	4	0	4	0	2	0	0	2	0	0	0	0	*12*
Harbour Tug	Miscellaneous	0	0	0	0	2	2	0	0	0	0	0	0	*4*
Coastal Tug	Miscellaneous	0	4	4	0	0	0	1	7	0	0	4	4	*24*
Conservancy Vessel	Miscellaneous	0	0	0	0	0	0	4	1	1	0	0	0	*6*
Training Ships	Miscellaneous	0	0	0	0	0	0	0	8	0	0	0	0	*8*
Barge	Miscellaneous	0	0	0	0	0	0	0	0	1	1	0	0	*2*
Other Naval Vessel	Naval	14	14	3	2	3	9	7	0	0	5	4	4	*65*
Underwater Examination Vessel	Oil Related	8	12	3	10	8	11	12	6	6	4	2	8	*90*
Misc Oil Vessel	Oil Related	5	16	2	8	6	13	2	10	14	10	10	8	*104*
Diving Support Vessel	Oil Related	12	12	21	13	19	14	25	34	23	28	18	8	*227*
Multi-Purpose Supply Vessel	Oil Related	659	665	797	879	800	794	804	797	780	658	669	661	*8963*
Guard Vessel	Oil Related	0	0	0	0	2	2	16	17	23	8	2	0	*70*
Cable/Pipe Laying Vessel	Oil Related	0	0	0	0	0	0	2	0	2	0	0	0	*4*
Seismic Vessel	Oil Related	12	3	4	9	16	1	11	31	18	7	6	10	*128*
Standby/Safety Vessel	Oil Related	116	113	103	129	122	123	143	139	135	141	136	112	*1512*
Cabin Cruiser	Recreational	0	0	0	0	2	0	0	0	0	0	2	0	*4*
Yacht (Tall Ships Race)	Recreational	0	0	0	0	0	0	2	4	0	0	0	0	*6*
Yacht	Recreational	4	6	4	10	7	14	28	17	6	6	0	0	*102*
Research Vessel	Research	9	10	6	19	18	10	13	13	5	4	3	4	*114*
TOTAL		***1208***	***1226***	***1325***	***1484***	***1476***	***1500***	***1597***	***1597***	***1528***	***1344***	***1249***	***1179***	***16713***

SUMMARY	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
Cargo	144	167	163	198	193	174	174	197	223	222	157	149	2161
Cruise	0	0	0	0	6	8	2	0	0	0	0	0	16
Ferries	103	99	115	100	117	111	121	123	133	121	115	97	1355
Fishing	116	105	92	104	152	214	230	191	157	127	119	110	1717
Miscellaneous	6	4	12	3	5	2	5	18	3	3	6	8	75
Naval	14	14	3	2	3	9	7	0	0	5	4	4	65
Oil Related	812	821	930	1048	973	958	1015	1034	1001	856	843	807	11098
Recreational	4	6	4	10	9	14	30	21	6	6	2	0	112
Research	9	10	6	19	18	10	13	13	5	4	3	4	114
TOTAL	***1208***	***1226***	***1325***	***1484***	***1476***	***1500***	***1597***	***1597***	***1528***	***1344***	***1249***	***1179***	***16713***

Appendix C: Receptor Model Results

Table 19: Modelled NO_2 Results for Five Meteorological years

ID	Location	Modelled Harbour Contribution, µg/m³ NO₂ (NOx x 0.7)					Harbour Contribution plus Background, µg/m³					Annual Mean Ship Contribution as % of Total Monitored or Modelled Concentration				
		2005	2006	2007	2008	2009	2005	2006	2007	2008	2009	2005	2006	2007	2008	2009
SR106	40 Market Street	1.8	2.1	1.9	2.2	2.0	25.8	29.1	24.9	27.2	28.0				4.1%	
SR108	35-37 Union Street	3.3	3.9	3.1	3.4	4.0	27.3	30.9	26.1	28.4	30.0				5.9%	
SR109	1-7 Virginia Street	2.2	2.5	2.3	2.6	2.4	26.2	29.5	25.3	27.6	28.4				4.0%	
SR116	15-29 Virginia Street	4.1	4.5	4.6	4.0	4.6	28.1	31.5	27.6	29.0	30.6				7.5%	
SR117	204-208 Market Street	2.3	2.3	2.1	2.1	1.9	26.3	29.3	25.1	27.1	27.9				3.3%	
ACC9	31 Market St	2.1	2.5	2.1	2.6	2.4	26.1	29.5	25.1	27.6	28.4		4.5%	3.6%	4.5%	4.4%
ACC10	184/192 Market St	2.4	2.4	2.2	2.2	2.0	26.4	29.4	25.2	27.2	28.0		3.4%	2.7%	2.9%	3.1%
ACC12	40 Union St	2.7	3.2	2.5	2.9	3.4	26.7	30.2	25.5	27.9	29.4		5.4%	3.8%	4.7%	6.4%
ACC16	Guild St/ Market Street	2.3	2.6	2.4	2.8	2.5	26.3	29.6	25.4	27.8	28.5		5.3%	4.0%	4.4%	4.8%
ACC17	43/45 Union St	2.7	3.2	2.5	2.9	3.4	26.7	30.2	25.5	27.9	29.4		5.8%	4.4%	4.9%	6.2%
ACC21	26 King Street	2.8	3.2	3.0	2.8	3.4	26.8	30.2	26.0	27.8	29.4		7.4%	6.7%	6.1%	7.7%
CM	Market Street CM	2.4	2.4	2.2	2.4	2.0	26.4	29.4	25.2	27.4	28.0	4.3%	4.4%	3.6%	3.4%	5.2%
H1	Virginia Street	5.3	6.4	5.2	5.3	6.6	29.3	33.4	28.2	30.3	32.6					
H2	Regent Quay	5.0	5.1	5.0	4.8	5.2	29.0	32.1	28.0	29.8	31.2					
H3	Regent Quay	3.7	3.5	4.7	4.1	3.9	27.7	30.5	27.7	29.1	29.9					
H4	Regent Quay	5.2	6.1	4.9	5.1	6.3	29.2	33.1	27.9	30.1	32.3					
H5	Market Street	1.8	1.8	1.8	2.1	1.8	25.8	28.8	24.8	27.1	27.8					

Table 20: Modelled PM_{10} Results for Five Meteorological years

ID	Location	Modelled Harbour Contribution, μg/m³					Harbour Contribution plus Background, μg/m³					Annual Mean Ship Contribution as % of Total Monitored or Modelled Concentration				
		2005	2006	2007	2008	2009	2005	2006	2007	2008	2009	2005	2006	2007	2008	2009
SR106	40 Market Street	0.58	0.67	0.61	0.72	0.65	19.6	20.7	17.6	18.7	15.7				4.5%	
SR108	35-37 Union Street	1.06	1.25	1.00	1.12	1.30	20.1	21.3	18.0	19.1	16.3				7.0%	
SR109	1-7 Virginia Street	0.72	0.81	0.74	0.86	0.78	19.7	20.8	17.7	18.9	15.8				4.7%	
SR116	15-29 Virginia Street	1.35	1.47	1.51	1.31	1.49	20.3	21.5	18.5	19.3	16.5				5.9%	
SR117	204-208 Market Street	0.75	0.76	0.69	0.69	0.63	19.8	20.8	17.7	18.7	15.6				2.9%	
ACC9	31 Market St	0.68	0.80	0.67	0.84	0.78	19.7	20.8	17.7	18.8	15.8					
ACC10	184/192 Market St	0.77	0.78	0.70	0.71	0.64	19.8	20.8	17.7	18.7	15.6					
ACC12	40 Union St	0.89	1.05	0.82	0.95	1.09	19.9	21.1	17.8	19.0	16.1					
ACC16	Guild St/ Market Street	0.76	0.86	0.77	0.91	0.83	19.8	20.9	17.8	18.9	15.8					
ACC17	43/45 Union St	0.89	1.05	0.82	0.95	1.09	19.9	21.1	17.8	19.0	16.1					
ACC21	26 King Street	0.90	1.04	0.98	0.91	1.10	19.9	21.0	18.0	18.9	16.1					
CM	Market Street CM	0.77	0.78	0.72	0.80	0.65	19.8	20.8	17.7	18.8	15.6	1.5%	1.5%	0.9%	1.0%	2.3%
H1	Virginia Street	1.71	2.07	1.68	1.74	2.15	20.7	22.1	18.7	19.7	17.1					
H2	Regent Quay	1.63	1.67	1.64	1.58	1.69	20.6	21.7	18.6	19.6	16.7					
H3	Regent Quay	1.21	1.14	1.54	1.33	1.28	20.2	21.1	18.5	19.3	16.3					
H4	Regent Quay	1.69	1.99	1.59	1.67	2.05	20.7	22.0	18.6	19.7	17.0					
H5	Market Street	0.58	0.60	0.59	0.68	0.59	19.6	20.6	17.6	18.7	15.6					

Appendix D: Plotted Model Outputs

Figure 10: Ship Emissions Contribution to Annual Mean NO_2, 2009

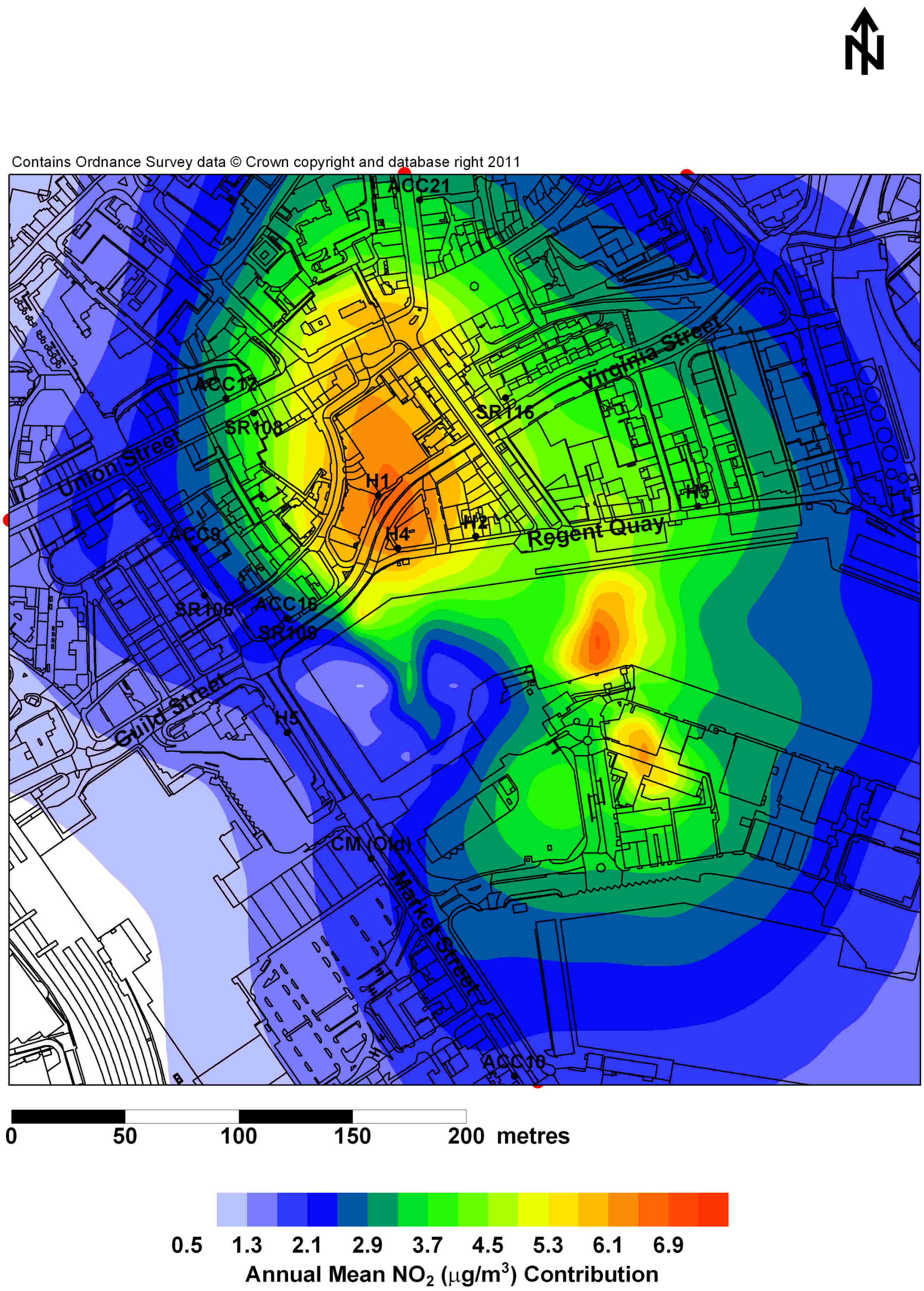


Figure 11: Ship Emissions Contribution to Annual Mean PM_{10}, 2009