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Grangemouth AQMA - Further Assessment

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EXECUTIVE SUMMARY

In November 2005, Falkirk Council declared an Air Quality Management Area (AQMA) in Grangemouth in recognition of the measured and predicted exceedences of the 15-minute mean SO_2 air quality objective concentration. The AQMA covers a large part of Grangemouth including the docks, the petro-chemical plant, other industrial sites and most of the residential areas.

As part of its requirement in reviewing and addressing air quality issues Falkirk Council has undertaken a Further Assessment to look in detail at sources of SO_2, measured SO_2 concentrations and climatic conditions resulting measured exceedences of the SO_2 objectives.

The study aimed in particular to identify contributions from each major SO_2 source and climatic conditions that result in exceedences of the 15-minute mean objective limit. The study focuses on monitoring and emission data from 2007.

The major sources identified were Ineos, Longannet power station and BP. It was recognised that there are other emitters of SO_2 within Grangemouth including shipping, rail traffic, other industrial operators and domestic and commercial properties. Emissions from these sources have been considered in previous assessments and therefore this report focuses on the emissions from the three largest sources in the area.

During 2007, there were a number of measured exceedences of the 15-minute SO_2 objective at the monitoring sites within the Grangemouth AQMA. The number and location of these measured exceedences were, however, different from those measured in previous years.

- In order to understand the reason for the change in the measured concentrations and to help identify the source(s) causing the measured exceedences, detailed analysis of both monitoring and meteorological data was undertaken. The analysis determined that exceedences of the objective were measured under differing meteorological conditions but that the following tended to apply in 2007:
- The meteorological conditions during which exceedences are most likely to be measured are unstable conditions, for example on sunny days, with low wind speeds and no cloud cover. These conditions can result in emissions plumes grounding closer to the source than other meteorological conditions.
- Exceedences are most likely to be measured when the wind is blowing from a north-east to easterly direction.
- Exceedences at different monitoring stations can sometimes be attributed to the same pollution episode.
- Exceedences are sometimes measured when the wind is from a south-westerly direction.

Based on the analysis it was considered that the most likely emission source causing the measured exceedence would be Ineos. The wind direction analysis also, however, identified that exceedences were recorded when the wind was not from an easterly direction, indicating a source located towards

the west of the monitoring locations or an upper air circulation where the wind direction at height differs from the wind direction at the monitoring station.

Potential sources could be smaller industrial operators, domestic emissions sources, railway emissions or transboundary sources. Previous modelling studies have ruled out these sources as insignificant. Another reason for exceedences being measured from a westerly direction could be localised changes in wind direction that are not picked up by the meteorological station. The main concern within the AQMA is exceedences of the 15-minute mean objective; however, the wind direction data is an hourly average. When considering short-term air quality objectives, short term changes in wind direction could be significant but will not be identifiable from a longer term averaging period.

The modelling study appeared to under-predict the number of exceedences at both Grangemouth MC and Moray automatic monitoring sites while over predicting at Inchyra. The various sources on the Ineos site, and emissions from Longannet, were modelled as individual groups to identify which source or sources may be responsible for the measured exceedences. The modelling study indicated that, while some exceedences were predicted, no individual group or group of sources, was likely to be responsible for causing an exceedence of the objective (i.e. greater than 35 exceedences) on their own. When all sources from the Ineos site were modelled as one group, the results indicated that the objective could be exceeded at numerous locations.

The conclusions from the modelling study therefore indicate that it is the combined impact of all sources on the Ineos site that is the most likely cause of the measured exceedences. The study also identified that, under certain meteorological conditions, the added contribution of emissions from Longannet, can contribute to total SO_2 emissions within the AQMA.

Falkirk Council has regular liaison with SEPA and Ineos during pollution events and through the text alert system that allows SEPA and Ineos' shift manager to investigate any pollution episode occurrence as it happens and subsequent emailing of both monitoring and meteorological data measured during the event. During the majority of the pollution episodes, Ineos was operating normally. The modelling study indicates that the major contributors to elevated levels of SO_2 in the area from Ineos are likely to be the Sulphur Recovery Units (SRUs). However, as an isolated group, the only exceedence due to the SRUs occurs at a very small area on the site.

Considering the meteorological analysis, the modelling study, and the fact that Ineos are frequently operating normally during pollution episodes, it would appear likely that the main cause of the 15-minute mean exceedences is the combined effect of all sources within Ineos.

Overall, the investigation into particular measured exceedences, and the dispersion modelling study, indicates that the area should remain designated as an AQMA. In addition, the dispersion modelling contour plots show the extent of predicted exceedences of the 15-minute SO_2 air quality objective. Considering the extent of the predicted exceedences, it is concluded that the current boundary of the AQMA is appropriate and does not need adjustment.

1 INTRODUCTION

Local authorities are required to assess air quality on a regular basis to determine compliance with air quality objectives for seven main pollutants. The air quality objectives are set out in the air quality (Scotland) Regulations 2000 and subsequent amendments. The relevant air quality objectives for SO_2 are presented in Table 1. Where exceedence of air quality objective is identified and relevant receptors are present, the local authority is required to declare an Air Quality Management Area (AQMA) and prepare an Action Plan that outlines measures for improving the air quality.

Table 1: Air quality objectives for SO_2

Objective	Measured as	Equivalent percentile	Date to be achieved by
266 µg/m^3 not to be exceeded more than 35 times a year	15 minute mean	99.9th	31/12/2005
350 µg/m^3 not to be exceeded more than 24 times a year	1 hour mean	99.7th	31/12/2004
125 µg/m^3 not to be exceeded more than 3 times a year	24 hour mean	99th	31/12/2004

In November 2005, Falkirk Council declared an AQMA in Grangemouth due to measured and predicted exceedences of the 15-minute mean objective for sulphur dioxide (SO_2). The exceedences are thought to be caused by emissions from local industry.

Following declaration of the AQMA, Falkirk Council commissioned a new air quality monitoring station at Moray Primary School (hereafter referred to as Moray), which is located between the two existing monitoring stations of Inchyra Park and Grangemouth Municipal Chambers. A number of exceedences of the 15-minute SO_2 objective, as well as exceedences of the 1-hour and 24-hour mean SO_2 objectives have been measured at the new monitoring station. However, the 1-hour and 24-hour objectives have not been breached.

The data from the three monitoring stations in Grangemouth indicate a change in ambient SO_2 concentrations in terms of both magnitude and spatial variation over the last three to four years. BMT Cordah Limited has been commissioned by Falkirk Council to undertake further analysis of measured concentrations and of emissions from local industrial sources to establish any identifiable cause for the changes in recorded ambient SO_2 concentrations.

The assessment consists of two main stages. The first stage will consist of an evidence-based study undertaken to analyse measured data in relation to meteorological data during the periods of measured exceedences. Historical relationships will also be investigated to establish any trends or changes to measured data.

The second stage will consist of a dispersion modelling study of emissions from industrial operators in or near Grangemouth. The dispersion modelling study will focus on the relative contribution of each item of plant on each site to predicted ambient concentrations under different meteorological conditions. The dispersion modelling study will also consider emissions from local industrial sites in the Grangemouth area during recent pollution episodes, as well as emissions from Longannet Power Station during a pollution episode in 2007.

Overall, the assessment is designed to determine whether the AQMA remains valid and to appraise the current AQMA boundary against areas of predicted exceedences.

2 SUMMARY OF MONITORING RESULTS

During 2007, Falkirk Council monitored SO_2 concentrations using automatic monitors at six locations, three of which were within the Grangemouth AQMA, namely Inchyra Park, Grangemouth Municipal Chambers (MC) and Moray. The Inchyra Park monitoring station is a member of the UK AURN network and the data has been fully ratified for 2007. Data for Grangemouth MC, Hope Street and Park Street sites have been ratified by AEA for the period after 1st July 2007. The results of the 2007 monitoring have been summarised as numbers of exceedences and are presented in Table 2.

Table 2: Summary of exceedences of SO_2 air quality objectives during 2007

AQ monitoring Station	Data capture rate	No of exceedences		
		15min mean SO_2 objective	1hr mean SO_2 objective	24hr mean SO_2 objective
Inchyra Park	96.2%	0	0	0
Grangemouth MC	96.1%	112	6	1
Moray	95.5%	126	6	2
Park Street	97.9%	5	0	0
Hope Street	84%	6	0	0
Bo'ness Town Hall	94.8%	0	0	0

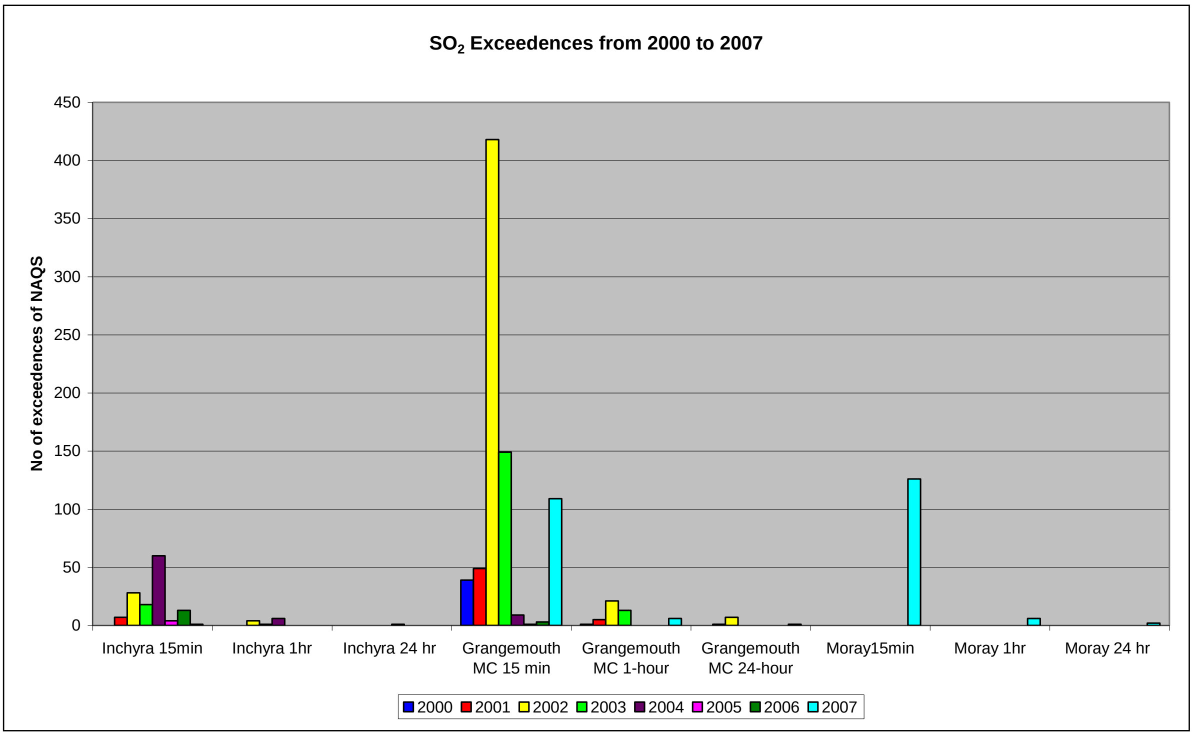
During 2007, there were 112 and 126 measured exceedences of the 15-minute mean SO_2 objective at Grangemouth MC and Moray respectively. The NAQS objective allows up to 35 exceedences of the objective level before the objective is breached, therefore, the NAQS SO_2 15-minute mean objective was not met at either Moray or Grangemouth MC monitoring locations during 2007.

Exceedences of the 1-hour mean SO_2 objective level were also measured at both Grangemouth MC and Moray in 2007; however, the number of measured exceedences was below the permitted 24 at both monitoring sites. The 24-hour mean NAQS objective level was also exceeded at both Moray and Grangemouth MC but, again the number of measured exceedences was below the permitted three. There were no measured exceedences of any of the NAQS SO_2 objectives at the Inchyra Park monitoring station.

The number of measured exceedences of NAQS objective levels at each of the monitoring sites within the AQMA between 2000 and 2007 is illustrated in Chart 1. It should be noted that the Moray monitoring site has only been operational since September 2006, thus limited historical data is available.

Between 2000 and 2003, Grangemouth MC tended to record the highest number of exceedences; however, from 2004 until 2006, the highest number of exceedences was recorded at Inchyra Park. In 2007, the new monitoring station at Moray recorded the highest number of exceedences, whilst more exceedences were recorded at Grangemouth MC than Inchyra Park.

Chart 1: Number of measured exceedences of SO_2 NAQS objectives 2000 to 2007



It is evident, therefore, that the air quality footprint in Grangemouth has changed over the period 2000-07. It is known that there have been changes to the emissions profiles of industrial processors within the Forth Valley; however, the source(s) of the measured exceedences are not fully understood such that the reason for the change can be determined. A further evaluation of the measured exceedences in 2007 is provided in Section 3 in order to determine the likely source(s) of the measured exceedences.

3 EVIDENCE BASED STUDY

In recent years, the pattern of measured exceedences of the 15-minute mean SO_2 objective has changed. As discussed in Section 2, between 2004 and 2006, the monitoring station at Inchyra Park measured the highest number of exceedences, but in 2007, no exceedences of the 15-minute mean SO_2 objective were measured at all. Furthermore, exceedences of the objective were identified at Park Street and Hope Street monitoring stations in Falkirk town centre when historically no exceedences have been measured at these sites. The new monitoring site at Moray measured the highest number of exceedences during 2007 of all monitoring locations.

The purpose of the evidence-based study is to identify any current or historical trends in measured exceedences, which could help pinpoint particular causes of each pollution episode. The study will focus on analysing the wind direction and measured pollution episodes. Identifying the wind direction at the time of a measured exceedence should improve identification of the emission source or sources that are contributing to the pollution episode.

This section also aims to analyse the relationships between measured pollution episodes at each monitoring site in order to identify any patterns or changes to wind direction. It is postulated that some pollution episodes recorded at different monitoring sites may be caused by the same emissions plume influenced by local air mass movements.

A description of the main mechanisms that are involved in atmospheric dispersion is also provided as an introduction to the study.

3.1 Atmospheric dispersion mechanisms

Sulphur dioxide (SO_2) emissions are mainly produced by the combustion of fossil fuels, particularly coal and oil, which contain sulphur. Once emitted, SO_2 is subject to various chemical reactions and dispersion mechanisms. It is important to consider the potential fate of pollutants in the atmosphere in order to anticipate when pollution episodes are likely to occur based on the particular meteorological conditions.

Atmospheric conditions can act to either enhance or prevent pollution episodes. Whether atmospheric pollutants result in a pollution episode will depend on the efficiency of the removal process in the atmosphere. Atmospheric pollutants can be removed through transformation via chemical reactions, wet or dry deposition, or diluted and dispersed through atmospheric turbulence and wind. Other factors that have an influence on pollutant dispersion include factors such as topography and the plume downwash effect of nearby buildings.

SO_2 emissions undergo chemical transformation into sulphuric acid (H_2SO_4) in the presence of the hydroxyl radical (OH). This process takes several days to occur and results in the formation of acid rain, which is a regional, not local, environmental problem. The removal of SO_2 via transformation to H_2SO_4 would effectively remove SO_2 from the atmosphere by wet deposition. Wet and dry deposition processes are generally a less important removal processes when considering local air quality. The main influence on local SO_2 concentrations in a local area such as Grangemouth will be atmospheric dispersion. The dispersion of pollutants in the atmosphere depends on wind speed, atmospheric turbulence, mixing depth, temperature and topography.

Atmospheric pollutants are usually released into the lowest layer of the atmosphere known as the boundary layer. The height of the boundary layer varies depending on the time of day, and it is usually bounded at the upper extent by a temperature inversion layer (where warm air lies above cooler air). The temperature inversion layer will usually prevent any further upward dispersion of pollutants. The boundary layer height is greatest during the day and can reach heights of around 1km. Boundary layer heights are typically shallower (100-300m) at night. The height varies due to the heating influence of the sun.

Atmospheric conditions are commonly referred to as stability classes. Daytime conditions with deep boundary layers are referred to as unstable conditions and they occur due to high levels of solar radiation. As the air is warmed by the sun, it rises, and large convective eddies can occur. These conditions cause the rapid dispersion of pollutants; however, in some cases they can result in high ground level concentrations as the plume can be brought to the ground before the plume has been diluted by ambient air.

Conditions at night are usually classified as stable and are characterised by cold, calm conditions often with temperature inversions present. These conditions result in very little atmospheric turbulence and pollutants can travel a long distance before grounding. Very little dilution of the plume occurs and when the inversion layer occurs close to the ground, it can result in high pollutant concentrations as the pollutants become trapped.

Neutral atmospheres provide the optimum conditions for dispersion as they are characterised by high wind speeds and moderate or low levels of solar radiation. The plume is rapidly mixed with ambient air, which reduces the pollutant concentrations within it. During neutral conditions, plumes also take longer to reach ground level.

Atmospheric dispersion of pollutants can be a complex process that is highly influential in determining if a pollution episode will occur. It is helpful to investigate the meteorological conditions at the time of a pollution episode in order to determine the cause.

3.2 Meteorological analysis

Meteorological data for the Forth Valley area, and particularly Grangemouth, were available from several sources. The UK Meteorological office operates a monitoring site at Edinburgh Gogarbank, which is situated approximately 22 km to the south east of Grangemouth. This meteorological site provides data on the full range of meteorological parameters including temperature, wind speed, wind direction, precipitation, cloud cover and humidity. Falkirk Council operates a meteorological station at Grangemouth MC. Anemometers on the Inchyra Park and Moray air quality monitoring stations provide data on wind speed and direction.

Meteorological conditions are also monitored locally by both Ineos Ltd and Scottish Power, data from which was supplied by both companies for use in the study. A summary of measured annual average meteorological parameters from each of the monitoring sites is presented in Table 3. It is evident from the presented data that there is some variability in measured parameters between the monitoring sites. The monitoring sites at Inchyra Park and Moray recorded wind speeds of up to 50 and 45 m/s respectively. This is quite different to the maximum wind speed of 13.9 m/s recorded at Grangemouth MC where the measured mean wind speeds are more consistent with those recorded at Edinburgh and Ineos. The anemometers, calibrations and recording interval of each meteorological station varies and therefore it is possible that the maximum wind speeds recorded at Inchyra and Moray emphasis the shorter term effects of gusts. However, it is evident that the local topography or other conditions have an effect on the measured wind speeds, e.g. the Ineos site is located in a more exposed location close to the River Forth compared to Edinburgh and Grangemouth MC and thus higher wind speeds tend to be recorded. The site at Inchrya is located within an open space in Grangemouth and therefore it is possible that the urban terrain is creating a channelling effect resulting in higher maximum recorded wind speeds.

Table 3: Summary of meteorological parameters

Meteorological site	Mean temperature (°C)	Maximum wind speed (m/s)	Mean wind speed (m/s)	Most frequent wind direction (°)	Mean wind direction (°)
Grangemouth MC	9.2	13.9	3.1	247.5[1]	226.7*
Ineos Ltd	-	26.9	7.5	240	216.8
Edinburgh Gogarbank	9.6	14.9	4.4	250	202.6
Inchyra Park	-	50	3.0	228	208.8
Moray	-	45	3.6	256	204.2

[1] Wind direction data at Grangemouth is in sectors that have been converted to degrees for comparison purposes

3.2.1 Exceedence analysis

A summary of the dates and times when exceedences of the 15-minute mean SO_2 objective were measured is presented in Table 4. The number of exceedences during each episode and the relevant station at which the exceedences were recorded are also presented. It is noted that greater numbers of exceedences were recorded during April, May, June, and August, whilst fewer exceedences tended to be recorded during the winter months, although there were a few measured exceedences in both February and December. The temporal distribution of exceedences appears to indicate that warmer summer weather i.e. more unstable conditions is a contributory factor.

Table 4: Summary of 15-minute mean SO_2 Exceedence Periods

Date	Time	Number of exceedences	Monitoring station
18 January 2007	06.15	1	Grangemouth MC
8th February 2007	13.15-15.45	5	Moray
9th February 2007	12.15-14.00	5	Grangemouth MC
22nd February 2007	01.30	1	Moray
1st April 2007	17.15	1	Grangemouth MC
3rd April 2007	13.15-16.15	4	Moray
13th April 2007	11.45-13.15	5	Moray (1), Grangemouth MC (4)
14th April 2007	10.00	1	Inchyra Park
14th April 2007	12.00	1	Moray
14th April 2007	18.00	1	Grangemouth MC
26th April 2007	16.45-19.45	3	Moray
27th April 2007	13.45-19.00	7	Moray
28th April 2007	9.00-16.30	4	Moray
29th April 2007	15.45-16.15	3	Grangemouth MC
30th April 2007	11.00	1	Grangemouth MC
30th April 2007	13.45-23.45	8	Moray
1st May 2007	14.00-19.30	7	Grangemouth MC
2nd May 2007	09.45-13.00	8	Moray
2nd May 2007	11.00-11.30	3	Park street
2nd May 2007	11.15-12.00	4	Hope Street
2nd May 2007	16.15-20.45	14	Grangemouth MC
3rd May 2007	10.45-11.00	2	Park Street
3rd May 2007	11.00-11.15	2	Hope Street
3rd May 2007	11.15-14.00	5	Moray
3rd May 2007	14.30-19.30	11	Grangemouth MC
11th May 2007	12.00-20.30	6	Moray

Date	Time	Number of exceedences	Monitoring station
15th May 2007	16.30	1	Moray
31st May 2007	11.30-19.00	11	Moray
31st May 2007	16.30	1	Grangemouth MC
1st June 2007	15.00-19.30	6	Grangemouth MC
2nd June 2007	00.00-03.15	5	Moray
7th June 2007	16.30	1	Grangemouth MC
11th June 2007	17.45	1	Moray
18th June 2007	00.15	1	Moray
19th June 2007	1.30-20.15	15	Moray
20th June 2007	1.15-6.45	2	Moray
21st June 2007	15.00-17.30	3	Grangemouth MC
15th July 2007	15.30-16.30	3	Grangemouth MC
15th July 2007	18.00-19.00	2	Moray
6th August 2007	1.30-1.45	2	Grangemouth MC
9th August 2007	15.15	1	Grangemouth MC
9th August 2007	16.15-16.30	2	Moray
14th August 2007	14.30	1	Moray
18th August 2007	10.45-14.00	14	Moray
22nd August 2007	10.30-13.45	13	Moray
22nd August 2007	18.45	1	Grangemouth MC
23rd August 2007	23.30	1	Moray
27th August 2007	17.15	1	Grangemouth MC
19th November 2007	6.30-7.45	3	Moray
8th December 2007	19.00	1	Moray
17th December 2007	21.45-22.15	2	Grangemouth MC
18th December 2007	5.30	1	Grangemouth MC

3.2.2 Wind direction analysis

Meteorological data for 2007 were obtained for the Ineos and Gogarbank meteorological sites along with the wind speed and direction from both Inchyra Park and Moray air quality monitoring stations. The measured concentration and the wind direction occurring at the time were plotted on a pollution rose for each site to determine the prevailing wind direction during periods of elevated SO_2 concentrations to try to identify the emission source(s). The analysis considers all wind directions recorded irrespective of recorded wind speed. Pollution roses have been produced for the average of measured 15-minute mean concentrations and for the 99.9th percentile of measured 15-minute mean concentrations for each wind direction. The pollution roses are presented in Charts 2 to 7 in the main text and are displayed on a map of the AQMA in Figures 1 to 6 in Appendix A Each site is discussed in turn.

Moray

A pollution rose of 15 minute mean concentrations measured at Moray is presented in Chart 2 and a pollution rose of 99.9th percentile concentrations measured at Moray in Chart 3. The pollution rose in Chart 2 indicates that the wind direction is between 60° and 120° for the majority of occasions when elevated SO_2 concentrations are measured. This would suggest that the primary source of SO_2 at Moray is located to the east of the monitoring station. Chart 2 displays the average measured concentration and so does not identify individual pollution episodes.

The pollution rose of 99.9th percentiles, from Chart 3, allows further analysis of the wind direction during a pollution episode. From Chart 3, it can be seen that when the wind direction was between 60°, 90°, 120°, and 220° there were measured exceedences of the 15-minute objective. The majority of pollution episodes occurred when the wind was blowing from the east, which would suggest a source towards the east of the monitoring station. However, there were also measured exceedences of the 15-minute objective when the wind direction was 220°, which could suggest a pollution source towards the south west of Grangemouth.

Based on the wind direction alone, it is possible that the majority of measured exceedences at Moray were attributable to emissions from sources within the Grangemouth petrochemical complex, however, the results indicate that there are other nearby pollution sources that are capable of causing exceedences.

Chart 2: Moray 15-minute mean pollution rose

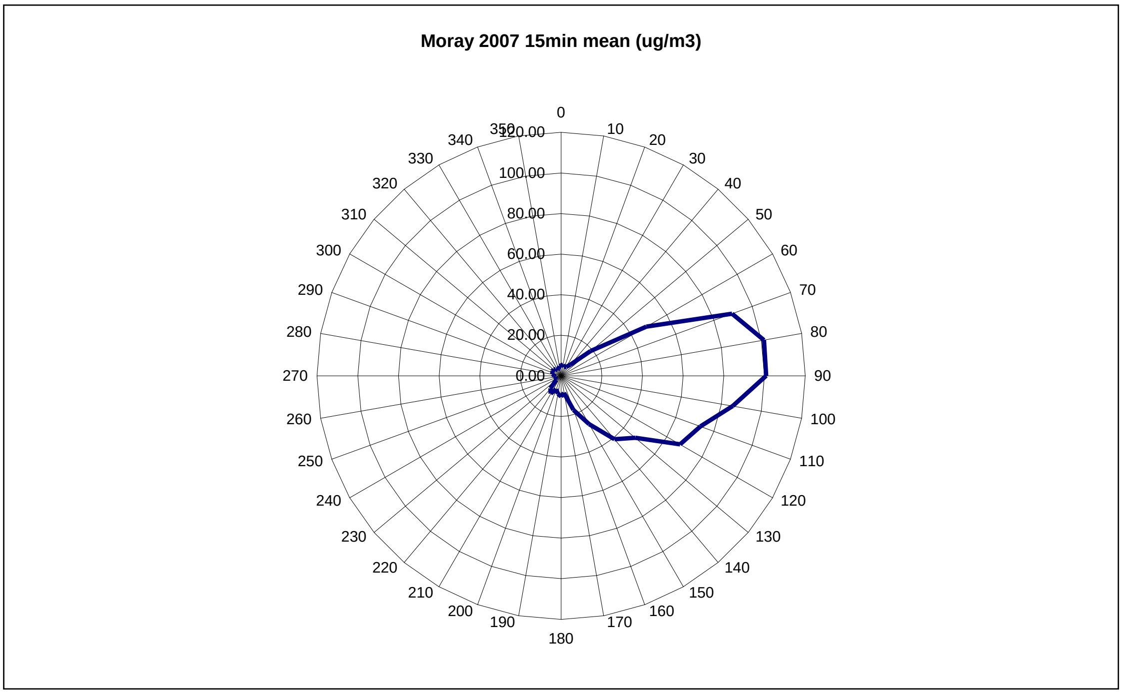
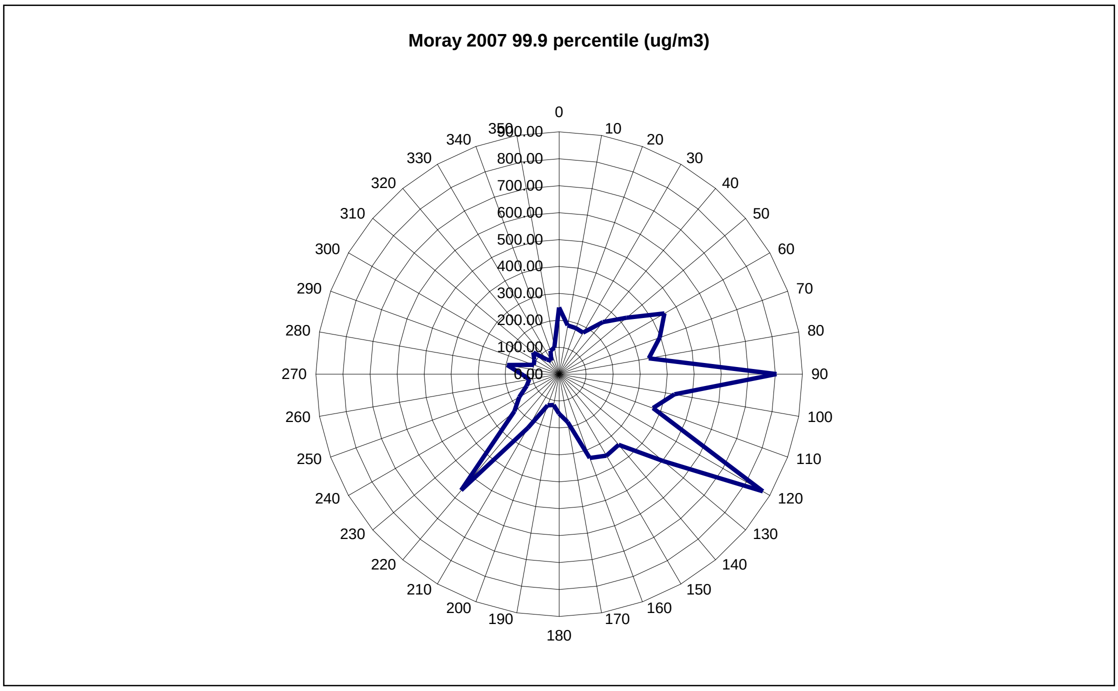


Chart 3: Moray 99.9th percentile pollution rose



Grangemouth Municipal Chambers

A pollution rose of 15 minute mean concentrations measured at Grangemouth MC is presented in Chart 4 and a pollution rose of 99.9th percentile concentrations in Chart 5.

The pollution roses for Grangemouth MC used wind speed and direction from the Moray air quality monitoring station as the meteorological station at Grangemouth MC suffered from data capture problems due to remote communication issues. The 15-minute mean pollution rose (Chart 4) suggests that the majority of measured SO_2 concentrations arise when the wind direction is between 80° and 120°. The pollution rose for 99.9th percentile (Chart 5) also indicates that during the measured exceedences the predominant source(s) of emissions contributing to the pollution episodes were likely to be from the east of the site, i.e. the Grangemouth petrochemical complex. The evidence therefore suggests that the majority of pollution episodes originate from within the Grangemouth complex but that there are also periods of elevated concentrations where the pollutants may be originating from elsewhere.

Chart 4: Grangemouth Municipal Chambers 15-minute mean pollution rose

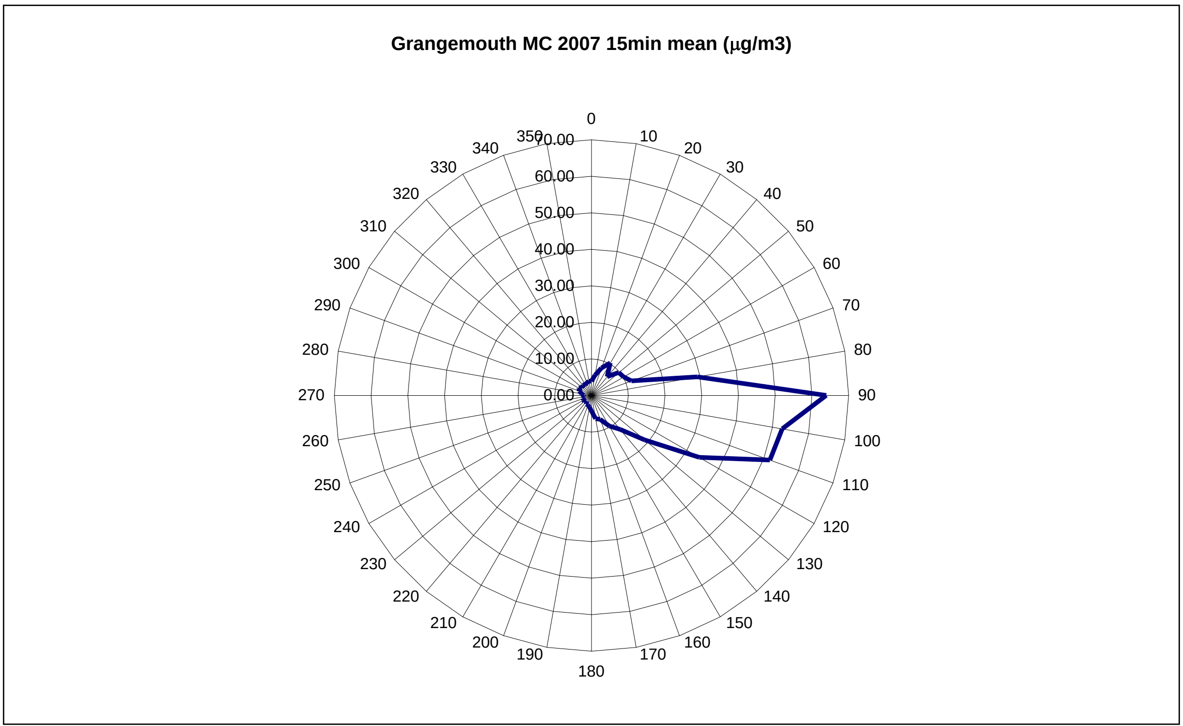
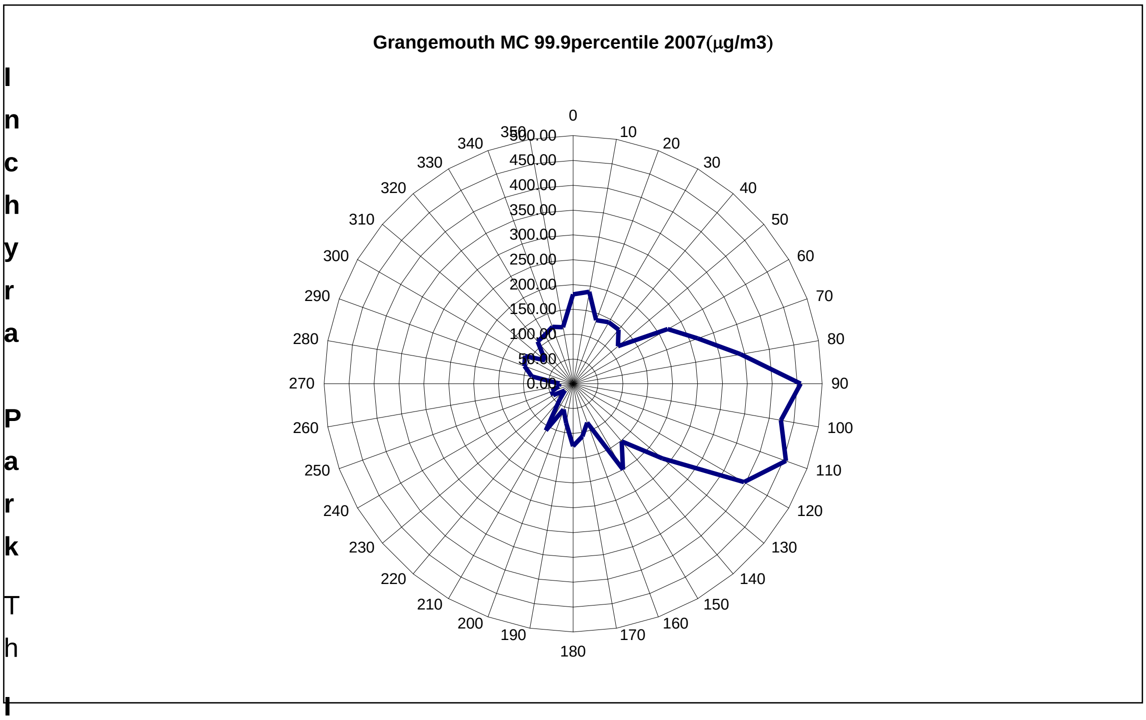


Chart 5: Grangemouth Municipal Chambers 99.9th percentile pollution rose



Inchyra Park

A pollution rose of 15 minute mean concentrations measured at Inchyra is presented in Chart 6 and a pollution rose of 99.9th percentile concentrations in Chart 7.

The 15-minute mean pollution rose for Inchyra Park, shown in Chart 6, would suggest that the majority of measured SO_2 episodes arise when the wind direction is between 20° and 80°. This wind direction is consistent with an emissions source from either the Grangemouth complex or Longannet Power Station in relation to the location of the monitoring station. However, in 2007 there were no measured exceedences of the 15-minute objective at Inchyra Park monitoring station. Chart 7 indicates that the elevated concentrations measured at Inchyra Park were found to be when the wind direction was between 0° and 120° indicating a source located towards the north-east of the monitoring station.

Chart 6: Inchyra Park 15-minute mean pollution rose

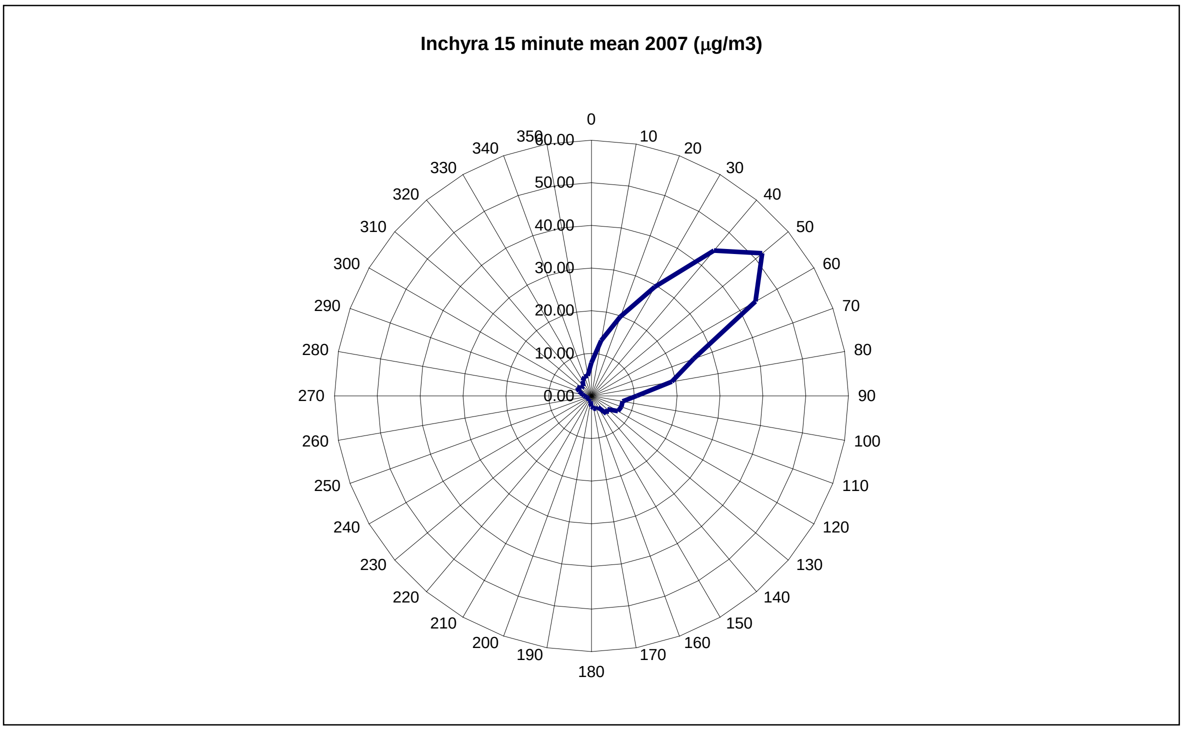
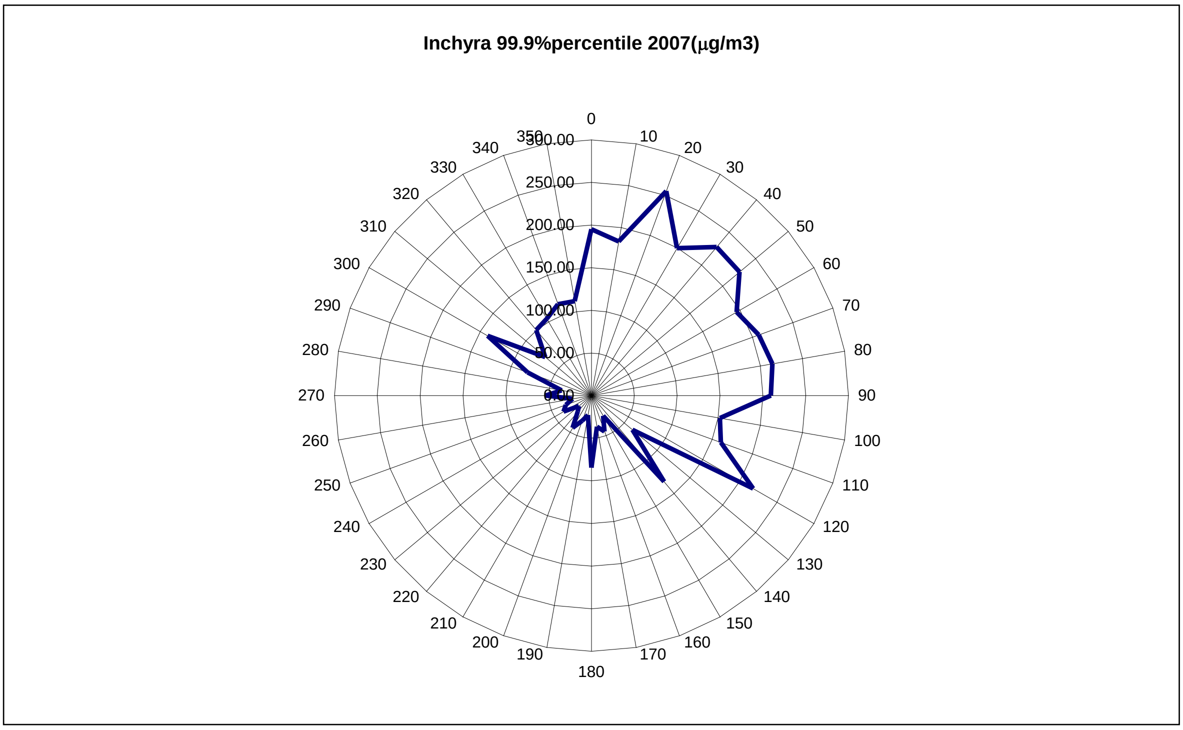


Chart 7: Inchyra Park 99.9th percentile pollution rose



Overall, the pollution roses indicate some recurring trends. The 15-minute mean averages indicate that for the majority of the time, measured SO_2 concentrations originate from the east of the Moray and Grangemouth MC monitoring stations and from the north-east of Inchyra Park monitoring station. Possible sources of SO_2 emissions in those locations include the Ineos site, Longannet Power Station, shipping, and smaller industrial operators.

However, the analysis of 99.9th percentile of 15-minute mean concentrations indicates that particular exceedences occurred at Moray during south-westerly winds and at Grangemouth MC and Inchyra during north-westerly and south-easterly winds. This could suggest that the large industrial complex at Grangemouth is not the cause of all measured exceedences of the SO_2 objectives, or that there is a complex atmospheric circulation occurring whereby low level measurements of wind direction are not representing direction of movement of the atmosphere at the level of emissions.

3.2.3 Trends analysis

During 2007, there were several days where the 15-minute mean SO_2 objective was exceeded on the same day at more than one location. The days with the highest number of exceedences were:

- 2nd May with 29 exceedences.
- 3rd May with 20 exceedences.
- 31st May with 12 exceedences.
- 19th June with 15 exceedences.
- 18th August with 14 exceedences.
- 22nd August with 14 exceedences.

Each individual day is discussed further as follows. A graph of measured concentrations for each day is presented in Charts B.1 to B.6 in Appendix B. The graphs are complex but are designed to identify if there were any similar trends in measured concentrations at each of the monitoring stations and present a lot of information.

2nd May 2007

There were 29 measured exceedences of the 15-minute mean SO_2 air quality objective on 2nd May 2007. These exceedences were distributed across four monitoring sites, namely Moray, Park Street, Hope Street and Grangemouth MC. A graph of the measured concentrations at each site, including the wind direction is shown in Chart B.1. The graph indicates that Inchyra Park experienced higher pollutant concentrations in the early hours of the morning, which gradually tailed off over the course of the day; however, no exceedences were measured. The first exceedences were recorded at Moray at around 9.45 am. Measured concentrations fluctuated but remained high until a large fall in concentrations between 1.00 pm and 2.00 pm. Measured concentrations then increased again until 3.45 pm. The increase in concentrations at Moray was followed by elevated concentrations and exceedences at both Park Street and Hope Street monitoring locations. The high concentrations measured at Park Street and Hope Street occurred at 11.15 am and 11.30 am respectively. The wind direction at this time was 94°, which suggests a pollution source to the east of the monitoring locations. Pollution concentrations at Hope Street, Park Street and Moray decreased at approximately the same time as concentrations at Grangemouth MC increased. This also coincided with a shift in wind directions to approximately 125°. Concentrations at Grangemouth MC remained high until around 10.00 pm.

3rd May 2007

The pollution episode on the 3rd May followed a similar pattern to that on the 2nd May (see Chart B.2). Inchyra Park recorded elevated concentrations between 10.00 am and 11.30 am, but while no exceedences were recorded, the pattern clearly shows elevated concentrations in relation to the rest of the day. The Park Street and Hope Street sites measured exceedences of the objective shortly after the peak at Inchyra Park, followed by Moray between 11.15 am and 1.45 pm. The wind direction during this period was from a north-easterly direction. Exceedences were then recorded at Grangemouth MC between 3.00 pm and 5.00 pm. This coincided with a change in wind direction to approximately 80°. The site at Bo'ness also demonstrated a spike in concentrations (although not an exceedence) at 3.45 pm where concentrations are usually low. Pollutant concentrations at Grangemouth MC decreased at approximately the same time as the wind direction changed to 136°.

31st May 2007

On the 31st May, measured exceedences of the objective were limited to the Moray and Grangemouth MC sites, as shown on Chart B.3. The pattern of measured concentration on the 31st differed to those presented for earlier in the month in that the exceedences presented as high spikes interspersed between low pollutant concentrations. In general, exceedences are recorded at Moray when not at Grangemouth MC and vice versa. The wind direction does not seem to have any influence on measured concentrations; however, a south-westerly wind was blowing for most of the day. This suggests a pollution source towards the south west of the monitoring sites.

19th June 2007

On the 19th June, all recorded exceedences occurred at the Moray monitoring location, as shown in Chart B.4. Measured concentrations at this site were high and variable for most of the day. One period occurred between 7.15 am and 10.15 am where concentrations were low. No local wind direction data were available for this day.

18th August 2007

All recorded exceedences of the objective on the 18th August occurred at Moray monitoring site, clustered around one pollution episode between 10.15 am and 1.45 pm. These are shown in Chart B.5. The wind direction during this period was easterly.

22nd August 2007

Chart B.6 shows measured concentrations for the 22nd August. Measured concentrations at all sites were very low during the early hours of the morning until around 9.30 am. The wind during the early hours was predominantly from an easterly direction. Inchyra Park recorded a short increase in measured concentrations between 9.30 am and 11.00 am. This was followed by a large increase in measured concentrations, and exceedences, at Moray that occurred between 9.30 am and 2.30 pm.

At around the same time, Park Street also recorded higher concentrations in comparison to the remainder of the day, although no exceedences occurred. Finally, Grangemouth MC recorded increased concentrations between 5.00 pm and 7.30 pm.

3.2.4 Analysis of wind conditions during pollution episodes

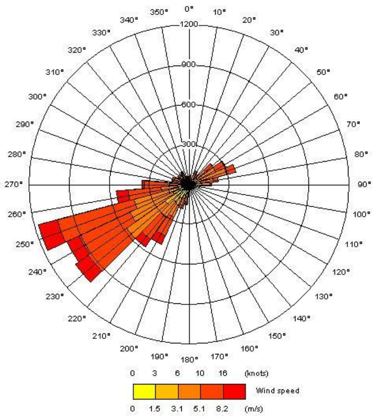
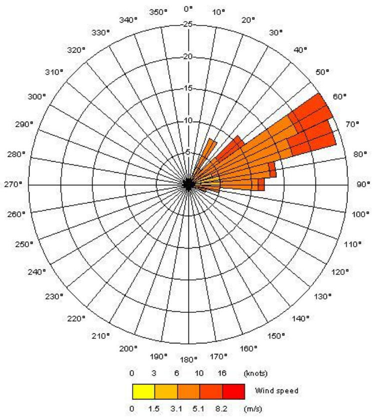
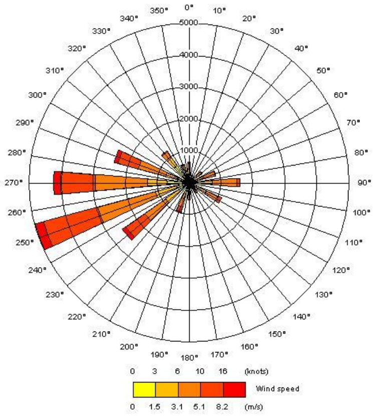
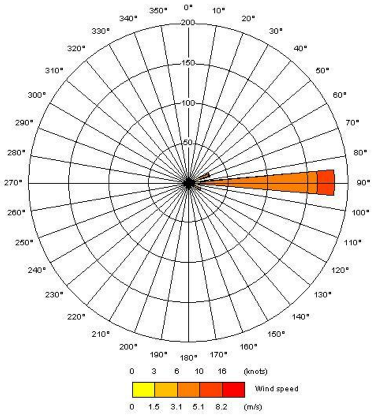
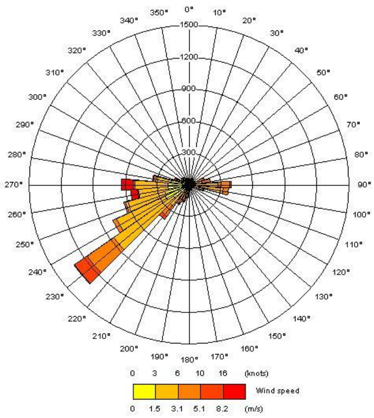
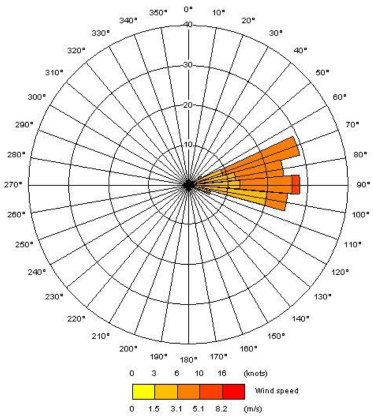
The wind conditions for 2007 at each meteorological station during periods of SO_2 objective exceedence and during periods when recorded SO_2 concentrations were below the objective level were analysed to determine the typical meteorological conditions that contribute towards exceedences of SO_2 objective concentrations. The analysis was carried out for the Moray and Grangemouth MC monitoring stations that each recorded multiple exceedences of the 15-minute and 1-hour SO_2 objective concentrations in 2007. The data is presented in the form of wind roses indicating the typical wind speed and directions recorded. The wind roses for the monitoring site at Moray are presented in Chart 8 and the wind roses for the monitoring site at Grangemouth MC are presented in Chart 9.

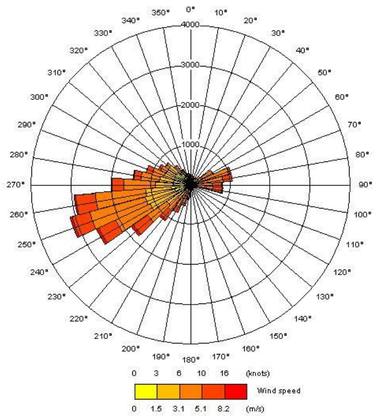
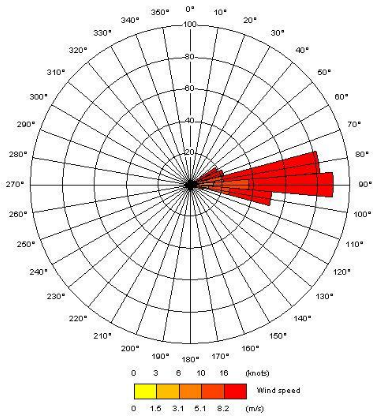
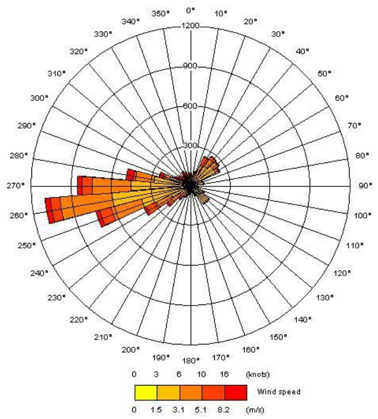
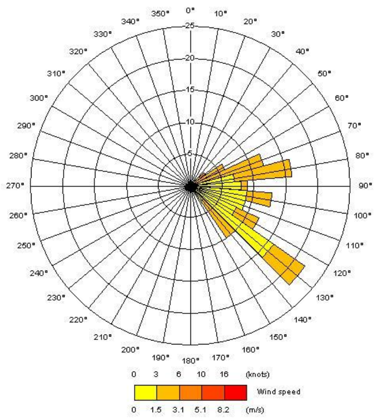
The wind roses presented in Chart 8 indicate that the wind conditions within the Forth Valley for periods during which SO_2 concentrations recorded at Moray exceeded the objective levels are significantly different to those during periods when SO_2 concentrations were below the objective level.

The typical wind direction during periods of measured exceedence at Moray is easterly at all five meteorological stations considered, compared to the predominant wind direction for the remainder of the year which was south-westerly or westerly.

The wind speeds recorded during periods of exceedence at Moray were noticeably lower at three of the meteorological stations (Moray, Grangemouth MC and Inchyra Park) compared to the mean wind speeds for the remainder of the year. The meteorological stations at Ineos and Edinburgh are located on the outskirts of urban areas and are more exposed to winds from the north and east than the stations at Grangemouth MC, Inchyra Park and Moray and therefore generally record higher wind speeds during periods of easterly and north-easterly winds.

Chart 8: Wind roses for 2007 indicating wind characteristics during periods of exceedence and low SO_2 concentrations at Moray monitoring station

	Wind roses of periods of low SO_2 concentrations at Moray monitoring site	Wind roses of periods of exceedence at Moray monitoring site
Edinburgh meteorological data		
Grangemouth MC meteorological data*		
Inchyra meteorological data		

	Wind roses of periods of low SO_2 concentrations at Moray monitoring site	Wind roses of periods of exceedence at Moray monitoring site
Ineos meteorological data		
Moray meteorological data		

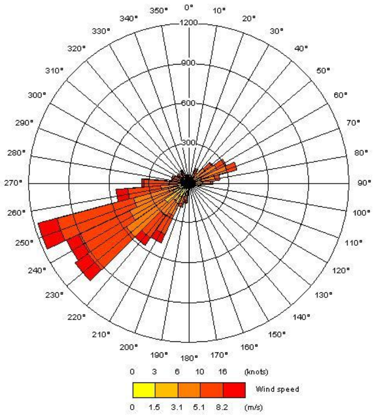
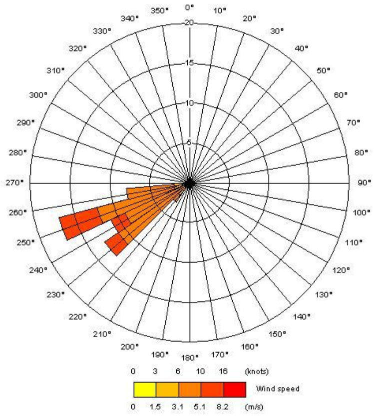
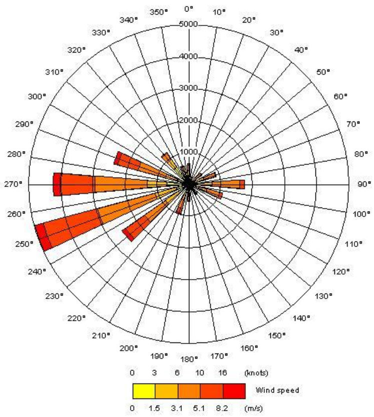
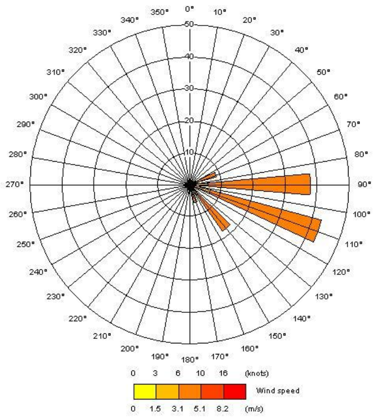
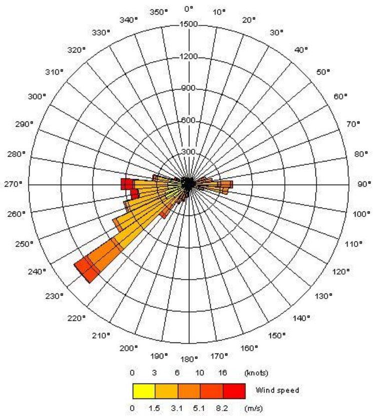
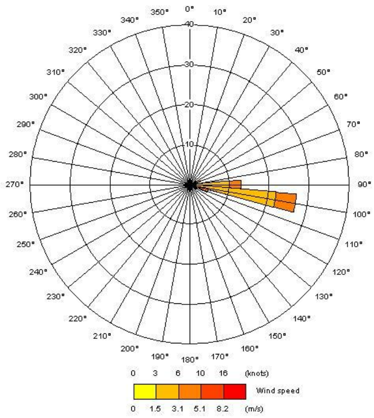
* Data capture rate for wind direction and speed at Grangemouth MC was approximately 76% and therefore not all pollution episodes are fully represented.

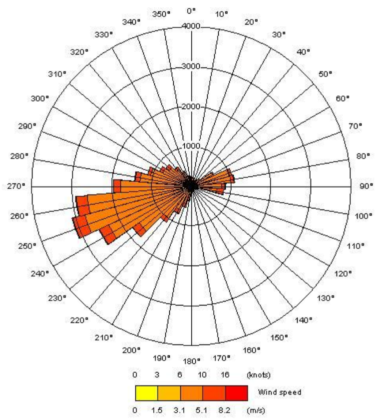
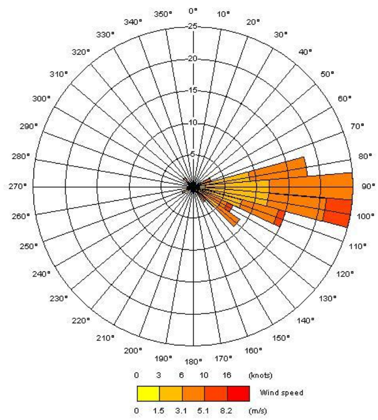
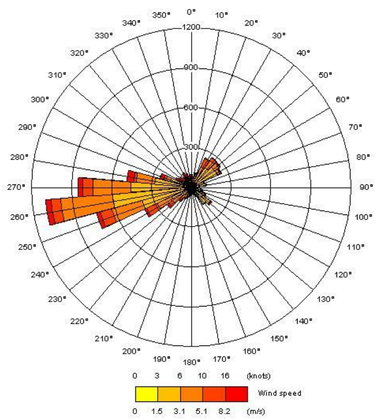
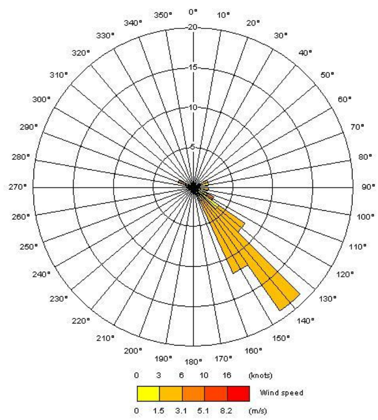
The wind roses presented in Chart 9 indicate that the wind conditions within the Forth Valley, for periods during which SO_2 concentrations recorded at Grangemouth MC exceeded the objective levels, are significantly different to those during periods when SO_2 concentrations were below the objective level.

The typical wind direction during periods of exceedence at Grangemouth MC is easterly or south-easterly at four of the meteorological stations considered, compared to the predominant wind direction for the remainder of the year, which was south-westerly or westerly. The wind direction at Edinburgh during periods of exceedence at Grangemouth MC was south-westerly. The meteorological station at Edinburgh is the furthest from the Grangemouth MC monitoring site and therefore the difference in wind conditions between periods of exceedence and periods when SO_2 concentrations are below the objective level are less evident. This may indicate local variations or influences on wind.

The wind speeds recorded during periods of exceedence at Grangemouth MC were noticeably lower at all five of the meteorological stations considered compared to the mean wind speeds for the remainder of the year. The lower wind speeds within the Forth Valley during periods of exceedence at Grangemouth MC appear to be a significant contributing factor to the high levels of SO_2 in the atmosphere around Grangemouth MC. The low wind speeds will result in slower dispersal of the emitted SO_2 from nearby sources.

Chart 9: Wind roses for 2007 indicating wind characteristics during periods of exceedence and low SO_2 concentrations at Grangemouth MC monitoring station

	Wind roses of periods of no exceedence at Grangemouth MC monitoring site	Wind roses of periods of exceedence at Grangemouth MC monitoring site
Edinburgh meteorological data		
Grangemouth MC meteorological data*		
Inchyra meteorological data		

	Wind roses of periods of no exceedence at Grangemouth MC monitoring site	Wind roses of periods of exceedence at Grangemouth MC monitoring site
Ineos meteorological data		
Moray meteorological data		

* Data capture rate for wind direction and speed at Grangemouth MC was approximately 76% and therefore not all pollution episodes are fully represented.

3.2.5 Discussion

The exceedences recorded during 2007 were not limited to the dates discussed in detail above. In total, exceedences were recorded within the Falkirk Council area on 39 different days during 2007.

The analysis of exceedences during 2007 indicates that there is a possibility that exceedences at different sites were caused by the same pollution event. The exceedences of the 15-minute and 1-hour mean SO_2 objective concentrations recorded at different monitoring stations on the same day may be attributed to changes in wind direction. The fact that the location of measured exceedences, or spikes in measured concentrations, changes as the wind direction changes supports this theory.

Historically, exceedences of the 15-minute mean SO_2 objective have been recorded at Inchyra Park; however, no exceedences were recorded at the site during 2007. The graphs of measured pollutant concentrations clearly show that Inchyra Park is still being affected by the same pollution episodes as the other monitoring locations; however, the concentrations remain below the objective. A possible explanation for this may be meteorological conditions. If the wind direction in relation to the pollution source is not taking the plume directly over the monitoring site, then exceedences are less likely to be recorded. It could also be that the main pollution source previously affecting Inchyra Park is no longer operational.

The analysis also indicates that the exceedences often occur when there is an easterly wind. This indicates a source to the east of the monitoring locations. There were also periods when the wind was blowing from a south-westerly direction which could indicate a source to the south west of the monitoring locations; however this was only evident at Moray.

The main sources of SO_2 emissions within the Falkirk area include the Grangemouth complex, Longannet, shipping emissions, railway emissions and other smaller industrial operators. In addition, transboundary SO_2 emissions are also possible. It is highly likely that the problem is caused by large emitters of SO_2 but also by the cumulative effect of several smaller sources clustered within a local area. In this case, no particular source would be easily identifiable. This may explain pollution episodes that cannot be attributed to a large pollution episode from a single source.

4 DISPERSION MODELLING STUDY

This section describes the dispersion modelling study undertaken as part of this Further Assessment.

4.1 Model description

The atmospheric emissions dispersion modelling study was undertaken using the proprietary model ADMS 4. ADMS 4 is a new generation dispersion model supplied by Cambridge Environmental Research Consultants Limited (CERC) and it is recommended for use in Defra and Environment Agency PPC Guidance Notes. The model has also been extensively validated using several data sets. New generation dispersion models describe the atmospheric boundary layer in terms of the boundary layer depth and the Monin-Obukhov length and allow for the use of a skewed Gaussian distribution under convective meteorological conditions. These facilities allow for more accurate prediction of pollutant concentrations under different meteorological conditions.

4.2 Background pollutant concentrations

In assessing air quality levels, background pollution sources should be considered in order to account for the cumulative effect of many pollution sources on overall concentrations in the atmosphere. The LAQM website† provides background concentrations for most pollutants on a 1km by 1km grid square basis. The average background concentrations of relevant pollutants are presented in Table 5. Short-term concentrations have been assumed to be twice the long-term concentrations, as recommended in the H1 guidance.

Table 5: Background pollutant concentrations (2007)

Pollutant	Background concentration (µg/m^3)	
	Long term	Short term
SO_2	2.57	5.14

4.3 Emissions inventory

Emissions data from Ineos, Longannet and BP were provided for 2007. Each company provided details of the location, and emission parameters for each SO_2 source. Where available, time varying emissions were also provided. The SO_2 sources and the respective emission parameters included in the dispersion modelling assessment are presented in Table 6 and the stack locations are shown in Figure 1. The raw data from the sources identified as time varying were formatted to provide numerical emissions for each hour of the year. Emissions were set to zero for periods of shut-down and to the source mean emission for periods when the stack analyser was not in operation.

† Defra et al, (2006). Local Air Quality Management. http://www.airquality.co.uk/archive/laqm/laqm.php.

Longannet has four flues within one chimney stack. In order to model the buoyancy and emissions from Longannet effectively the flues are combined and modelled as one. This is done through a v4 file.

Flare sources can be modelled similar to point sources, except that there are buoyancy flux reductions associated with radiative heat losses and a need to account for flame length in estimating plume height. Input requirements are similar to those for a point source, except that the release height must be calculated as an effective release height and stack parameters need to be estimated to match the radiative loss reduced buoyancy flux. In order to model the flares the air dispersion modelling guideline for Ontario[‡] was used. Due to the high temperature associated with flares, an effective release height of the plume and effective stack diameter based on the heat release rate, temperature of the flare, and an assumed exit velocity of 20m/s were calculated. By using this guidance, it allows ADMS4 to model the flares in the same manner as AERMOD. These new parameters were included in the model run within the variation file, which allows for any change in stack diameter and are shown in Table 6.

[‡] http://www.ene.gov.on.ca/envision/gp/5165e.pdf

Table 6: Emission parameters for SO_2 sources included in the dispersion modelling assessment

Source name	Stack height (m)	Stack diameter (m)	Effective stack height (m)	Effective stack diameter (m)	Effective exit velocity (m/s)	Grid reference	Volume flow rate (m^3/s)	Exit temperature (°C)
Ineos -No.1 Flare	91.5	1.075	94.47	3.725	20	295010,681720	1.54	600
Ineos -No. 2 Flare	91.5	1.075	102.01	9.198	20	294940,681590	2.57	600
Ineos -No. 3 Flare	91.5	1.075	96.35	4.801	20	294850,681450	1.87	600
Ineos -P/ST8	65	2.7	-	-	-	294560,681210	18.00	126
Ineos -Boiler 9/10	91	3.3	-	-	-	294630,681150	24.9	154
Ineos -Boiler 11	94	2.1	-	-	-	294670,681140	24.8	169
Ineos -Boiler 12	94	2.1	-	-	-	294675,681140	26.1	165
Ineos -Boiler 13	94	2.1	-	-	-	294670,681145	23.3	175
Ineos -Boiler 14	91	2.4	-	-	-	294720,681140	46	204
Ineos -1CDUB1	42.3	1.37	-	-	-	294520,681960	12.1	449
Ineos -CRU-Main	95.7	2.7	-	-	-	294870,68166	51.6	226
Ineos -CRU 1st Interheater	67.5	2.4	-	-	-	294620,681820	15.9	179
Ineos -Hydrofiner	80	1.35	-	-	-	294500,681790	3.68	340
Ineos -H/Unit	84	4.19	-	-	-	294710,681540	29.59	230
Ineos -SRU 5 tail Stack	70	0.752	-	-	-	294790,681530	1.6	800
Ineos -1 CDUB1A	56.4	1.58	-	-	-	294540,681940	4.3	307
Ineos -CDU2/DHT2	61	3.38	-	-	-	294620,681820	20.6	340
Ineos -CDU3/DHT3	79	3.7	-	-	-	294850,681830	32.8	239
Ineos -VDU/HCU	85	3.5	-	-	-	294620,681820	26.3	285

Source name	Stack height (m)	Stack diameter (m)	Effective stack height (m)	Effective stack diameter (m)	Effective exit velocity (m/s)	Grid reference	Volume flow rate (m^3/s)	Exit temperature (°C)
Ineos -SRU 6 Tail Stack	70	0.752	-	-	-	294750,681610	1.6	800
Ineos -FCCU	70	1.32	-	-	-	294630,68198	36.1	233
Ineos -HCU Mild Vacuum Column Reboiler	70	1.5	-	-	-	29477,68137	5.69	390
Longannet 1	183	7.6	-	-	-	295250,685250	Variation file	134
Longannet 2	183	7.6	-	-	-	295250,685250	Variation file	134
Longannet 3	183	7.6	-	-	-	295250,685250	Variation file	134
Longannet 4	183	7.6	-	-	-	295250,685250	Variation file	134
BP A17 (T3 flare)	88	1.2	97.78	3.3	20	296009,680802	Variation file	700

4.4 Modelled domain and receptors

Concentrations were calculated over a regular Cartesian grid pattern and at specific receptor points. The modelled domain consisted of a 10km by 8km square grid covering the area (289500, 679500) to (299500, 687500). The number of calculation points was set at 100 by 100, which provides predicted concentrations every 100m by 80m. The modelled domain was large enough to encompass the Grangemouth AQMA and the area surrounding Longannet. The receptors included in the study are presented in Table 7 and are shown on Figure 2. The receptors that have been included comprise of points representative of the monitoring locations in order to allow model verification, as well as locations of relevant public exposure such as residential properties, schools, recreation areas and public buildings.

Table 7: Receptor locations

Receptor	Grid reference	Description
Inchyra Park AQU	293835 681020	Recreation area (M)
Moray AQU	293469 681321	School (M)
Grangemouth Municipal Chambers AQU	292818 682008	Public building (M)
Inch Farm (Fife)	294030 686590	Residential
Blair Mains (Fife)	296960 686220	Residential (M)
Culross (Fife)	298380 685920	Residential
Kinneil Primary School	299510 680850	School
Bo`ness Town Hall	299816 681469	Public building
Woodhead Farm	298180 679720	Residential
Avondale House	295810 680350	Residential
Inchyra Grange Hotel	293510 679680	Residential
West Beancross Farm	292450 679750	Residential
Forth Valley College	289800 680540	School
Bothkennar Primary School	290810 683360	School
Grangemouth Docks – Western Channel	295160 683700	Workplace
Grangemouth Docks – Eastern Channel	295160 683710	Workplace
East Kerse Mains	296980 680360	Workplace
Wholeflats	294210 680070	Residential
Oil refinery	294360 681820	Workplace
Grangemouth Stadium	293628 680508	Public building
Sports Complex, Grangemouth	292826 681146	Public building
Grangemouth High School	293030 680300	School
Beancross Primary	292480 680510	School
Bowhouse Primary	293350 680450	School
Sacred Heart primary	293120 680630	School
Zetland Pavilion	292950 681530	Recreation area
Roxburgh St, Grangemouth	293520 682010	Residential

Receptor	Grid reference	Description
Bo'ness Road, Grangemouth	294040 681470	Residential
Grange Manor Hotel	291220 681640	Residential
Dalgrain Park, Grangemouth	291200 682120	Recreation area
Asda, Grangemouth	292895 682198	Public building
Albert Avenue, Grangemouth	293874 681941	Residential
Oxgang Hotel, Grangemouth	293574 681623	Residential

4.5 Meteorological data

ADMS4 requires a minimum input of six meteorological parameters for hourly sequential or statistical data. The six required parameters are surface temperature (in ºC), wind speed (in m/s), wind direction (as degrees from north), relative humidity (as a %), cloud cover (in oktas) and precipitation (in mm). A review of meteorological data was carried out to determine the most appropriate set of meteorological parameters available.

Meteorological data from several stations within the vicinity of the Grangemouth AQMA were available. The closest meteorological station to the Grangemouth AQMA, which records the full suite of required meteorological parameters, is Edinburgh International Airport (Gogarbank). Edinburgh airport is a lowland station located approximately 22 km southeast of the AQMA. The site is close to the Firth of Forth and is located in predominantly suburban surroundings.

At the time of this study Falkirk Council operates a full meteorological station at Grangemouth MC. However, measured wind direction at this site is provided in sectors rather than degrees; it is not therefore possible to determine the finer details of wind direction variability at the site. At both Inchyra Park and Moray automatic air quality monitoring stations, wind speed and direction data are available. Meteorological data were also available from Ineos Ltd from a station situated within the Grangemouth complex.

A sensitivity analysis was conducted to determine the meteorology dataset that predicted the most accurate ground level concentrations. Where the full suite of required parameters was not available from a particular meteorological station, data from Gogarbank were used. The datasets used and the results of the sensitivity analysis are discussed in detail in Section 4.12

4.6 Surface characteristics

The surface characteristics of an area have an influence on the dispersion of atmospheric pollutants through the generation of turbulence. The surface roughness factor used in ADMS 4 is a measure of this turbulence. The land use near the Grangemouth AQMA is urban with some industrial sites nearby. The frictional effects within the vicinity of the site will therefore be greater than in a rural area, for example. A surface roughness factor of 1.5 has been used in the assessment as this is representative of an urban or built up area, this is also representative of the surface roughness at the meteorological site.

4.7 Treatment of terrain

The terrain of an area can act to either increase or decrease ground level concentrations through altering the plume dispersion pattern. The effects of terrain upon pollutant dispersal are generally insignificant if the gradients within the assessment area are less than 1 in 10. The terrain in the immediate vicinity of the Grangemouth AQMA is relatively flat and comprises carseland with the River Forth floodplain. The River Forth and the estuarine mudflats are located to the north and east of the AQMA.

The terrain to the north and south of the study area is more complex and there are some slopes with gradients greater than 1 in 10. A sensitivity analysis of the effect of topographical data was carried out and is discussed in detail in Section 4.12

4.8 Treatment of buildings

Due to the size of the source area and the complexity of the site, buildings were not explicitly modelled but were accounted for in the surface roughness.

4.9 Fluctuations module

The fluctuations module takes account of the variations in concentration caused by the short time scale turbulence in the lower atmosphere. This module can produce a more representative output for short-term concentrations such as the 15-minute mean SO_2 NAQS objective. Limitations in the model, however, only allow a maximum of ten emission sources when using the fluctuations module, which limits the input data for this option. This is particularly relevant for this study as more than ten emission sources were considered. The fluctuations module was therefore used on a restricted basis.

4.10 Calm conditions

ADMS4 is unable to model wind speeds of less than 0.75ms^{-1}; therefore, these met lines will be skipped during the model run, which will have an effect on the predicted concentrations. Due to the number of meteorology lines within the meteorological data set with wind speeds of 0ms^{-1}, a v4 file was used to model these calm meteorology lines. When using a v4 file the model automatically replaces any 0ms^{-1} wind speeds in the data file with a wind speed of 0.3ms^{-1}.

Unfortunately, due to limitations of ADMS4 it is not possible to include both the hills option and calm conditions together. Although the terrain had an impact as discussed in the sensitivity analysis it was felt that it was more desirable to include as many of the meteorology lines as possible so that greater confidence in the model output would be obtained, especially for percentile values.

4.11 Modelling scenarios

The aim of the modelling study is to identify the most likely source, or sources, that are contributing to the measured exceedences of the 15-minute mean SO_2 objective. To do this it is necessary to model the different sources in groups so that the relative contribution of each source can be identified. The emissions sources included in each group are presented in Table 8.

Table 8: Emissions source groups

Group	Source	
Flares	• No.1 Flare • No. 2 Flare • No. 3 Flare	
CDU3	• CDU3/DHT3	
VDU/HCU	• VDU/HCU	
H/Unit	• H/Unit	
SRU units	• SRU 5 tail Stack • SRU 6 Tail Stack	
Boilers	• P/ST8 • Boiler 9/10 • Boiler 11	• Boiler 12 • Boiler 13 • Boiler 14
FCCU unit	• FCCU	
All Ineos	• 1CDUB1 • CRU-Main • CRU 1st Interheater • Hydrofiner • H/Unit • SRU 5 tail Stack • SRU 6 Tail Stack • 1 CDUB1A	• CDU2/DHT2 • CDU3/DHT3 • VDU/HCU • FCCU • HCU Mild Vacuum Column Reboiler • Boilers • Flares
Longannet	• Longannet 1 • Longannet 2 • Longannet 3 • Longannet 4	
BP	• BP_A17	

4.12 Sensitivity analysis

The assessment considered various meteorological data sets, inclusion of terrain data, investigation of the fluctuations of 15-minute mean concentrations and inclusion of calm conditions. Due to limitations of the model, it is not possible to include all modelling options in combination. A sensitivity analysis was therefore undertaken to determine the model output that best represents the monitored pollutant concentrations and greatest number of meteorological data lines used by the model.

The predicted pollutant concentrations at the three automatic monitoring sites were compared to the monitored concentrations for 2007. The results of the comparison are presented in Tables 9, 10 and

11. Typically, the model over-predicted the SO_2 concentrations at Inchyra Park and under-estimated the concentrations at the Grangemouth MC and Moray monitoring sites.

Previous model studies have indicated that terrain has a significant effect upon the predicted concentrations in the Grangemouth area. The initial model runs therefore included the effects of terrain. The model output using meteorological data from Edinburgh, Moray and Inchyra Park monitoring sites reported data usage of less than the recommended 90%. This means that calm conditions (< 0.7m/s) are present for more than 10% of the time.

The investigation of the fluctuations module results indicated that although the model output produced more representative 15-minute predictions for Inchyra Park the predicted concentrations at Moray and Grangemouth MC were significantly below monitored concentrations. The fluctuations module allows a maximum of ten sources to be modelled, there were 23 sources in the final model set up and therefore the fluctuations option included only the sources from the Ineos refinery. It was therefore considered inappropriate to use the fluctuations module in the final model set-up because not all sources could be included and it cannot be used in combination with the calm conditions option.

The calm conditions option allowed for consideration of low wind speeds (0.3m/s and greater) which resulted in a greater use of meteorological data (93.5%). The predicted concentrations of SO_2 at Inchyra Park were greater than the monitored concentrations, however there was a closer match compared to the results from other model options. The predicted annual mean concentrations at Grangemouth MC and Moray reflect the monitored concentrations; however, the predicted short-term concentrations were below the monitored concentrations. There is no annual mean air quality objective for SO_2 concentrations contained within the National Air Quality regulations, however the measurement allows for comparison between modelled and monitored results.

Considering the limitations of the model in combining different model options, the percentage usage of meteorological data and the comparison of predicted and monitored concentrations it was determined that the most representative model set-up was the a mixed file which included the meteorological data from Edinburgh with the wind speed and direction data from Moray, with inclusion for calm conditions. The effect of fluctuations and terrain were not included in the final model outputs

.

Table 9: Predicted SO_2 concentrations at Inchyra Park automatic analyser

Model scenario	Annual mean	99.18th %ile of 24-hr mean SO_2 concentrations	No. of exceedences of 24-hr standard	99.7th %ile of 1-hr mean SO_2 concentrations	No. of exceedences of 1-hr standard	99.9th %ile of 15-min mean SO_2 concentrations	No. of exceedences of 15-min standard	Met data usage (%)
Objective	**20**	**125**	**3**	**350**	**24**	**266**	**35**	**90**
2007 Edinburgh met data with time varying emissions from Longannet and Ineos including terrain	16	83	0	167	0	210	9	87.3
2007 Inchyra met data with time varying emissions from Longannet and Ineos including terrain	11	66	0	161	1	262	23	69.1
2007 Moray met data with time varying emissions from Longannet and Ineos including terrain	17	97	0	207	0	269	38	74.5
2007 Moray met data with time varying emissions from Ineos refinery including fluctuations and terrain	7	N/A	N/A	N/A	N/A	155	5	74.5
2007 Moray met data with time varying emissions from Longannet and Ineos including calm conditions	15	94	0	183	0	227	12	93.5
Measured concentration	**5**	**47**	**0**	**126**	**0**	**178**	**0**	**N/A**

Table 10: Predicted SO_2 concentrations at Grangemouth Municipal Chambers automatic analyser

Model scenario	Annual mean	99.18th %ile of 24-hr mean SO_2 concentrations	No. of exceedences of 24-hr standard	99.7th %ile of 1-hr mean SO_2 concentrations	No. of exceedences of 1-hr standard	99.9th %ile of 15-min mean SO_2 concentrations	No. of exceedences of 15-min standard	Met data usage (%)
Objective	**20**	**125**	**3**	**350**	**24**	**266**	**35**	**90**
2007 Edinburgh met data with time varying emissions from Longannet and Ineos including terrain	9	39	0	113	0	149	0	87.3
2007 Inchyra met data with time varying emissions from Longannet and Ineos including terrain	18	79	0	130	0	181	0	69.1
2007 Moray met data with time varying emissions from Longannet and Ineos including terrain	10	44	0	156	0	213	16	74.5
2007 Moray met data with time varying emissions from Ineos refinery including fluctuations and terrain	2	N/A	N/A	N/A	N/A	134	0	74.5
2007 Moray met data with time varying emissions from Longannet and Ineos including calm conditions	10	46	0	146	0	218	21	93.5
Measured concentration	**10**	**89**	**1**	**253**	**6**	**360**	**112**	**N/A**

Table 11: Predicted SO_2 concentrations at Moray automatic analyser

Model scenario	Annual mean	99.18th %ile of 24-hr mean SO_2 concentrations	No. of exceedences of 24-hr standard	99.7th %ile of 1-hr mean SO2 concentrations	No. of exceedences of 1-hr standard	99.9th %ile of 15-min mean SO_2 concentrations	No. of exceedences of 15-min standard	Met data usage (%)
Objective	**20**	**125**	**3**	**350**	**24**	**266**	**35**	**90**
2007 Edinburgh met data with time varying emissions from Longannet and Ineos including terrain	18	101	0	156	0	181	5	87.3
2007 Inchyra met data with time varying emissions from Longannet and Ineos including terrain	16	90	0	164	0	232	0	69.1
2007 Moray met data with time varying emissions from Longannet and Ineos including terrain	14	73	0	169	0	237	11	74.5
2007 Moray met data with time varying emissions from Ineos refinery including fluctuations and terrain	4	N/A	N/A	N/A	N/A	149	0	74.5
2007 Moray met data with time varying emissions from Longannet and Ineos including calm conditions	12	73	0	162	0	201	8	93.5
Measured concentration	**13**	**109**	**2**	**242**	**6**	**346**	**126**	**N/A**

5 MODELLING RESULTS AND DISCUSSION

5.1 Ineos

Ineos emissions sources were modelled as a combined group and as individual groups. The model is able to predict the point of maximum concentration from each group. The predicted maximum concentration from each group will occur at a different point spatially and with temporal variation.

Due to this spatial and temporal variation, it is not possible to definitively apportion short-term SO_2 concentrations within the AQMA. The study, therefore, considers the maximum predicted contribution of each emission source to 15-minute mean SO_2 concentrations across the study area, as well as the 99.9th percentile of 15-minute mean SO_2 concentrations.

The study also identifies the meteorological conditions responsible for each source's predicted maximum concentrations. This is discussed in Section 5.5.

5.1.1 All Sources

The modelling results for all sources, when compared to the NAQS objectives indicate that the 1-hour mean and 24-hour mean objectives will be met as the number of predicted exceedences were below the maximum number allowed for each objective. However, a breach of the 15-minute mean objective is predicted at certain locations within the AQMA. The results for each group will be discussed in turn. Contour plots of predicted concentrations are provided in Appendix C.

5.1.2 Flares

The lowest predicted concentrations at the automatic monitoring sites occurred with the flares modelled as one group. A contour plot of predicted concentrations is presented in Figure 3. The contour plot indicates that the highest concentrations resulting from flare emissions occur towards the north-west of the AQMA; however, no exceedences of the 15-minute mean SO_2 concentration from the flares were predicted.

5.1.3 VDU/HCU

The highest predicted concentrations resulting from emissions from the VDU/HCU emissions were substantially below the SO_2 15-minute mean air quality objective. No exceedences were predicted from this source. A contour plot of the predicted concentrations is presented in Figure 4.

5.1.4 H-Unit

The emissions from the H-Unit contribute the third lowest contribution to total predicted concentrations and the highest predicted concentrations were substantially below the SO_2 objectives. The contour plot in Figure 5 also indicates that the area of maximum concentrations resulting from the H-Unit is limited to a small region close to the centre of the AQMA but away from the residential areas.

5.1.5 CDU3 and FCCU

Emissions from the CDU3 and FCCU sources follow similar dispersion patterns. Contour plots of predicted concentrations from the CDU3 and FCCU units are presented in Figures 6 and 7 respectively. No exceedences of objectives were predicted from either the CDU3 or FCCU emissions sources when modelled in isolation. The highest concentrations were predicted to be approximately 40% and 50% of the 15-minute mean SO_2 objective for the CDU3 and FCCU sources respectively.

5.1.6 Boilers

A contour plot of predicted SO_2 concentrations resulting from boiler emissions is presented in Figure 8. Again, no exceedences were predicted to occur due to boiler emissions alone. The maximum concentration from the calculation grid was predicted to be approximately 70% of the 15-minute mean air quality objective, which is a substantial contribution towards it. However, the maximum concentrations were restricted to non residential areas within the AQMA.

5.1.7 SRUs

The SRUs contribute the highest percentage towards total emissions from Ineos sources. A contour plot of predicted concentrations is provided in Figure 9. The model also predicted a small area where the 15-minute mean objective was exceeded as result of emissions from the SRUs. The area of exceedence is a residential area close to the industrial complex and is presented in Figure 10.

Contour plots of predicted concentrations and the predicted areas of exceedence resulting from all Ineos sources combined are presented in Figures 11 and 12. The predicted concentrations at receptor locations are presented in Table D.1 in Appendix D. The results in Table D.1 show that the model, whilst under-predicting the number of exceedences of the 15-minute mean recorded in 2007, more accurately predicts that there will be exceedences at Grangemouth MC and Moray monitoring stations and that there will be no exceedences at Inchyra Park monitoring site.

5.1.8 Summary

The maximum predicted concentrations and the 99.9th percentiles for each emission source are presented in Table 12. The maximum impact from each individual source occurs at different times and under different meteorological conditions. Further Analysis of the maximum predicted contribution of each source group within the Ineos complex identified which source or group of sources had the highest predicted 15 minute mean SO_2 concentrations, in descending order:-

- SRUs
- Boilers
- FCCU
- CDU3
- H-UNIT, VDU/HCU

- FLARES

The modelling results also indicate that the emissions from the SRUs on their own do not cause a breach of the NAQS 15-minute mean objective but are responsible for exceedences of the standard.

Overall, when the maximum contribution of each individual group is analysed, it was determined that no source, or group of sources, would result in a breach of the air quality objective when taken in isolation.

Based on the modelling predictions, it is the combined effect of several emissions sources on site that is responsible for the exceedences of the objective.

Table 12: Maximum contribution of each group of sources within the Ineos Refinery

Emission source	NAQS objective SO_2	Maximum predicted concentration ($\mu g/m^3$)	99.9%tile of 15 min mean SO^2 ($\mu g/m^3$)
Ineos - all	15 min mean	569	390
Flares	15 min mean	47	28
SRUs	15 min mean	314	205
Boilers	15 min mean	186	87
H-Unit	15 min mean	64	47
CDU3	15 min mean	104	70
VDU/HCU	15 min mean	64	41
FCCU	15 min mean	134	88

5.2 Longannet

The modelling results from Longannet alone indicate that emissions from Longannet could potentially give rise to elevated concentrations of the 15-minute mean within the AQMA under certain meteorological conditions., However although the concentrations predicted are elevated the modelling results do not indicate that there would be any exceedences of the 15-minute mean objective within the AQMA .

A contour plot of maximum predicted 15-minute mean SO_2 concentrations is presented in Figure 13, whilst a plot indicating the predicted locations of exceedences is presented in Figure 14. Predicted concentrations and number of exceedences at receptor locations are presented in Table D.2 in Appendix D.

The contour plots indicate that emissions from Longannet would give rise to elevated concentration of SO_2 within the AQMA. It is noted, however, that in 2007 Scottish Power undertook monitoring of SO_2 concentrations approximately 2km north-west of the Longannet plant at Blair Mains, The maximum measured 15-minute SO_2 concentration in 2007 at Blair Mains was 138$\mu g/m^3$, which is below the predicted concentration of 204 $\mu g/m^3$ in this study.

It is considered that the model may have over-predicted the impact of emissions from Longannet, although it is evident that emissions from Longannet may give rise to elevated SO_2 concentrations within the AQMA.

5.3 BP emissions

The modelling results from the flare at BP alone indicate that there would be no predicted exceedences of the 15-minute mean objective and the maximum predicted 15-minute mean concentration would be 13μg/m^3.

A contour plot of maximum predicted 15-minute mean SO_2 concentrations is presented in Figure 15. The contour plot indicates that the areas of predicted maximum concentrations occur to the north and south west of the AQMA and are away from any residential areas.

5.4 Cumulative Impact

Contour plots of predicted concentrations for all sources are shown in Figure 16 and the area of predicted exceedences in Figure 17. Predicted concentrations at receptor locations are presented in Table D.3 in Appendix D. The modelling results for all sources for 2007 appear to under-predict the number of exceedences of the NAQS objectives, in particular the number of exceedences of the 15-minute mean at both Moray and Grangemouth MC. The modelling results also indicate that the model is over predicting the number of exceedences seen at Inchyra Park.

Overall, the modelling study indicates that the majority of SO_2 emissions sources affecting the AQMA are not large enough to cause an exceedence of the 15-minute mean objective when taken in isolation. Some sources, however, were predicted to result in exceedences of the standard, but not of the objective, i.e. fewer than 35 individual exceedences were predicted. However, considering that the model appears to have under-predicted the number of exceedences at the automatic monitoring stations; it is possible that this under-prediction is prevalent across all receptor locations and across the calculation grid.

Despite the apparent under-prediction, the model clearly indicates that the SRUs on the Ineos site have the potential to exceed the standard, even if at a localised level. However, the modelling study indicates that it is the cumulative impact of all sources on the Ineos site that results in the greatest number of exceedences.

The model also indicates that Longannet has the potential to cause elevated SO_2 concentrations within the AQMA. Where the model considered the impact of emissions from Longannet in addition to emissions from Ineos, the area over which an exceedence of the NAQS objective is predicted increases substantially.

5.5 Meteorological analysis of modelling results

The modelling study and the pattern of predicted and measured exceedences indicate that the meteorological conditions are influential in determining if there will be exceedences of the objectives. The meteorological conditions within the modelling met file were identified for each of the highest predicted concentrations for Longannet and all Ineos emissions sources. The line at which the highest predicted concentrations occur at is recorded in the 'max' file. The 'max' output file provides the overall highest concentration from the calculation grid, the specified percentile value and the values higher than the percentile value. These met lines were identified, regardless of whether they were above the objective. The results of the met analysis are presented in Tables E.1 to E.4 in Appendix E.

The modelling results from Longannet emissions indicate that the point of maximum concentration is in excess of the 15-minute mean standard, however it is not located within the AQMA. The meteorological conditions at the hour for which the maximum concentration was predicted could be broadly classified in to stability category B. There was a low wind speed (3m/s); no rainfall and cloud cover was measured at 0 Oktas.

The number of met lines with the same wind speed, precipitation and cloud cover measurements were identified. Wind direction was included and excluded from the count to compare the results. When wind direction is not taken into account, the meteorological conditions that resulted in maximum concentrations from Longannet occur for approximately 3.0% of the year. When the wind direction was taken into account, the meteorological conditions occur for only 1.4% of the year.

Overall, the meteorological conditions occurring at the time of the highest predicted concentrations were classified as category D. Category D generally represents good atmospheric conditions for dispersion as mixing occurs easily and wind speeds are sufficient to take the plume away. In addition, the wind direction for the 99.9^{th} percentile and the remaining highest results was from the south west. This is contrary to expectation considering the actual location of Longannet in relation to Grangemouth.

The exceedence analysis in Section 3 identified some exceedences that occurred at the Moray site when the wind was from the south west, which were assumed to be caused by a source to the south-west. The modelling results now indicate Longannet as a possible contributor to those exceedences. The predicted concentrations from Longannet emissions were not high enough to breach the objective alone, however, they were high enough to result in an exceedence when added to other SO_2 emissions in the area. It is possible that the complex effects of topography on air movements within the Firth of Forth is causing local variability in wind direction and turbulence that causes a re-circulation of emissions plumes in a localised area.

The modelling results from Ineos emissions indicate that the point of maximum concentration and 99.9^{th} percentile are in excess of the 15-minute mean standard. The meteorological conditions at the hour for which the maximum concentration was predicted could be broadly classified in to stability category D. There was a low wind speed (1m/s); no rainfall and cloud cover was measured at 8 Oktas.

The number of met lines with the same wind speed, precipitation and cloud cover measurements were identified. Wind direction was included and excluded from the count to compare the results. When wind direction is not taken into account, the meteorological conditions that resulted in maximum concentrations from Ineos occur for approximately 7.6% of the year. When the wind direction was taken into account, the meteorological conditions occur for only 1.8% of the year.

Overall, the meteorological conditions occurring at the time of the highest predicted concentrations were classified as category B. Category B generally represents unstable conditions for dispersion and are characterised by deeper boundary layers and turbulent eddies which can bring a plume to the ground closer to the source In addition, the wind direction for the 99.9th percentile and the remaining highest results was from the north east.

The meteorological conditions at the time of highest predicted concentrations from all Ineos emissions sources were different to those causing highest concentrations from Longannet. The meteorological conditions were characterised by low wind speeds, no rainfall and no cloud, except for the maximum predicted concentration, which was predicted during overcast conditions. The wind direction for all met lines was from the north-east. The exceedences generally occurred during April and May. This was contrary to the highest concentrations from Longannet emissions as they were predicted to occur mainly over the winter months. The atmospheric stability was also determined to be mainly class B, which is slightly unstable. .

Overall, the met conditions resulting in highest predicted concentrations from Ineos occurred more frequently than the met conditions causing high concentrations from Longannet.

6 CONCLUSIONS

During 2007, there were a number of measured exceedences of the 15-minute SO_2 objective at the monitoring sites within the Grangemouth AQMA. The number and location of these measured exceedences were, however, different from those measured in previous years.

In order to understand the reasoning behind the change in the measured concentrations and to help identify the source(s) causing the measured exceedences, detailed analysis of both monitoring and meteorological data was undertaken. The analysis determined that exceedences of the objective were measured under differing meteorological conditions but that the following tended to apply:

- The meteorological conditions during which exceedences are most likely to be measured are unstable conditions, for example on sunny days, with low wind speeds and no cloud cover. These conditions can result in emissions plumes grounding closer to the source than other meteorological conditions.
- Exceedences are most likely to be measured when the wind is blowing from a north-east to easterly direction.
- Exceedences at different monitoring stations can sometimes be attributed to the same pollution episode.
- Exceedences are sometimes measured when the wind is from a south-westerly direction.

Based on the analysis it was considered that the most likely emission source causing the measured exceedence would be Ineos. The wind direction analysis also, however, identified that exceedences were recorded when the wind was not from an easterly direction, indicating a source located towards the west of the monitoring locations. However, the meteorological analysis of the modelling file indicated that this might not necessarily be the case since Longannet emissions were predicted to occur when the wind was from the south west.

Despite this, potential sources could be smaller industrial operators, domestic emissions sources, railway emissions or transboundary sources. Previous modelling studies have ruled out these sources as insignificant. Another reason for exceedences being measured from a westerly direction could be localised changes in wind direction that are not picked up by the meteorological station. The main concern within the AQMA is exceedences of the 15-minute mean objective; however, the wind direction data is an hourly average. When considering short-term air quality objectives, short term changes in wind direction could be significant but will not be identifiable from a longer term averaging period.

The modelling study appeared to under-predict the number of exceedences at the automatic monitoring sites. However, the predictions accurately reflected the fact that Grangemouth MC and Moray measured exceedences and Inchyra Park measured none. The various sources on the Ineos site, and emissions from BP and Longannet, were modelled as individual groups to identify which source or sources may be responsible for the measured exceedences. The modelling study indicated that, while some exceedences were predicted, no individual group or group of sources, was likely to be responsible for causing an exceedence of the objective (i.e. greater than 35 exceedences) on their own. When all sources from the Ineos site were modelled as one group, the results indicated that the objective could be exceeded at numerous locations.

The conclusions from the modelling study therefore indicate that it is the combined impact of all sources on the Ineos site that is the most likely cause of the measured exceedences. The study also identified that, under certain meteorological conditions, the added contribution of emissions from Longannet, can contribute to elevated SO_2 emissions within the AQMA.

Falkirk Council has regular liaison with SEPA and Ineos during pollution events and through the text alert system, which allows SEPA and Ineos's shift manager to investigate any pollution episode occurrence as it happens. During the majority of the pollution episodes, Ineos was operating normally. The modelling study indicates that the major contributors to elevated levels of SO_2 in the area from Ineos are likely to be the SRUs. However, as an isolated group, the only exceedence due to the SRUs occurs at a small residential area to the west of the site.

Considering the meteorological analysis, the modelling study, and the fact that Ineos are frequently operating normally during pollution episodes, it would appear likely that the main cause of the 15-minute mean exceedences is the combined effect of all sources within Ineos.

Overall, the investigation into particular measured exceedences, and the dispersion modelling study, indicates that the area should remain designated as an AQMA. In addition, the dispersion modelling contour plots show the extent of predicted exceedences of the 15-minute SO_2 air quality objective.

Considering the extent of the predicted exceedences, it is concluded that the current boundary of the AQMA is appropriate and does not need adjustment.

APPENDIX A
POLLUTION ROSES

APPENDIX B

SO_2 CONCENTRATION CHARTS

Chart B.1: Pollutant concentrations 2nd May 2007

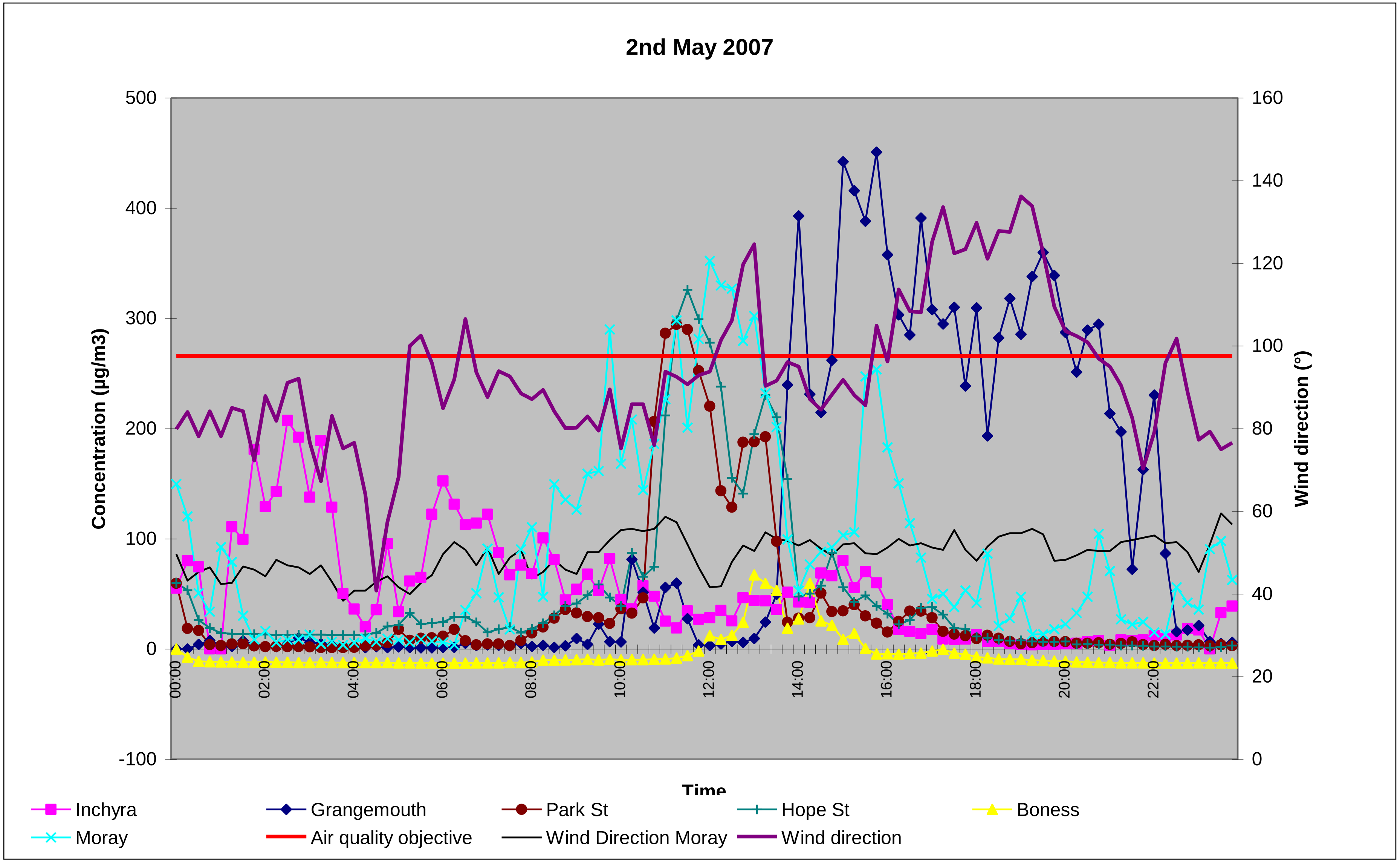


Chart B.2: Pollutant concentrations 3rd May 2007

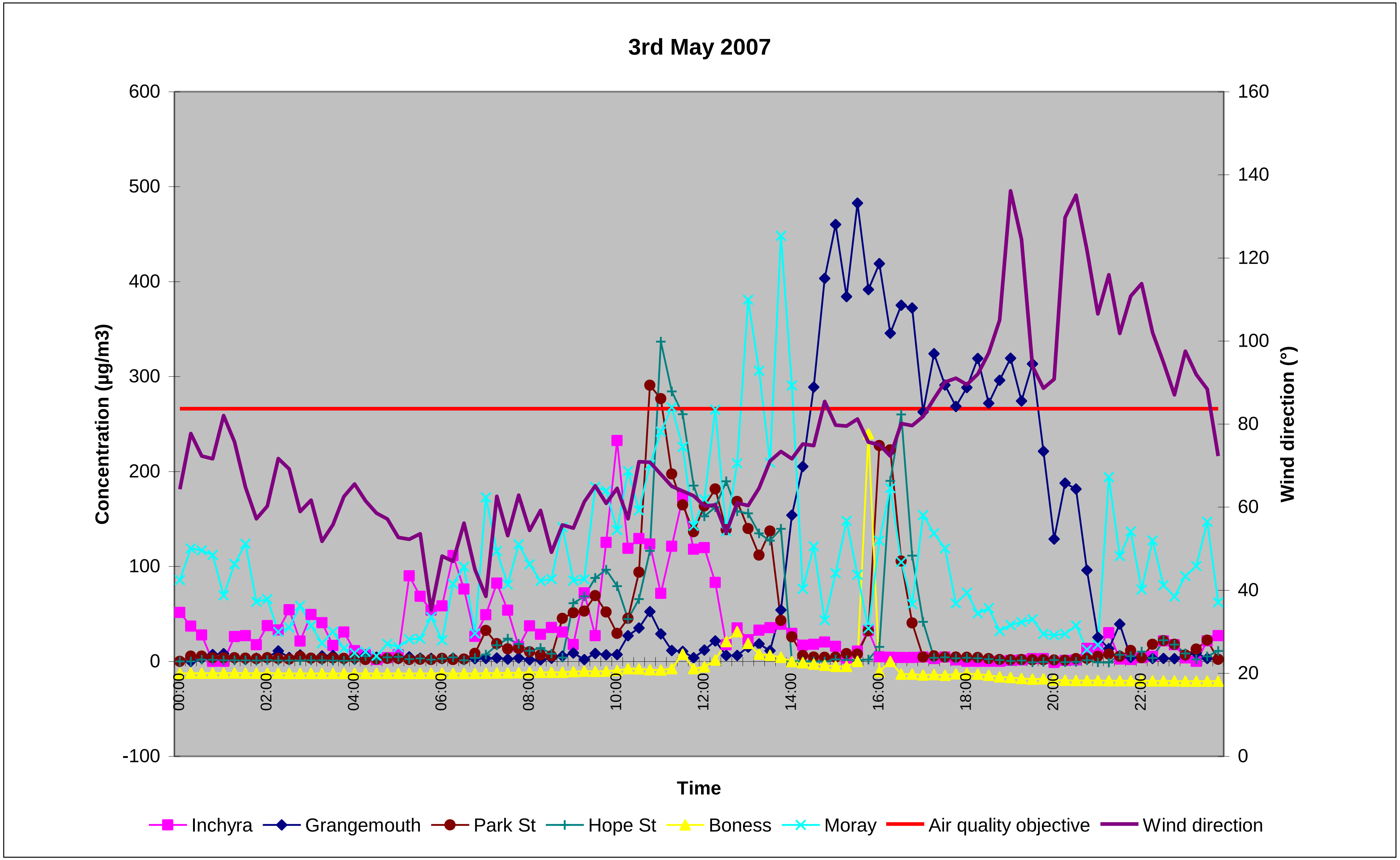
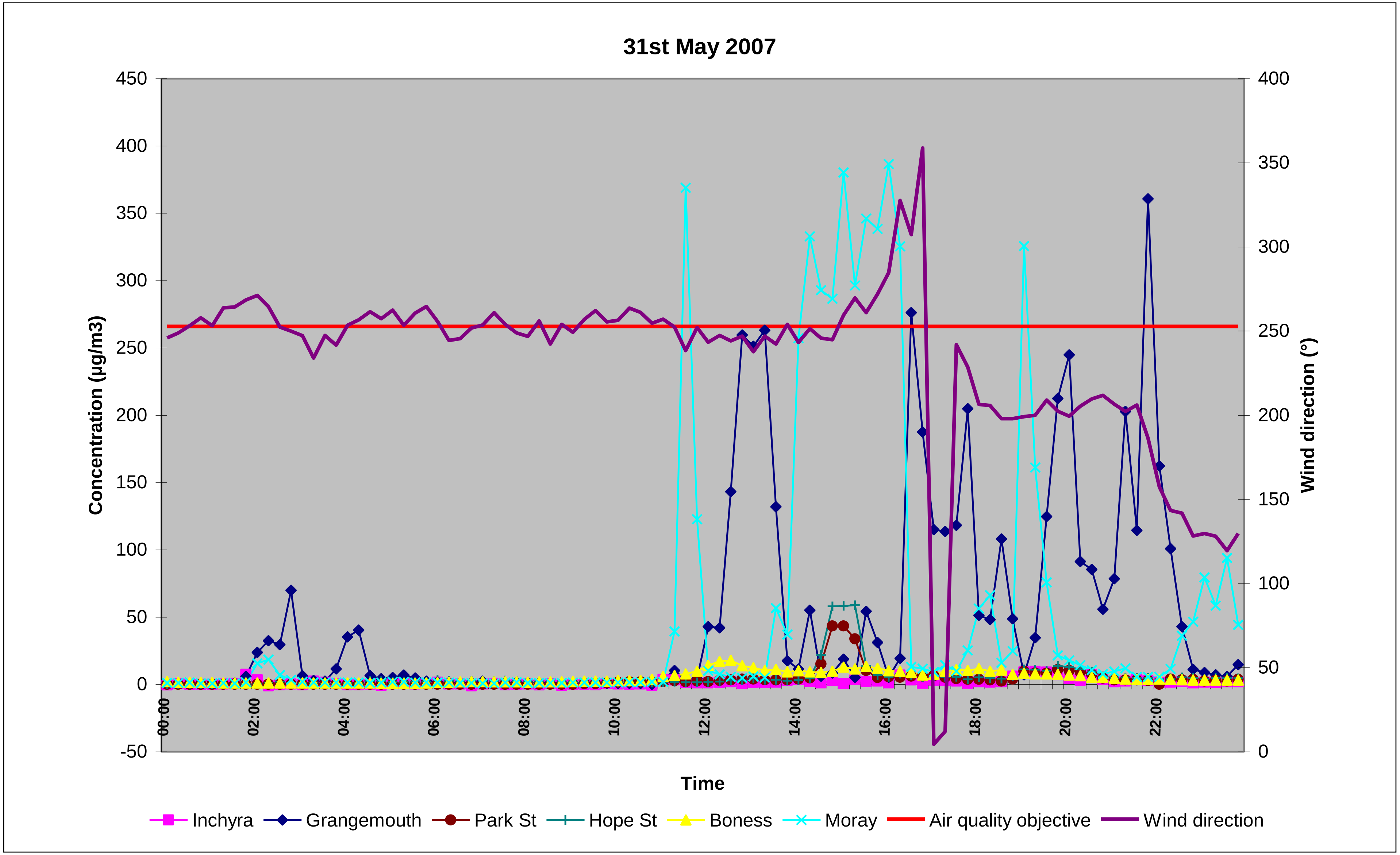


Chart B.3: Pollutant concentrations 31st May 2007



31st May 2007
Concentration (µg/m3)
Wind direction (°)
450
400
350
300
250
200
150
100
50
0
-50
400
350
300
250
200
150
100
50
0
00:00
02:00
04:00
06:00
08:00
10:00
12:00
14:00
16:00
18:00
20:00
22:00
Time
Inchyra
Grangemouth
Park St
Hope St
Boness
Moray
Air quality objective
Wind direction

Chart B.4: Pollutant concentrations 19th June 2007

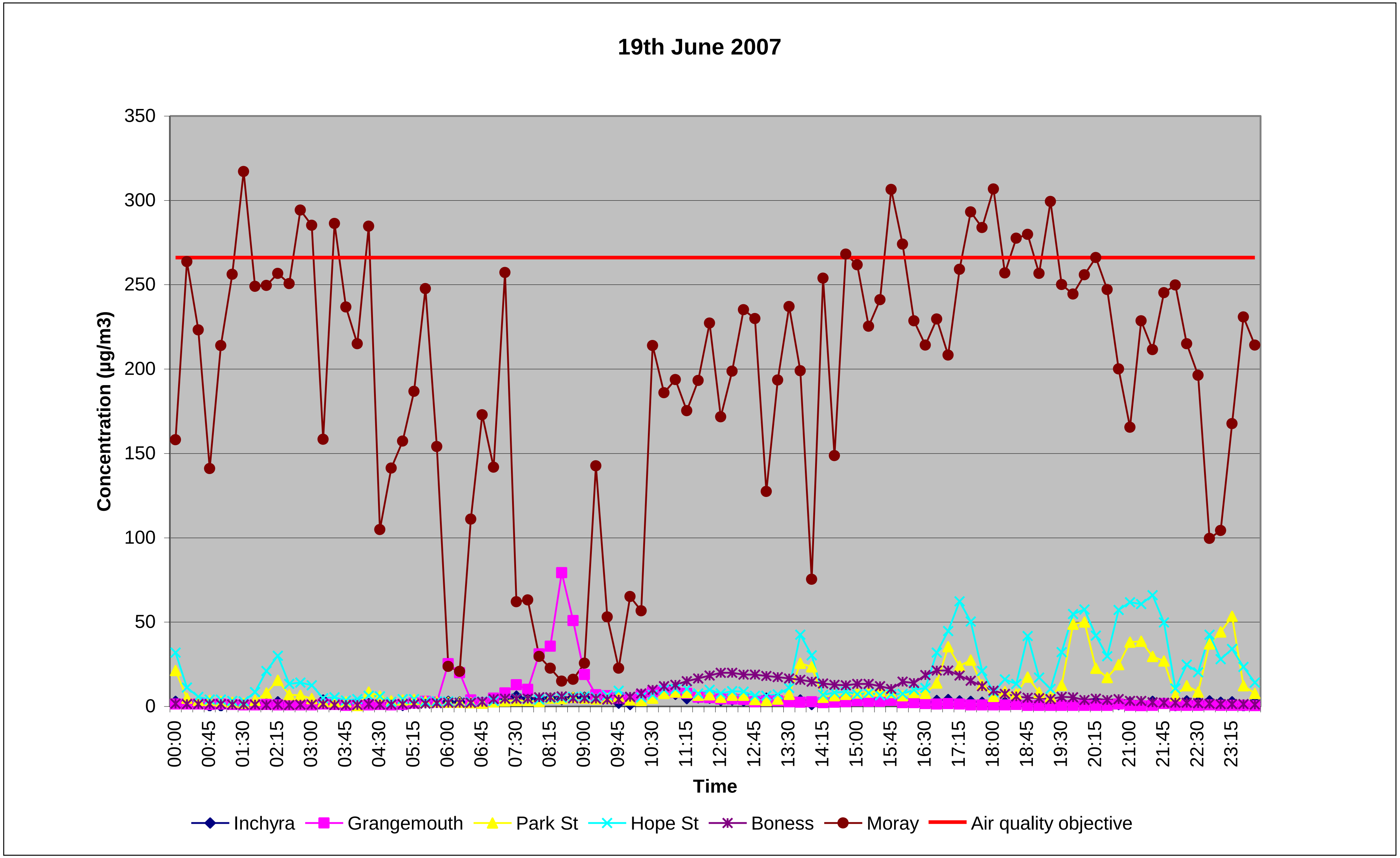


Chart B.5: Pollutant concentrations 18th August 2007

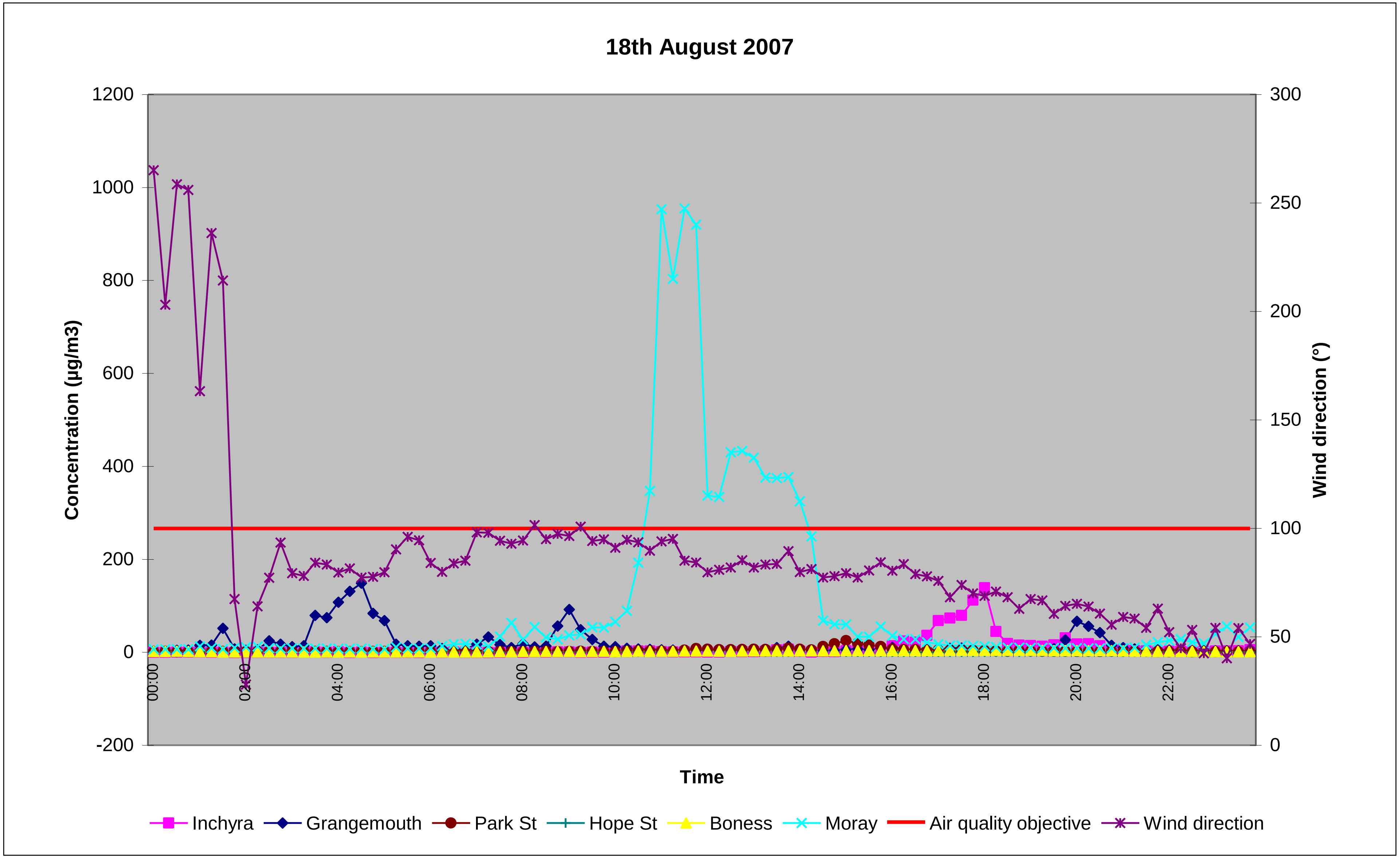
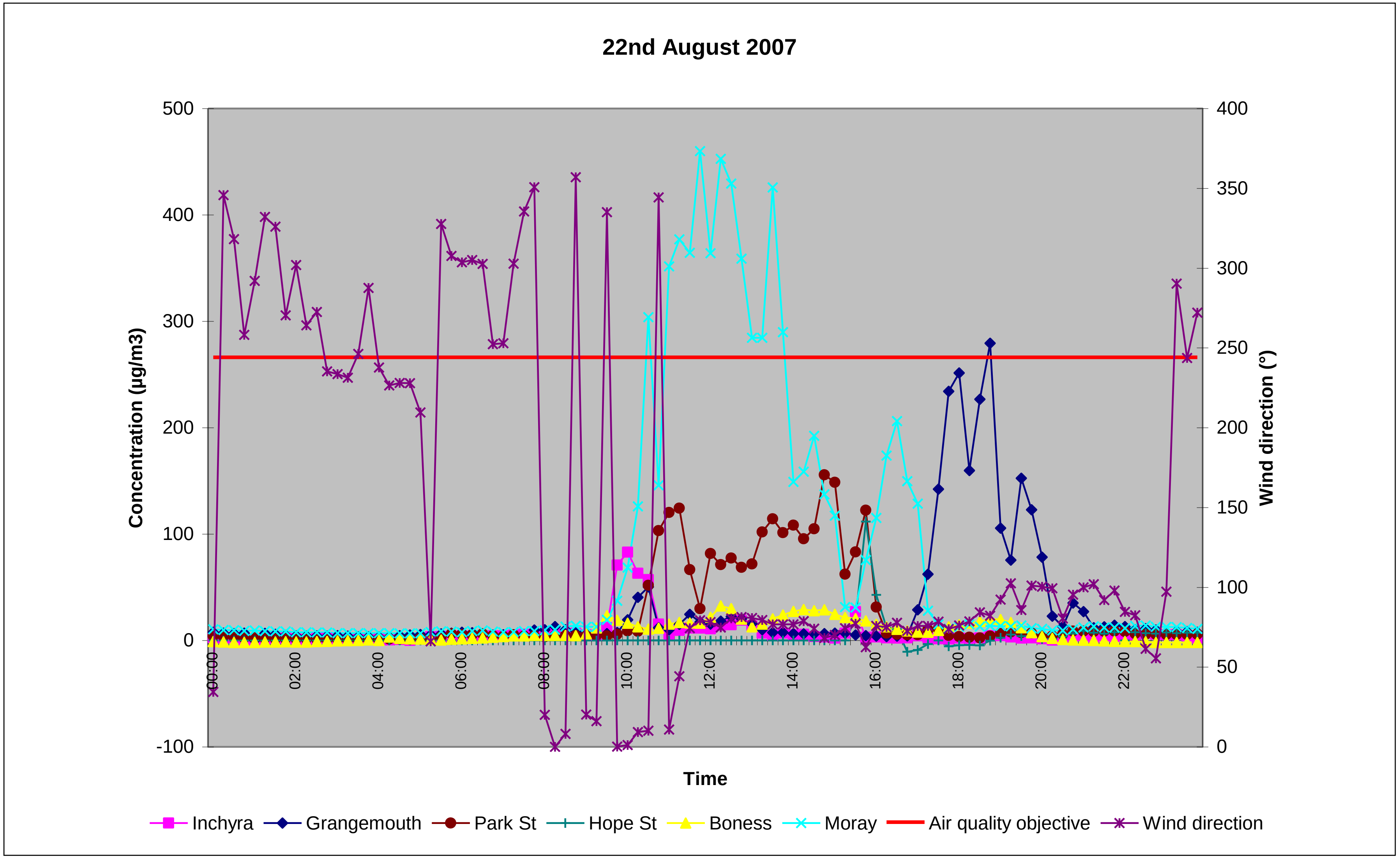


Chart B.6: Pollutant concentrations 22nd August 2007



Appendix C
Figures

Appendix D
Modelling results

Table D.1: Predicted SO_2 concentrations from Ineos emissions sources

Receptor	NAQS 15min mean objective		NAQS 1hr mean objective		NAQS 24hr mean objective	
	99.9th percentile	No of predicted exceedences	99.7th percentile	No of predicted exceedences	99th percentile	No of predicted exceedences
Inchyra Park AQU	200	0	160	0	98	0
Moray AQU	194	4	147	0	73	0
Grangemouth Municipal Chambers AQU	217	17	133	0	34	0
Inch Farm (Fife)	73	0	40	0	17	0
Blair Mains (Fife)	80	0	49	0	21	0
Culross (Fife)	75	0	44	0	19	0
Kinneil Primary School	119	0	55	0	25	0
Bo`ness Town Hall	100	0	57	0	27	0
Woodhead Farm	85	0	55	0	18	0
Avondale House	243	17	113	0	37	0
Inchyra Grange Hotel	114	0	84	0	42	0
West Beancross Farm	153	0	83	0	38	0
Forth Valley College	95	0	62	0	23	0
Bothkennar Primary School	143	0	78	0	24	0
Grangemouth Docks – Western Channel	124	0	96	0	29	0
Grangemouth Docks – Eastern Channel	124	0	95	0	29	0
East Kerse Mains	117	0	78	0	24	0
Wholeflats	146	4	106	0	43	0
Oil refinery	275	41	186	0	61	0
Grangemouth Stadium	176	4	119	0	74	0
Sports Complex, Grangemouth	185	0	112	0	47	0
Grangemouth High School	178	4	102	0	54	0
Beancross Primary	161	4	92	0	49	0

Receptor	NAQS 15min mean objective		NAQS 1hr mean objective		NAQS 24hr mean objective	
	99.9th percentile	No of predicted exceedences	99.7th percentile	No of predicted exceedences	99th percentile	No of predicted exceedences
Bowhouse Primary	186	4	109	0	64	0
Sacred Heart Primary	200	0	114	0	60	0
Zetland Pavilion	228	29	133	0	37	0
Roxburgh St, Grangemouth	212	8	152	0	40	0
Bo'ness Road, Grangemouth	252	21	200	0	90	1
Grange Manor Hotel	167	0	91	0	28	0
Dalgrain Park, Grangemouth	149	0	86	0	24	0
Asda, Grangemouth	208	17	132	0	36	0
Albert Avenue, Grangemouth	236	8	187	0	50	0
Oxgang Hotel	227	21	170	0	47	0

Table D.2: Predicted SO_2 concentrations from Longannet emissions sources

Receptor	NAQS 15min mean objective		NAQS 1hr mean objective		NAQS 24hr mean objective	
	99.9th percentile	No of predicted exceedences	99.7th percentile	No of predicted exceedences	99th percentile	No of predicted exceedences
Inchyra Park AQU	84	0	53	0	28	0
Moray AQU	97	0	74	0	28	0
Grangemouth Municipal Chambers AQU	97	0	64	0	26	0
Inch Farm (Fife)	99	0	42	0	14	0
Blair Mains (Fife)	160	0	121	0	46	0
Culross (Fife)	123	0	97	0	38	0
Kinneil Primary School	88	0	49	0	17	0
Bo`ness Town Hall	91	0	52	0	17	0
Woodhead Farm	98	0	51	0	16	0
Avondale House	67	0	41	0	12	0
Inchyra Grange Hotel	82	0	48	0	19	0

Receptor	NAQS 15min mean objective		NAQS 1hr mean objective		NAQS 24hr mean objective	
	99.9th percentile	No of predicted exceedences	99.7th percentile	No of predicted exceedences	99th percentile	No of predicted exceedences
West Beancross Farm	91	0	60	0	26	0
Forth Valley College	100	0	51	0	18	0
Bothkennar Primary School	108	0	52	0	18	0
Grangemouth Docks – Western Channel	120	0	49	0	14	0
Grangemouth Docks – Eastern Channel	120	0	49	0	14	0
East Kerse Mains	83	0	47	0	14	0
Wholeflats	73	0	39	0	14	0
Oil refinery	71	0	48	0	20	0
Grangemouth Stadium	88	0	55	0	27	0
Sports Complex, Grangemouth	102	0	69	0	30	0
Grangemouth High School	88	0	65	0	27	0
Beancross Primary	98	0	64	0	29	0
Bowhouse Primary	87	0	62	0	28	0
Sacred Heart Primary	90	0	69	0	27	0
Zetland Pavilion	105	0	73	0	31	0
Roxburgh St, Grangemouth	108	0	80	0	28	0
Bo'ness Road, Grangemouth	86	0	55	0	27	0
Grange Manor Hotel	96	0	53	0	19	0
Dalgrain Park, Grangemouth	98	0	56	0	19	0
Asda, Grangemouth	95	0	63	0	26	0
Albert Avenue, Grangemouth	103	0	73	0	27	0
Oxgang Hotel	99	0	76	0	27	0

Table D.3: Predicted SO_2 concentrations from all sources

Receptor	NAQS 15min mean objective		NAQS 1hr mean objective		NAQS 24hr mean objective	
	99.9th percentile	No of predicted exceedences	99.7th percentile	No of predicted exceedences	99th percentile	No of predicted exceedences
Inchyra Park AQU	204	4	171	0	98	0
Moray AQU	200	4	155	0	74	0
Grangemouth Municipal Chambers AQU	219	17	138	0	37	0
Inch Farm (Fife)	103	0	54	0	20	0
Blair Mains (Fife)	160	0	121	0	46	0
Culross (Fife)	123	0	97	0	39	0
Kinneil Primary School	122	0	72	0	28	0
Bo`ness Town Hall	112	0	71	0	30	0
Woodhead Farm	115	0	72	0	26	0
Avondale House	243	17	130	0	39	0
Inchyra Grange Hotel	172	0	112	0	52	0
West Beancross Farm	176	0	109	0	54	0
Forth Valley College	124	0	76	0	28	0
Bothkennar Primary School	164	0	96	0	30	0
Grangemouth Docks – Western Channel	140	0	107	0	30	0
Grangemouth Docks – Eastern Channel	139	0	106	0	30	0
East Kerse Mains	127	0	89	0	30	0
Wholeflats	216	12	134	0	52	0
Oil refinery	289	58	193	0	66	0
Grangemouth Stadium	199	8	141	0	75	0
Sports Complex, Grangemouth	191	0	122	0	50	0
Grangemouth High School	188	4	121	0	61	0
Beancross Primary	174	4	113	0	51	0

Receptor	NAQS 15min mean objective		NAQS 1hr mean objective		NAQS 24hr mean objective	
	99.9th percentile	No of predicted exceedences	99.7th percentile	No of predicted exceedences	99th percentile	No of predicted exceedences
Bowhouse Primary	198	4	135	0	66	0
Sacred Heart Primary	206	0	130	0	63	0
Zetland Pavilion	228	29	140	0	41	0
Roxburgh St, Grangemouth	217	8	165	0	57	0
Bo'ness Road, Grangemouth	252	25	204	0	90	1
Grange Manor Hotel	193	0	103	0	30	0
Dalgrain Park, Grangemouth	158	0	99	0	28	0
Asda, Grangemouth	214	17	140	0	37	0
Albert Avenue, Grangemouth	236	12	197	0	55	0
Oxgang Hotel	233	21	173	0	56	0

Appendix E

Meteorological analysis of modelling results

Table E.1: Met conditions during highest predicted concentrations from Longannet emissions

Predicted concentration (µg/m^3)	Met line	Date	Hour	Temperature (°C)	Wind speed (m/s)	Wind direction (°)	Precipitation (mm)	Cloud cover (Oktas)	Relative Humidity
305.3(maximum)	6946	17th Oct.	09:00	8.4	3	275	0	0	75
199.4	6902	15th Oct	13:00	14.1	6	238	0	8	84
188.2	7692	17th Nov	11:00	10.8	6	235	0	4	66
176.5	7851	24th Nov	02:00	3.2	8	241	0	8	71
171.2	7852	24th Nov	03:00	3.7	8	239	0	2	76
166.74	8147	6th Dec	10:00	8.5	10	240	0	8	81
166.2	7879	25th Nov	00:00	3.6	13	244	0	0	79
164.5	62	3rd Jan	13:00	12	8	241	0	8	74
161.6	7853	24th Nov	04:00	4.2	8	241	0	7	85
161.3 (99th percentile)	58	3rd Jan	09:00	11.3	8	239	0	8	83

Table E.2: Frequency of occurrence of met conditions resulting in highest concentrations from Longannet emissions

Met line	Approximate stability class	Number of rows of similar met data (± 20° wind direction)	Number of rows of similar met data for all wind directions	% occurrence (± 20° wind direction)	% occurrence all wind directions
6946	B	126	265	1.4	3.0
6902	D	46	82	0.5	0.9
7692	D	6	12	0.1	0.1
7851	D	21	48	0.2	0.5
7852	D	5	5	0.1	0.1
8147	D	7	17	0.1	0.2
7879	B	3	8	0.03	0.1
62	D	21	48	0.2	0.5
7853	D	12	28	0.1	0.3
58	D	9	48	0.2	0.5

Table E.3: Met conditions during highest predicted concentrations from All Ineos emissions

Predicted concentration (µg/m³)	Met line	Date	Hour	Temperature (°C)	Wind speed (m/s)	Wind direction (°)	Precipitation (mm)	Cloud cover (Oktas)	Relative Humidity
569.2 (maximum)	2914	2nd May	09:00	7.6	1	135	0	8	84
460.6	2943	3rd May	14:00	14	1	131	0	0	63
433.6	2918	2nd May	13:00	13.6	1	124	0	0	67
429.4	2869	30th April	12:00	12.6	2	127	0	0	75
410.6	2944	3rd May	15:00	12.8	1	149	0	0	70
408.8	2919	2nd May	14:00	14	1	125	0	0	67
400.9	2796	27th April	11:00	12.2	2	138	0	1	77
395.1	2870	30th April	13:00	12.9	1	123	0	0	72
394.6	2797	27th April	12:00	12.5	2	138	0	0	65
389.6 (99.9th percentile)	2920	2nd May	15:00	14.4	1	120	0	0	64

Table E.4: Frequency of occurrence of met conditions resulting in highest concentrations from All Ineos emissions

Met line	Approximate stability class	Number of rows of similar met data (± 20° wind direction)	Number of rows of similar met data for all wind directions	% occurrence (± 20° wind direction)	% occurrence all wind directions
2914	D	162	669	1.8	7.6
2943	B	47	236	0.5	2.7
2918	B	49	236	0.6	2.7
2869	B	22	333	0.3	3.8
2944	B	23	236	0.3	2.7
2919	A	49	237	0.6	2.7
2796	B	8	110	0.1	1.3
2870	A	49	237	0.6	2.7
2797	B	25	333	0.3	3.8
2920	A	53	237	0.6	2.7