July 2014

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Grangemouth Tail Gas Study

Falkirk Council

Executive Summary

Falkirk Council has a statutory obligation to review and assess air quality within its boundaries, with reference to air quality objectives for key pollutants as set out in the National Air Quality Strategy. Falkirk Council has been assessing air quality in its area since 1998, through monitoring of ambient air quality levels and evaluation of identified significant emission sources.

Following measured exceedence of the 15-minute National Air Quality Strategy (NAQS) objective for sulphur dioxide (SO2) at automatic monitoring stations in Grangemouth, located around the town’s petrochemical complex, an Air Quality Management Area was declared in 2005. In response to the AQMA declaration a Working Group of key stakeholders, including the Council, SEPA, Scottish Government and the petrochemical plant operators (Ineos and Petroineos) was formed to implement an Action plan of measures to improve air quality.

Petroineos, in discussion with SEPA, brought forward proposals to install a Tail Gas Treatment (TGT) de-sulphurisation plant to reduce emissions of SO2 from the site. In order to understand the effect of the proposed installation on ambient SO2 concentrations within the AQMA an air dispersion modelling study was commissioned.

An air dispersion model of the petrochemical complex was developed with reference to similar historic studies. The modelling study was developed based on emissions data provided by the petrochemical complex operators and was configured to reflect local meteorological and topographic conditions, with models developed to predict baseline (2010) SO2 concentrations and future concentrations post-TGT installation.

Meteorological conditions have a critical effect on the dispersion of pollutants and the direction in which pollutant plumes will travel from the site. Differing meteorological datasets were available for use in the study, therefore analysis was undertaken as to the most appropriate dataset to use. The analysis indicated that a combined dataset utilising measured parameters from Edinburgh Gogarbank and local wind monitoring from the Grangemouth Moray air quality monitoring station provided the closest correlation to measured concentrations in this assessment.

The baseline model, therefore considered 2010 emissions data for the site and the combined Edinburgh-Moray meteorological dataset. Emissions were considered as both a time-varying emission, i.e. the actual hour by hour emission (where available) and as an annual average emission for each source. Annual average emissions were considered to allow direct comparison with future year post-TGT installation modelling predictions for which only annual emissions data were available.

The baseline modelling predictions were verified against local monitoring data from the three automatic analysers in Grangemouth. The predictions were found to typically over-estimate the highest predicted   
15-minute mean concentrations when time varying emissions were considered. When annual mean emissions data were considered predicted concentrations were within 20% of measured concentrations for all averaging periods and at each measurement site, however there is no systematic under or over-prediction evident in the results. The model performs better in comparison with predicted 1-hour mean concentrations, with predictions within 10% of measured concentrations. Based on the correlation with measured 1-hour mean concentrations the baseline model was considered to provide a realistic approximation of air quality levels in Grangemouth.

The future year model was developed based on predicted average emission levels both with and without the installation of the TGT.

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# Introduction

Local authorities have a statutory obligation to assess air quality in their area on a regular basis to determine compliance with National Air Quality Strategy (NAQS) air quality objectives as set out in the air quality (Scotland) Regulations 2000 and subsequent amendments. The process, known as Local Air Quality Management (LAQM) commenced in 1998 and is now on its fifth round of assessment.

Falkirk Council has undertaken review and assessment of air quality in its administrative area since 1998. Initial assessments identified the potential for exceedence of NAQS objectives in Grangemouth based on emissions from both industrial operators in the area and transboundary sources.

The Council has undertaken extensive monitoring and detailed dispersion modelling studies to confirm the potential for exceeding air quality objectives for sulphur dioxide (SO2) in Grangemouth and currently operates six SO2 monitors within the surrounding area. Three SO2monitors are sited within the Grangemouth AQMA and three monitors are located outside the AQMA. It is considered that this provides a good balance between locations at risk of breaching the objective and locations that ensure the AQMA boundary is correct.

The relevant NAQS air quality objectives for SO2 are presented in Table 1. Under the LAQM process, 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 Standards

|  |  |  |  |
| --- | --- | --- | --- |
| Objective | Measured as | Equivalent percentile | Date to be achieved by |
| 266 µg/m3 not to be exceeded more than  35 times a year | 15 minute mean | 99.9th | 31/12/2005 |
| 350 µg/m3 not to be exceeded more than 24 times a year | 1 hour mean | 99.7th | 31/12/2004 |
| 125 µg/m3 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 (SO2).

Following declaration of the AQMA the Council completed a Further Assessment of SO2 within the AQMA which considered emissions from Longannet Power Station in Fife, the Grangemouth Refinery operated by Ineos and neighbouring BP oil terminal.

Emissions of SO2 are generated by Longannet Power Station as a product of the combustion of coal, which has an embedded sulphur content. Emissions of SO2 from the Grangemouth refinery are generated as a by-product of the desulphurisation process applied to sour (high H2S content) feedstock to the refinery in production of low sulphur fuel products, whilst emissions from the oil terminal are a consequence of flaring of sour gas.

The Further Assessment concluded that exceedences of the 15-minute mean objective were primarily attributable to emissions from the Grangemouth Refinery. No individual source or group of sources were identified for which the exceedence of objectives could be attributed, rather the exceedences were identified to be due to the cumulative effect of a number of sources. The modelling did, however, indicate that the emissions from the Sulphur Recover Units (SRU) on the refinery were the largest contributor to ambient SO2concentrations at receptor locations.

Subsequent to completion of the Further Assessment, Ineos has undertaken their own modelling study which verified that the SRU’s were the greatest contributor to ambient SO2 concentrations and therefore initiated plans to install a Tail Gas Treatment (TGT) process to the SRUs to abate SO2 emissions.

The council is aware there is some monitoring duplication in Falkirk Town Centre with Hope Street and Park Street sites operating close to each other. Falkirk Council is currently considering the relocation of a Falkirk Town Centre monitoring site in light of the commissioning of the TGT, if resources permit. This may assist in justifying future amendment or revocation of the AQMA and could be sited within the AQMA but close to the boundary.

Golder Associates (UK) Limited (Golder) has been commissioned by Falkirk Council to undertake a study of the effect of the TGT process on emissions from the SRUs and thus on ambient SO2 concentrations within the AQMA. Emissions data to support the study has been provided by the refinery’s operators Ineos (and subsequently its successor company for part of the site Petroineos). The study is based on emissions data for 2010 for the baseline case. To ensure consistency, the study is based on a consistent 2010 case (including monitoring data and meteorological data), although sensitivity analysis of inter-annual variation in conditions is considered.

The study considers measured ambient SO2 concentrations from within the AQMA. Predictions of ambient SO2 concentrations by detailed dispersion modelling, based on the emissions data provided by Ineos, are then presented with an analysis of the sensitivity of the predictions to inter-annual variations in meteorological conditions. The data are subsequently analysed to consider the continued requirement for an AQMA and implications for the Grangemouth Action Plan.

The findings of the report have been updated in 2014 from the original draft to reflect comments from the Scottish Environment Protection Agency (SEPA) and discussed during the AQMA Working Group meeting. The reported modelling predictions reflect the incorporation of variable surface roughness length across the modelling domain which was identified as providing a closer correlation with modelling predictions.

# 

# measured so2 concentrations in grangemouth

The Council operate three ambient air quality monitoring stations in Grangemouth. Measured SO2 concentrations at each of the stations, from 2006 to 2012, expressed as the number of measured exceedences of NAQS objectives are presented in Table 2, and Graphs 1 to3. Where the number of measured exceedences is greater than that permitted under NAQS objectives the results are highlighted in bold.

Table 2:Summary of measured SO2 objective exceedences in Grangemouth, 2006 to 2012

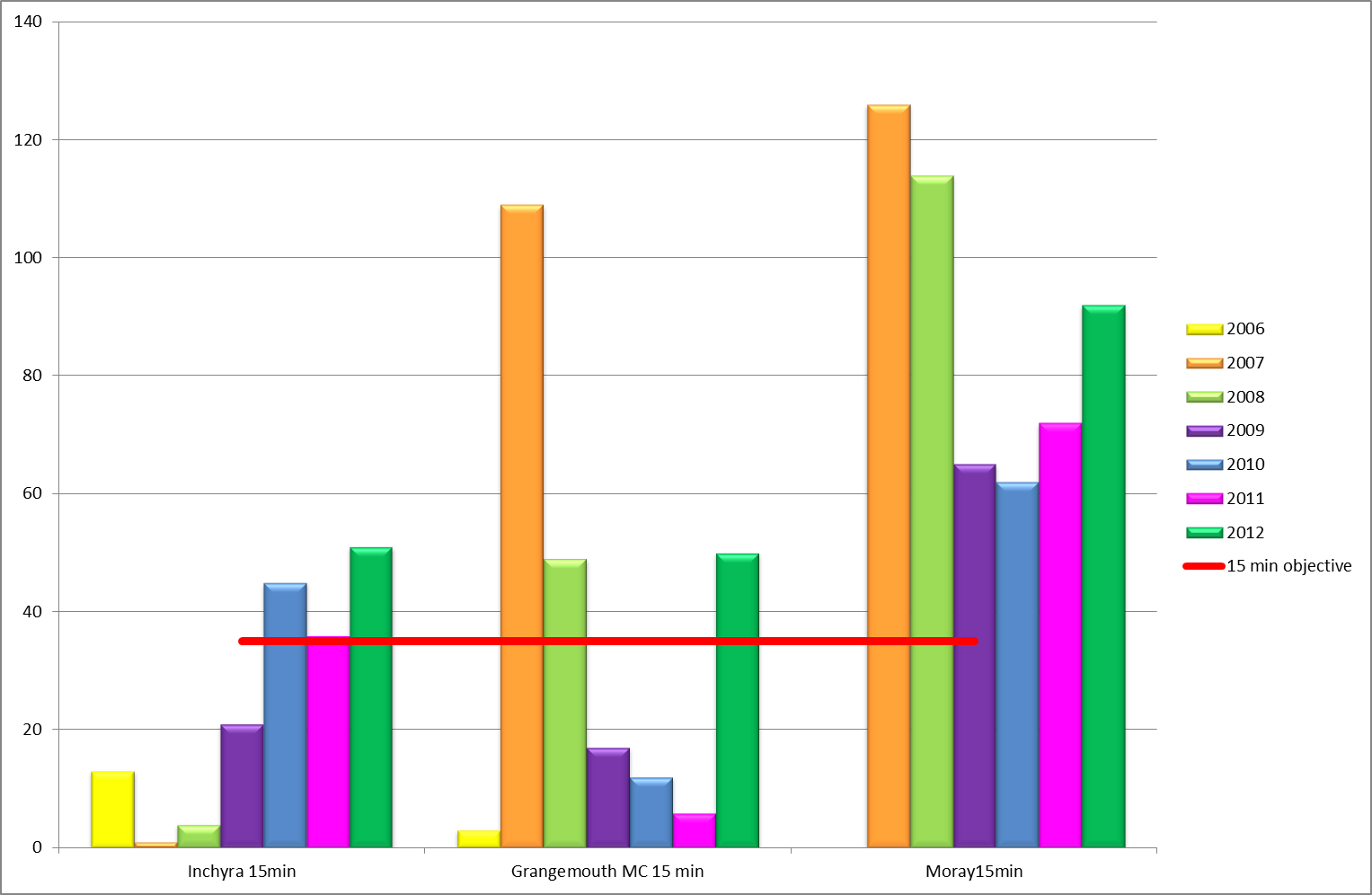
| Monitoring Station | Ave period | 2006 | 2007 | 2008 | 2009 | 2010 | 2011 | 2012 |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Grangemouth AURN (Inchyra Park) | 15-minute | 13 | 1 | 4 | 21 | **45** | **36** | **50** |
| Grangemouth AURN (Inchyra Park) | 1-hour | 0 | 0 | 0 | 0 | 2 | 2 | 0 |
| Grangemouth AURN (Inchyra Park) | 24-hour | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Grangemouth MC | 15-minute | 3 | **109** | **49** | 17 | 12 | 6 | **51** |
| Grangemouth MC | 1-hour | 0 | 6 | 0 | 0 | 0 | 0 | 0 |
| Grangemouth MC | 24-hour | 0 | 1 | 1 | 0 | 0 | 0 | 2 |
| Grangemouth Moray | 15-minute | 0 | **126** | **114** | **65** | **62** | **72** | **92** |
| Grangemouth Moray | 1-hour | 0 | 6 | 1 | 1 | 2 | 1 | 0 |
| Grangemouth Moray | 24-hour | 0 | 2 | 2 | 2 | 0 | 2 | 4 |

The results indicate that the number of measured exceedences of the 15-minute mean objective peaked in 2007. The number of measured exceedences showed a downward trend at Grangemouth MC until 2012, however a substantial increase in exceedences, to 2008 levels, was measured in 2012.

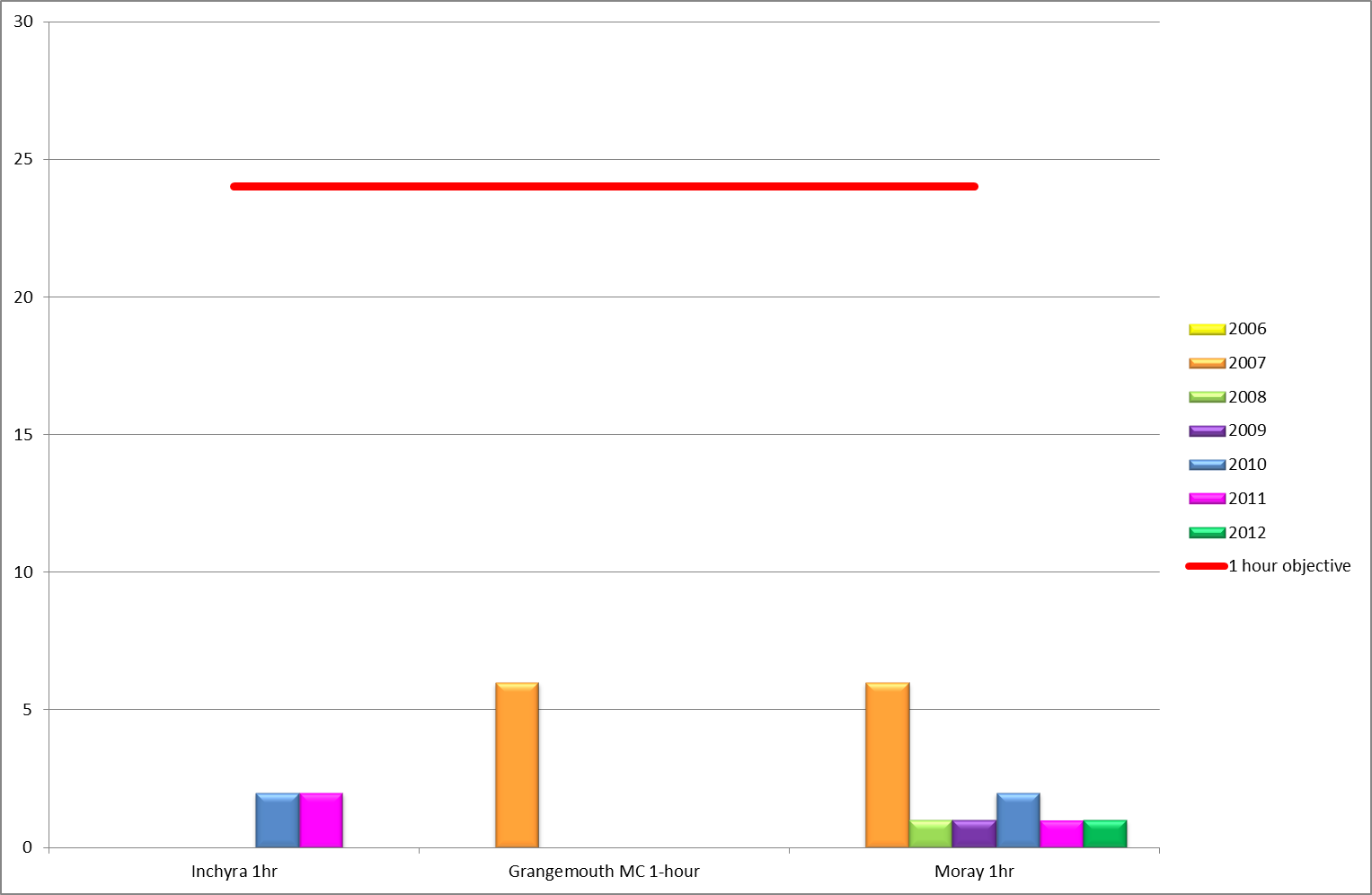
At Grangemouth Moray, the 15-minute mean objective (35 permitted exceedences per year) has been breached since the monitoring station began operation in 2007.The number of measured exceedences was exhibiting a downward trend until 2011, however since 2011, the number of measured exceedences has increased.

At Grangemouth AURN (Inchyra Park), the 15-minute mean objective was met until 2010, with few exceedences of the objective measured in the period 2006-2008. Since 2010 the number of measured exceedences has increased, in line with Grangemouth Moray and Grangemouth MC, with the data indicating that the 15 min mean SO2 objective was breached at all three monitoring sites in Grangemouth in 2012.

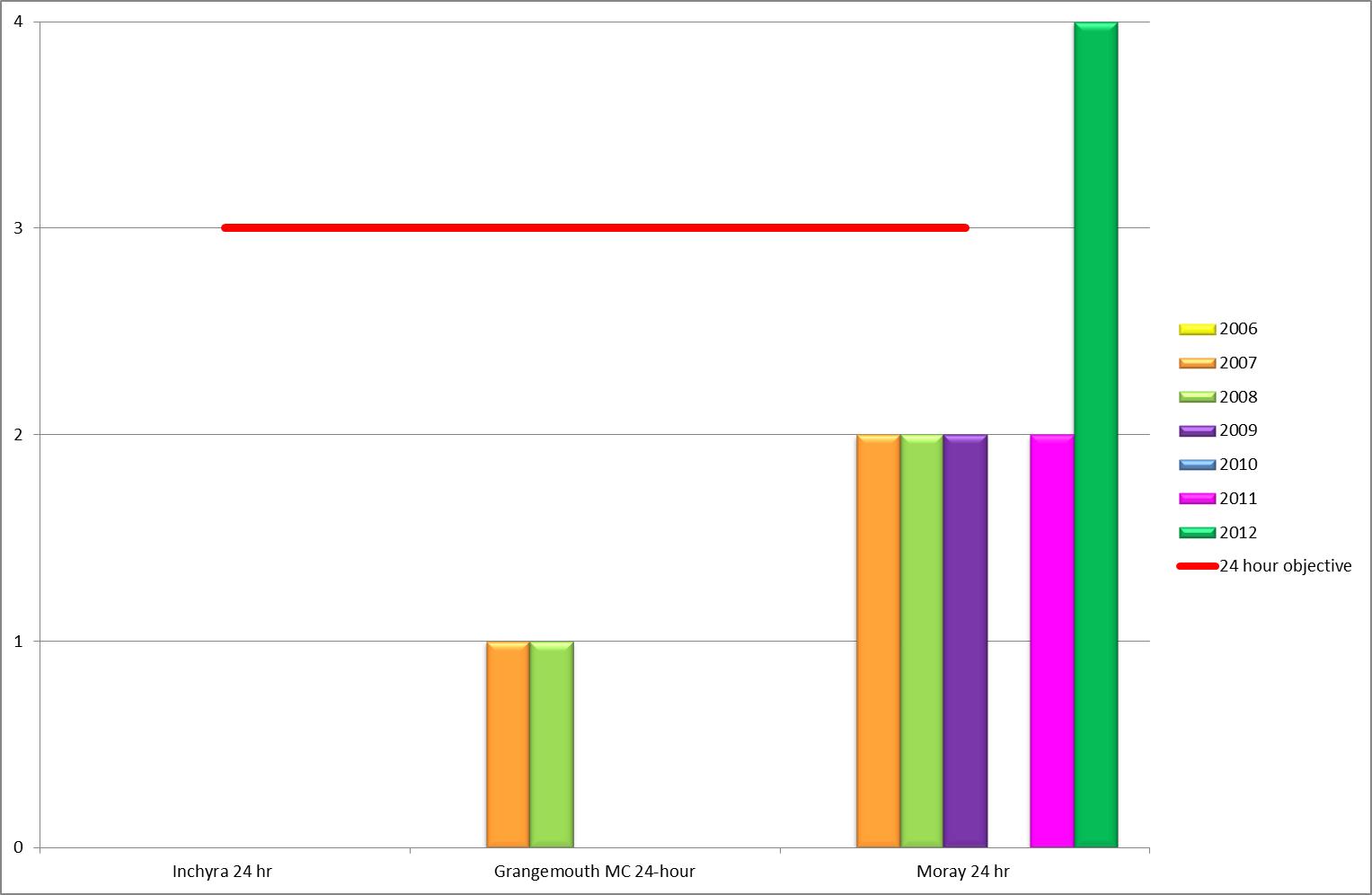
The measured exceedences of the 1-hour mean and 24-hour mean objective at both Grangemouth AURN (Inchyra Park) and Grangemouth Moray remained relatively consistent between2006-2001. Measured exceedence of the 24 hour mean objective at Grangemouth MC and Grangemouth Moray were recorded in 2012, indicating a general increase in ambient SO2 concentrations. A breach of the daily (24-hour mean) objective was recorded at the Grangemouth Moray site in 2012, however it was concluded that further Detailed Assessment was not required. This was primarily due to the expected change in emissions which are expected following the commissioning of the TGT in 2013.



Graph1: No of exceedences of 15minute objective, 2006 to 2012



Graph2: No. of exceedences of 1 hour mean objective, 2006 to 2012



Graph3: No of exceedences of 24hour mean objective, 2006 to 2012

To allow comparison with the baseline modelling study the maximum measured concentrations at each monitoring station for each objective in 2010 are presented in Table 3

Table 3: Maximum measured SO2 (g/m3) in 2010

| AQ Monitoring station | Maximum Measured concentrations SO2 (g/m3) | | |
| --- | --- | --- | --- |
| 15 min mean | 1 hour mean | 24 hour mean |
| Grangemouth AURN (Inchyra Park) | 628 | 471 | 119 |
| Grangemouth Moray | 766 | 436 | 165 |
| Grangemouth MC | 447 | 317 | 142 |

# 

# MODELLING STUDY

## Model Description

The atmospheric emissions dispersion modelling study was undertaken using the proprietary model ADMS 4.2. 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.

## 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. However as this study is more concerned with the short term objectives background concentrations are not as critical. The LAQM website provides background concentrations for most pollutants on a 1 km by 1 km grid square basis. For SO2 this is based on 2001 data.

In order to determine the most appropriate background concentration for the study the 2010 measured annual mean concentrations for the nearest Urban Background monitoring sites was compared with the projected background data. The results are presented in Table 4 for comparison. Short-term concentrations have been assumed to be twice the long-term concentrations, as recommended in IPPC H1[[1]](#footnote-1) guidance. Based on this comparison a short term background concentration of 8g/m3 was applied in the study.

Table 4: Background Concentrations.

|  |  |  |
| --- | --- | --- |
| Site | Long Term (g/m3) | Short Term (g/m3) |
| 2001 background map | 2.6 | 5.2 |
| Glasgow Centre | 4 | 8 |
| Edinburgh St Leonards | 4 | 8 |

## Emissions Inventory

Emissions data were provided by Ineos for the 2010 base case and estimated emission data for 2013. The data included the grid reference and emission parameters for each SO2 source. The SO2 sources and the respective emission parameters included in the dispersion modelling assessment are presented in Table 5.Where available, time varying emissions were also provided (Table 6). 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.

Time varying emissions data were available for all sources, with the exception of the following, for which annual average emissions were assumed:

* Source 11, 1CDUB1;
* Source 14, Hydrofiner;
* Source 17, 1CDUB1A;
* Source 18 CDU2/DHT2; and
* Source 23, HCU Mild Vacuum Column.

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 guidance for Ontario[[2]](#footnote-2) 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. Full details of the sources included in the study are presented in Table 5.

Table 5: Emission Sources

| Source Number | Source Name | Stack Height (m) | Stack Diameter (m) | Velocity (m/s) | Volume flow rate (m3/s) | Exit Temperature (oC) | Worst case annual emission (g/s) | Normal operation annual emission(g/s) | Grid Reference (x) | Grid Reference (y) |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| 1 | No. 1 Flare | 91.5 | 1.075 | 2.00 |  | 600 | 82 | 1.02 | 295010 | 681720 |
| 3 | No. 3 Flare | 91.5 | 1.075 | 2.00 |  | 600 | 1,470 | 36.4 | 294850 | 681450 |
| 4 | Boiler 8 | 65 | 2.7 |  | 24.00 | 130 | 11.6 | 0.7 | 294560 | 681210 |
| 5 | Boiler 9 / 10 | 91 | 3.3 |  | 21.70 | 154 | 87.3 | 2.4 | 294630 | 681150 |
| 7 | Boiler 12 | 94 | 2.1 |  | 29.40 | 163 | 67.5 | 1.5 | 294670 | 681140 |
| 9 | Boiler 14 | 91 | 2.4 |  | 26.00 | 170 | 65.4 | 1.5 | 294720 | 681110 |
| 10 | Boiler 15 | 91 | 2.4 |  | 23.00 | 182 | 58.4 | 3.0 | 294720 | 681110 |
| 11 | 1CDUB1 | 42.3 | 1.37 |  | 14.00 | 485 | 18.4 | 15.08 | 294520 | 681960 |
| 12 | CRU-Main | 95.7 | 2.7 |  | 20.40 | 339 | 56.3 | 2.1 | 294870 | 681660 |
| 13 | CRU 1stInterheater | 67.5 | 2.4 |  | 16.40 | 190 | 20.3 | 1.8 | 294620 | 681820 |
| 14 | Hydrofiner | 80 | 1.35 |  | 3.68 | 340 | 10 | 0.03 | 294500 | 681790 |
| 15 | H / Unit | 84 | 4.19 |  | 29.59 | 230 | 76.2 | 0.6 | 294710 | 681540 |
| 16 | SRU 5 | 70 | 0.752 | 3.60 |  | 800 | 28.4 | 13.8 | 294790 | 681530 |
| 17 | 1CDUB1A | 56.4 | 1.58 |  | 6.40 | 406 | 1.04 | 0.81 | 294540 | 681940 |
| 18 | CDU2/DHT2 | 61 | 3.38 |  | 20.60 | 340 | 16.84 | 13.68 | 294620 | 681820 |
| 19 | CDU3/DHT3 | 79 | 3.7 |  | 28.40 | 263 | 61.7 | 26.9 | 294850 | 681830 |
| 20 | VDU/HCU | 85 | 3.5 |  | 28.80 | 300 | 43.8 | 11 | 294620 | 681820 |
| 21 | SRU 6 | 70 | 0.752 | 3.60 |  | 800 | 24.92 | 14.44 | 294750 | 681610 |
| 22 | FCCU | 70 | 1.32 |  | 34.40 | 220. | 72.8 | 44.8 | 294630 | 681980 |
| 23 | HCU Mild Vacum Column | 70 | 1.5 |  | 5.69 | 390 | 2.85 | 0.07 | 294770 | 681370 |

Table 6: Time Varying Emissions and Annual Emissions Comparison

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Source Number | Source Name | Stack Height (m) | Stack Diameter (m) | Worst Case Annual Emission (g/s) | Normal Operation Annual Emission(g/s) | Minimum Time Varying Emission Rate (g/s) | Average Time Varying Emission Rate (g/s) | Maximum Time Varying Emission Rate (g/s) |
| 1 | No. 1 Flare | 91.5 | 1.1 | 82.0 | 1.0 | 0.0 | 1.0 | 82.0 |
| 3 | No. 3 Flare | 91.5 | 1.1 | 1470.0 | 36.4 | 0.0 | 36.4 | 1470.0 |
| 4 | Boiler 8 | 65.0 | 2.7 | 11.6 | 0.7 | 0.0 | 0.7 | 11.6 |
| 5 | Boiler 9 / 10 | 91.0 | 3.3 | 87.3 | 2.4 | 0.0 | 2.7 | 94.4 |
| 7 | Boiler 12 | 94.0 | 2.1 | 67.5 | 1.5 | 0.0 | 1.5 | 67.5 |
| 9 | Boiler 14 | 91.0 | 2.4 | 65.4 | 1.5 | 0.0 | 1.5 | 65.4 |
| 10 | Boiler 15 | 91.0 | 2.4 | 58.4 | 3.0 | 0.0 | 3.0 | 58.4 |
| 11 | 1CDUB1 | 42.3 | 1.4 | 18.4 | 15.1 | N/A | N/A | N/A |
| 12 | CRU-Main | 95.7 | 2.7 | 56.3 | 2.1 | 0.0 | 2.0 | 56.3 |
| 13 | CRU 1stInterheater | 67.5 | 2.4 | 20.3 | 1.8 | 0.0 | 1.8 | 20.3 |
| 14 | Hydrofiner | 80.0 | 1.4 | 10.0 | 0.0 | N/A | N/A | N/A |
| 15 | H / Unit | 84.0 | 4.2 | 76.2 | 0.6 | 0.0 | 0.6 | 76.2 |
| 16 | SRU 5 | 70.0 | 0.8 | 28.4 | 13.8 | 0.0 | 26.5 | 61.7 |
| 17 | 1CDUB1A | 56.4 | 1.6 | 1.0 | 0.8 | N/A | N/A | N/A |
| 18 | CDU2/DHT2 | 61.0 | 3.4 | 16.8 | 13.7 | N/A | N/A | N/A |
| 19 | CDU3/DHT3 | 79.0 | 3.7 | 61.7 | 26.9 | 0.0 | 26.5 | 61.7 |
| 20 | VDU/HCU | 85.0 | 3.5 | 43.8 | 11.0 | 0.0 | 10.9 | 43.8 |
| 21 | SRU 6 | 70.0 | 0.8 | 24.9 | 14.4 | 0.0 | 14.4 | 24.9 |
| 22 | FCCU | 70.0 | 1.3 | 72.8 | 44.8 | 0.0 | 44.6 | 72.8 |
| 23 | HCU Mild Vacum Column | 70.0 | 1.5 | 2.9 | 0.1 | N/A | N/A | N/A |

## Modelled Domain and Receptors

Concentrations were calculated over a regular Cartesian grid pattern and at specific receptor points. The modelled domain consisted of a 10 km by 10 km square grid covering the area (289500, 679500) to   
(299500, 689500). The number of calculation points was set at 100 by 100, which provides predicted concentrations every 100m by 100m. The receptors included in the study are presented in Table 7 and are shown on Figure 1. 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: Specified Receptors

|  |  |  |
| --- | --- | --- |
| Receptor | Grid Reference (x) | Grid Reference (y) |
| Grangemouth AURN (Inchyra Park) | 293835 | 681020 |
| Grangemouth Moray | 293469 | 681321 |
| Grangemouth MC | 292818 | 682008 |
| Inch Farm(Fife) | 294030 | 686590 |
| Blair Mains | 296960 | 686220 |
| Culross | 298380 | 685920 |
| Kinneil Primary | 299510 | 680850 |
| Bo`ness Town Hall | 299816 | 681469 |
| Woodhead Farm | 298180 | 679720 |
| Avondale House | 295810 | 680350 |
| Inchyra Grange Hotel | 293510 | 679680 |
| West Beancross Farm | 292450 | 679750 |
| Forth Valley College | 289940 | 680570 |
| Bothkennar Primary | 290810 | 683360 |
| Docks West | 295160 | 683700 |
| Docks East | 295160 | 683710 |
| East Kerse Mains | 296980 | 680360 |
| Wholeflats | 294210 | 680070 |
| Oil refinery | 294360 | 681820 |
| Grangemouth Stadium | 293628 | 680508 |
| Polmont station | 293483 | 678963 |

## 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.

Falkirk Council operates a full meteorological station at Grangemouth Municipal Chambers. At both Grangemouth AURN (Inchyra Park) and Grangemouth Moray automatic air quality monitoring stations, wind speed and direction data are available.

A sensitivity analysis was conducted to determine the meteorology dataset for 2010 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. This proved to be the case using Grangemouth AURN (Inchyra Park) and Grangemouth Moray meteorological data for which only wind speed and direction data were available, the missing variables (temperature, relative humidity, cloud cover and precipitation) were imported from the Gogarbank dataset to supplement the Grangemouth AURN (Inchyra Park) and Grangemouth Moray meteorological files.

The datasets used and the results of the sensitivity analysis are discussed in detail in Section 5.

In order to have a better understanding of the influence the meteorological conditions could have on future predictions. The sensitivity analysis also considers five years of meteorological data from Gogarbank.

## 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 ADMS4 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 variable surface roughness file ranging from 1.5 (large, urban areas) to 0.0001 (sea) has been used in the assessment as this is representative of the complex surface roughness at the site.

## 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.

## 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.A sensitivity analysis of the effect of topographical data was carried out and is discussed in Section 5.

## Calm conditions

ADMS4 is unable to model wind speeds of less than 0.75m/s; 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 0m/s, a model-specific aai file was used to model these calm meteorology lines. When using an aai4 file the model automatically replaces any 0m/s wind speeds in the data file with a default wind speed of 0.3m/s. A sensitivity analysis of the effect of calms module was carried out and is discussed in Section 5.

# 

# Modelling scenarios

The aim of the modelling study is to predict the impact to SO2 concentrations in the existing AQMA both during and after the tail gas treatment plant is fully operational. The baseline study is compared with measured concentrations during 2010 to verify the performance of the model.

## Baseline Scenario

The baseline scenario considered time varying emissions based on the continuous monitoring data provided by Ineos. A further baseline model will be considered with annual mean operating emissions to allow for like-for-like comparison with the 2013 post-TGT scenario for which no time varying emissions data are available.

Previous modelling of the refinery using annual emission data only has been shown to under predict the   
15-minute mean concentrations when compared with the measured concentrations at the monitoring sites due to short-term fluctuations in emission concentrations. Comparison of a like-for-like scenario, however, allows any improvement in concentration post-installation of the TGT to be qualified.

## 2013 Scenario

During 2013 it is expected that the oil fields supplying the refinery will be more “sour” in nature with greater sulphur content. This will result in an increase in SO2emissions from some sources in 2013. In order to identify the benefit in air quality due to the introduction of the TGT in 2013 the post-TGT installation scenario considers two emission profiles:

* 2013 without the TGT, SRU operating as per 2010; and
* 2013 with the TGT.

All emission data were provided by Ineos and are presented in Table 8.

Table 8: Emission Data

| Source name | Baseline Scenario | | | 2013 without TGT | | | 2013 with TGT | | |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Volumetric Flow  (m3/s) | Annual emission (g/s) | Temperature (K) | Volumetric Flow  (m3/s) | Annual emission (g/s) | Temperature (K) | Volumetric Flow  (m3/s) | Annual emission (g/s) | Temperature (K) |
| No. 1 Flare | N/A | 1.02 | 873 | N/A | 1.02 | 873 | N/A | 1.02 | 873 |
| No. 3 Flare | N/A | 36.4 | 873 | N/A | 36.4 | 873 | N/A | 36.4 | 873 |
| Boiler 8 | 24.00 | 0.7 |  | As baseline | | | | | |
| Boiler 9 / 10 | 21.70 | 2.4 |  |
| Boiler 12 | 29.40 | 1.5 |  |
| Boiler 14 | 26.00 | 1.5 |  |
| Boiler 15 | 23.00 | 3.0 |  |
| 1CDUB1 | 14.00 | 15.08 | 758 | 9.99 | 1.34 | 684 | 9.99 | 1.34 | 684 |
| CRU-Main | 20.40 | 2.1 | 612 | 18.69 | 2.5 | 578 | 18.69 | 2.5 | 578 |
| CRU 1stInterheater | 16.40 | 1.8 | 463 | 10.21 | 1.37 | 430 | 10.21 | 1.37 | 430 |
| Hydrofiner | 3.68 | 0.03 | 613 | 5.26 | 0.7 | 508 | 5.26 | 0.7 | 508 |
| H / Unit | 29.59 | 0.6 | 503 | 30.8 | 4.12 | 501 | 30.8 | 4.12 | 501 |
| SRU 5 | 2.70 | 13.8 | 1073 | As baseline | | | 1.76 | 0.81 | 1048 |
| 1CDUB1A | 6.40 | 0.81 | 679 | 4.4 | 0.59 | 737 | 4.4 | 0.59 | 737 |
| CDU2/DHT2 | 20.60 | 13.68 | 613 | 23.49 | 7.72 | 693 | 23.49 | 7.72 | 693 |
| CDU3/DHT3 | 28.40 | 26.9 | 536 | 31.79 | 23.24 | 426 | 31.79 | 23.24 | 426 |
| VDU/HCU | 28.80 | 11 | 573 | 34.31 | 16.83 | 546 | 34.31 | 16.83 | 546 |
| SRU 6 | 2.7 | 14.44 | 1073 | As baseline | | | 1.76 | 0.81 | 1048 |
| FCCU | 34.40 | 44.8 | 493 | 34.31 | 45.00 | 468 | 34.31 | 45.00 | 468 |
| HCU Mild Vacum Column | 5.69 | 0.07 | 663 | 8.84 | 1.18 | 625 | 8.84 | 1.18 | 625 |

# Sensitivity analysis

Falkirk Council operates a full meteorological station at Grangemouth Municipal Chambers. At both the Grangemouth AURN (Inchyra Park) and Grangemouth Moray automatic air quality monitoring stations, wind speed and direction data are available. Where the full suite of required parameters was not available from a particular meteorological station, data from Gogarbank were used. This proved to be the case using Grangemouth AURN (Inchyra Park) and Grangemouth Moray meteorological data for which only wind speed and direction data were available, the missing variables (temperature, relative humidity, cloud cover and precipitation) were imported from the Gogarbank dataset to supplement the Grangemouth AURN (Inchyra Park) and Grangemouth Moray meteorological files.

A sensitivity analysis was conducted with each meteorological data set utilising either the calms or the terrain module. The sensitivity analysis compared predicted SO2concentrations for different input datasets to determine the potential for significant deviations and to ascertain which dataset provides the most conservative (worst case) predictions. The results of the analysis are presented in Table 10and Table 11.

The results of the sensitivity analysis indicate that the model predicts more conservative ground level concentrations when the terrain model is utilised. The model also predicts a higher number of exceedences of the 15-minute mean objective using the terrain module, with the Edi-Grangemouth Moray meteorological dataset providing the closest comparison to the 2010 monitoring results. This result is only valid for 2010 and alternate meteorological datasets may be more representative for other years, the data capture rate is also an important factor in considering the appropriateness of a meteorological dataset and may affect future meteorological data choices. It is shown that the Edi-Grangemouth Moray meteorological dataset has a suitably high data capture rate and is the most accurate in representing the monitored conditions (Table 9). The modelling study was, therefore, undertaken with the Edi-Grangemouth Moray meteorological dataset with the terrain module.

Table 9: Data Capture Rates and Percentage Recorded Calms for each Meteorological Dataset Considered

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
|  | Edinburgh Met | Edi/Grangemouth AURN (Grangemouth AURN (Inchyra Park) Park) Met | Edi/Grangemouth Moray  Met | Grangemouth  Met |
| Data Capture Rate | 100% | 100% | 100% | 90% |
| Percentage Calms (<0.75 m/s) Recorded | 9% | 29% | 37% | 32% |

Table 10: Predicted SO2 (µg/m3)concentrations withCalms

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Receptor Name | Edinburgh Met | | Edi/Grangemouth AURN (Grangemouth AURN (Inchyra Park) Park) Met | | Edi/Grangemouth Moray  Met | | Grangemouth  Met | |
| 15min mean (µg/m3) | No of exceedences | 15min mean (µg/m3) | No of exceedences | 15min mean (µg/m3) | No of exceedences | 15min mean (µg/m3) | No of exceedences |
| Grangemouth AURN (Inchyra Park) | 254.6 | 0 | 286.3 | 4 | 261.6 | 0 | 317.6 | 5 |
| Grangemouth Moray | 285.1 | 4 | 338.1 | 4 | 234.6 | 0 | 269.2 | 5 |
| Grangemouth MC | 142.1 | 0 | 251.5 | 0 | 307.5 | 8 | 151.2 | 0 |

Table 11: Comparison of MeteorologicalDatasets with Terrain

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Receptor Name | Edinburgh Met | | Edi/Grangemouth AURN (Grangemouth AURN (Inchyra Park) Park) Met | | Edi/Grangemouth Moray  Met | | Grangemouth  Met | |
| 15min mean (µg/m3) | No of exceedences | 15min mean (µg/m3) | No of exceedences | 15min mean (µg/m3) | No of exceedences | 15min mean (µg/m3) | No of exceedences |
| Grangemouth AURN (Inchyra Park) | 423.7 | 19 | 327.2 | 20 | 535.6 | 37 | 564.9 | 33 |
| Grangemouth Moray | 441.7 | 10 | 325.5 | 13 | 450.2 | 59 | 389.6 | 13 |
| Grangemouth MC | 217.8 | 0 | 259.7 | 0 | 394.5 | 22 | 243.2 | 0 |

# Comparison of Meteorological Years

In order to determine the possible impact on measured concentrations due to differing meteorological conditions, modelling of five years of meteorological data was undertaken. Comparisons for five years of meteorological data measured at Edinburgh Gogarbank were undertaken under 2010 operating conditions with terrain. The results for the comparison are presented in Table 12 and Table 13 and a windrose for each year of meteorological data is presented in Graph 4.

Analysis of the results indicate that meteorological data from 2010 result in the highest predicted 15 minute mean SO2 concentrations at all monitoring sites, therefore can be considered a worst-case year of meteorological data.

|  |  |  |
| --- | --- | --- |
|  |  |  |
|  |  |  |

Graph4: Windrose - Edinburgh Gogarbank 2008 to 2012

Table 12: Predicted 15-minute SO2 concentrations, 2008-2012 meteorological datasets, µg/m3

| Site | 2008 | | | 2009 | | | 2010 | | | 2011 | | | 2012 | | |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Max 15-min mean | 99.9%ile 15-min mean | No. of Predict Exceed of 15-min mean | Max 15-min mean | 99.9%ile 15-min mean | No. of Predict Exceed of 15-min mean | Max 15-min mean | 99.9%ile 15-min mean | No. of Predict Exceed of 15-min mean | Max 15-min mean | 99.9%ile 15-min mean | No. of Predicted Exceed of 15-min mean | Max 15-min mean | 99.9%ile 15-min mean | No. of Predict Exceed of 15-min mean |
| Grangemouth AURN (Inchyra Park) | 477.0 | 192.8 | 14 | 449.4 | 193.6 | 23 | 644.4 | 237.1 | 34 | 609.7 | 263.3 | 34 | 555.5 | 196.5 | 15 |
| Grangemouth Moray | 409.4 | 178.6 | 14 | 424.8 | 226.4 | 9 | 506.9 | 170.3 | 9 | 387.2 | 196.2 | 19 | 410.2 | 195.4 | 25 |
| Grangemouth MC | 374.2 | 135.4 | 19 | 239.9 | 126.1 | 0 | 196.4 | 123.8 | 0 | 331.0 | 135.3 | 19 | 400.5 | 173.1 | 20 |

Table 13: Percentage Difference in Predicted Maximum 15min SO2between lowest and highest meteorological years

|  |  |  |  |
| --- | --- | --- | --- |
| Receptor name | Lowest predicted 15 min mean SO2(g/m3) | Highest Predicted 15 min mean SO2(g/m3) | % Change |
| Grangemouth AURN (Inchyra Park) | 477 | 644 | 35 |
| Grangemouth Moray | 387 | 507 | 31 |
| Grangemouth MC | 196 | 400 | 104 |

The Further Assessment[[3]](#footnote-3) identified through a series of pollution roses the wind directions during which the highest measured 15-minute mean concentrations typically occurred. A summary of these findings are presented in Table 14.

Table 14: Wind directions during highest measured 15-minute mean SO2µg/m3

| Monitoring Station | Wind direction (o) |
| --- | --- |
| Grangemouth AURN (Inchyra Park) | 40 to 60 |
| Grangemouth Moray | 70 to 100 |
| Grangemouth MC | 90 to 120 |

Further analysis was carried out on each of the five years of met data and the results are presented in   
Table 15.

The results of the meteorological comparison indicate that out of the five years of meteorological data considered, 2010 provides the most conservative predictions.

Further analysis of the meteorological data shows that 2010 had the highest number of hours of calm conditions compared to other years. The 2010 data also had a higher number of hours of data where the wind direction was between 40 and 60o compared to the other years. During periods of calm conditions, where the wind direction is within this sector, measured concentrations are typically at their highest.

Table 15: Inter-annual comparison of meteorological data 2008-2012

|  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Year | Max wind Speed | Most Frequent Wind Speed | \*Most Frequent Wind Direction (o) | \*Mean Wind Direction (o) | Mean Temperature | No of met lines used | No of calm met lines | No of met lines Wind Direction equals 70 to 100(o) | No of met lines Wind Direction equals 90 to 120 (o) | No of met lines Wind Direction equals 40 to 60 (o) |
| 2008 | 16.0 | 1.5 | 250 | 181 | 7.7 | 7451 | 22 | 963 | 522 | 767 |
| 2009 | 15.5 | 1.5 | 240 | 185 | 2.5 | 7513 | 62 | 887 | 509 | 522 |
| 2010 | 15.4 | 2.1 | 250 | 173 | 7.8 | 7208 | 739 | 744 | 403 | 1189 |
| 2011 | 18.0 | 1.5 | 240 | 200 | 9.6 | 7310 | 111 | 820 | 558 | 475 |
| 2012 | 21.1 | 2.6 | 240 | 187 | 8.6 | 7055 | 62 | 965 | 455 | 1035 |

*\*Measured to nearest degree (o)*

# Modelling results and discussion

## Baseline Model

Time varying emissions and annual mean emissions for 2010 were modelled and the results are presented in Table 16 and Table 17. Concentrations above their respective objective have been annotated in bold.

Table 16: Predicted Maximum 2010 SO2 concentrations from time varying emissions

|  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Receptor Name | Predicted Concentrations | | | | | | Predicted No. of Exceedences | | |
| 24 hour mean (100%ile, g/m3) | 24 hour mean (99.18%ile, g/m3) | 1hour mean (100%ile, g/m3) | 1hour mean (99.73%ile, g/m3) | 15min mean (100%ile, g/m3) | 15min mean (99.9%ile, g/m3) | 24 hour mean | 1hour mean | 15min mean |
| Grangemouth AURN (Inchyra Park) | **166.3** | **135.5** | **474.8** | 218.6 | **520.2** | **380.7** | **4** | 7 | **66** |
| Grangemouth Moray | 114.4 | 98.5 | 297.1 | 177.4 | **326.3** | **280.9** | 0 | 0 | **51** |
| Grangemouth MC | 98.2 | 83.0 | 249.6 | 169.9 | **291.0** | 250.6 | 0 | 0 | 15 |
| Inch Farm(Fife) | 32.2 | 25.4 | 131.4 | 62.1 | 162.5 | 121.4 | 0 | 0 | 0 |
| Blair Mains | 28.6 | 23.9 | 107.4 | 57.4 | 121.7 | 93.3 | 0 | 0 | 0 |
| Culross | 31.8 | 27.0 | 115.3 | 56.7 | 139.4 | 84.3 | 0 | 0 | 0 |
| Kinneil Primary | 84.2 | 53.2 | 119.0 | 109.2 | 153.1 | 140.7 | 0 | 0 | 0 |
| Bo`ness Town Hall | 54.9 | 53.1 | 153.3 | 107.9 | 223.5 | 169.8 | 0 | 0 | 0 |
| Woodhead Farm | **134.0** | 57.7 | 180.4 | 108.7 | 225.8 | 172.0 | 1 | 0 | 0 |
| Avondale House | **332.1** | 75.4 | **389.7** | 179.3 | **507.6** | **301.8** | 1 | 2 | **44** |
| Inchyra Grange Hotel | 85.7 | 76.2 | 304.8 | 126.2 | **382.5** | 246.0 | 0 | 0 | 22 |
| West Beancross Farm | 97.8 | 85.5 | 185.4 | 121.7 | 226.6 | 192.1 | 0 | 0 | 0 |
| Forth Valley College | 53.4 | 49.2 | 175.4 | 86.8 | 238.6 | 119.6 | 0 | 0 | 0 |
| Bothkennar Primary | 57.5 | 55.6 | 182.5 | 108.6 | 224.7 | 163.0 | 0 | 0 | 0 |
| Docks West | 62.5 | 51.4 | 285.4 | 132.0 | **349.8** | 223.4 | 0 | 0 | 22 |
| Docks East | 62.4 | 51.4 | 284.5 | 131.8 | **348.0** | 223.8 | 0 | 0 | 22 |
| East Kerse Mains | **178.9** | 81.3 | 262.5 | 139.1 | **308.1** | 230.3 | 1 | 0 | 7 |
| Wholeflats | 119.1 | 93.2 | 347.3 | 171.5 | **399.1** | **367.0** | 0 | 0 | **58** |
| Grangemouth Stadium | **128.1** | 112.4 | **433.5** | 176.4 | **459.3** | **300.3** | 1 | 4 | **51** |
| Sports Complex | 115.5 | 95.3 | 327.0 | 148.3 | **396.8** | 245.1 | 0 | 0 | 29 |
| Beancross Primary | 124.5 | 96.7 | 241.6 | 149.4 | **296.5** | 232.1 | 0 | 0 | 15 |
| Bowhouse Primary | **132.0** | 101.4 | 298.8 | 175.6 | **351.6** | 263.9 | 1 | 0 | 29 |
| Sacred Heart Primary | **137.8** | 99.0 | 234.5 | 167.1 | 261.2 | 243.7 | 2 | 0 | 0 |
| Zetland Pavillion | 97.8 | 92.6 | 325.2 | 161.5 | **379.9** | 211.8 | 0 | 0 | 7 |
| Roxburgh St | **143.1** | 118.0 | **374.1** | 221.7 | **395.8** | **356.6** | 2 | 4 | **88** |
| Bo`ness road | **154.5** | **143.9** | **457.5** | 237.6 | **482.7** | **310.9** | **10** | 2 | **73** |
| Grange Manor Hotel | 56.0 | 52.7 | 141.4 | 104.8 | 172.1 | 149.6 | 0 | 0 | 0 |
| Dalgrain Park | 57.0 | 49.7 | 156.8 | 104.2 | 195.0 | 155.9 | 0 | 0 | 0 |
| Asda | 96.6 | 85.9 | 297.9 | 176.0 | **321.0** | **285.9** | 0 | 0 | **58** |
| Albert Avenue | **197.1** | **144.6** | **425.1** | 273.4 | **457.5** | **384.5** | **7** | 13 | **146** |
| Oxgang Hotel | **141.5** | **128.3** | 341.2 | 206.5 | **371.5** | **276.1** | **3** | 0 | **36** |
| Polmonthill Cottage | **127.4** | 74.0 | 281.3 | 133.2 | **395.9** | 228.3 | 1 | 0 | 15 |
| Residential Prop | 91.7 | 71.5 | 274.6 | 128.2 | **313.4** | 243.1 | 0 | 0 | 29 |
| Reddoch Road | **127.7** | 68.7 | 343.6 | 145.4 | **433.8** | 245.8 | 1 | 0 | 22 |
| Orchard Grove | 76.1 | 58.4 | 237.9 | 105.0 | **277.8** | 196.0 | 0 | 0 | 7 |
| Grangemouth High | 124.7 | 93.3 | 300.8 | 170.4 | **359.8** | 237.0 | 0 | 0 | 22 |
| Victoria Primary | 44.8 | 41.7 | 171.9 | 84.4 | 235.8 | 113.9 | 0 | 0 | 0 |
| Falkirk Stadium | 78.0 | 68.9 | 178.2 | 101.7 | 221.6 | 147.5 | 0 | 0 | 0 |
| Oakwood School | 81.7 | 63.6 | 156.7 | 92.9 | 205.7 | 146.8 | 0 | 0 | 0 |
| G`mouth Rd Bo`ness | **176.0** | 59.9 | 218.8 | 132.7 | **267.0** | 195.9 | 1 | 0 | 7 |
| Polmont AQMU | 66.2 | 55.3 | 240.2 | 104.5 | **289.9** | 183.3 | 0 | 0 | 7 |

The results of the baseline modelling indicate that the model compares well with monitored data, with predicted exceedence of the 15-minute mean objective at both Grangemouth AURN (Inchyra Park) and Grangemouth Moray monitoring sites, although concentrations at Grangemouth MC were predicted to be compliant with the objective. The predicted number of exceedences of the 15-minute objective at Grangemouth AURN (Inchyra Park) are however greater than measured in reality whilst at Grangemouth MC the predicted number of exceedences are lower than observed.

Predicted concentrations are within 20% of measured concentrations for all averaging periods and at each measurement site, however there is no systematic under or over-prediction evident in the results.

Table 17: Predicted MaximumSO2 (g/m3) concentration due to annual mean emissions

| Receptor Name | Predicted Concentrations | | | | | | Predicted No of Exceedences | | |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| 24 hour mean (100%ile, g/m3) | 24 hour mean (99.18%ile, g/m3) | 1hour mean (100%ile, g/m3) | 1hour mean (99.73%ile, g/m3) | 15min mean (100%ile, g/m3) | 15min mean (99.9%ile, g/m3) | 24 hour mean | 1hour mean | 15min mean |
| Grangemouth AURN (Inchyra Park) | **156.0** | 121.2 | **414.0** | 181.1 | **459.7** | **352.8** | 2 | 4 | **51** |
| Grangemouth Moray | **148.8** | 108.9 | 315.1 | 155.6 | **358.0** | **267.4** | 2 | 0 | **36** |
| Grangemouth MC | 88.3 | 70.0 | 260.7 | 151.4 | **305.9** | 203.0 | 0 | 0 | 15 |
| Inch Farm(Fife) | 25.6 | 20.6 | 102.9 | 52.4 | 138.7 | 91.1 | 0 | 0 | 0 |
| Blair Mains | 26.0 | 22.4 | 82.1 | 56.0 | 92.5 | 82.5 | 0 | 0 | 0 |
| Culross | 31.4 | 27.3 | 89.5 | 51.6 | 109.4 | 80.8 | 0 | 0 | 0 |
| Kinneil Primary | 85.0 | 53.3 | 124.3 | 87.5 | 160.3 | 115.5 | 0 | 0 | 0 |
| Bo`ness Town Hall | 72.4 | 45.7 | 124.5 | 84.8 | 171.3 | 157.5 | 0 | 0 | 0 |
| Woodhead Farm | 103.8 | 47.6 | 132.6 | 96.0 | 167.8 | 139.9 | 0 | 0 | 0 |
| Avondale House | **255.3** | 64.6 | 315.5 | 148.7 | **415.8** | **266.8** | 1 | 0 | **36** |
| Inchyra Grange Hotel | 67.4 | 63.5 | 247.2 | 110.3 | **310.0** | 211.0 | 0 | 0 | 7 |
| West Beancross Farm | 80.8 | 73.3 | 186.4 | 103.9 | 226.1 | 155.8 | 0 | 0 | 0 |
| Forth Valley College | 59.3 | 40.0 | 128.1 | 72.7 | 171.4 | 106.7 | 0 | 0 | 0 |
| Bothkennar Primary | 48.0 | 41.6 | 145.6 | 91.4 | 185.4 | 135.8 | 0 | 0 | 0 |
| Docks West | 68.5 | 51.8 | 235.4 | 108.9 | **282.2** | 203.7 | 0 | 0 | 15 |
| Docks East | 68.3 | 51.7 | 235.2 | 108.4 | **280.9** | 203.6 | 0 | 0 | 15 |
| East Kerse Mains | **136.8** | 63.1 | 189.7 | 113.1 | 224.3 | 177.4 | 1 | 0 | 0 |
| Wholeflats | 101.0 | 76.0 | 274.6 | 157.3 | **316.5** | **280.6** | 0 | 0 | **44** |
| Grangemouth Stadium | 106.2 | 95.5 | 336.6 | 170.5 | **386.8** | 229.1 | 0 | 0 | 29 |
| Sports Complex | 120.3 | 86.6 | 243.3 | 133.7 | **301.1** | 228.8 | 0 | 0 | 7 |
| Beancross Primary | 107.4 | 89.9 | 198.0 | 131.0 | 241.1 | 199.3 | 0 | 0 | 0 |
| Bowhouse Primary | 109.0 | 97.0 | 245.7 | 144.2 | **286.9** | 219.3 | 0 | 0 | 15 |
| Sacred Heart Primary | **127.0** | 103.0 | 241.5 | 145.7 | **279.0** | 200.6 | 1 | 0 | 7 |
| Zetland Pavillion | 100.6 | 88.2 | 232.4 | 152.7 | **274.4** | 212.2 | 0 | 0 | 7 |
| Roxburgh St | **125.5** | 106.3 | **363.8** | 201.4 | **404.0** | 262.3 | 1 | 2 | 29 |
| Bo`ness road | **184.0** | **144.8** | 342.0 | 201.8 | **366.1** | **291.5** | **8** | 0 | **44** |
| Grange Manor Hotel | 54.5 | 43.3 | 138.9 | 100.6 | 180.6 | 154.0 | 0 | 0 | 0 |
| Dalgrain Park | 55.6 | 41.7 | 163.0 | 89.1 | 203.4 | 142.8 | 0 | 0 | 0 |
| Asda | 82.6 | 71.6 | 265.7 | 164.8 | **314.5** | 219.1 | 0 | 0 | 15 |
| Albert Avenue | **159.1** | 124.6 | **372.7** | 224.8 | **402.6** | **317.6** | 2 | 4 | **80** |
| Oxgang Hotel | **146.8** | 115.0 | 275.0 | 176.8 | **299.2** | 228.6 | 1 | 0 | 22 |
| Polmonthill Cottage | **134.9** | 62.2 | 218.3 | 120.0 | 252.9 | 216.6 | 1 | 0 | 0 |
| Residential Prop | 80.0 | 58.9 | 245.8 | 114.4 | **297.8** | 204.8 | 0 | 0 | 7 |
| Reddoch Road | 110.0 | 56.8 | 286.7 | 132.0 | **362.5** | 221.7 | 0 | 0 | 15 |
| Orchard Grove | 67.3 | 49.6 | 200.0 | 94.2 | 246.0 | 160.5 | 0 | 0 | 0 |
| Grangemouth High | 101.2 | 92.3 | 244.7 | 133.1 | **295.5** | 205.4 | 0 | 0 | 7 |
| Victoria Primary | 53.5 | 38.2 | 124.9 | 72.1 | 171.0 | 108.7 | 0 | 0 | 0 |
| Falkirk Stadium | 73.1 | 59.0 | 144.7 | 80.2 | 188.3 | 133.8 | 0 | 0 | 0 |
| Oakwood School | 74.3 | 60.9 | 133.9 | 82.2 | 176.5 | 146.8 | 0 | 0 | 0 |
| G`mouth Rd Bo`ness | **136.3** | 51.2 | 178.0 | 106.6 | 216.0 | 178.9 | 1 | 0 | 0 |
| Polmont AQMU | 53.3 | 48.7 | 176.4 | 102.3 | 218.5 | 182.1 | 0 | 0 | 0 |

The predicted concentrations using annual mean emissions are typically higher than those predicted using the time varying data but this is dependent on proximity to source and geographical location.

Predicted maximum concentrations for the 15-minute, 1-hour and 24-hours mean are typically under-predicting.

The predicted concentrations indicate that when annual mean emissions data are used the model appears to be adequately predicting the number of exceedences of all objectives, specifically at Grangemouth MC.

Analysis of predictions of ambient concentrations using the 2010 annual mean emissions data should therefore be considered in the context of this improved model.

## Future Years

### 2013 Without TGT

Estimated annual mean emissions for 2013 without the TGT in operation were modelled and the results presented in Table 18. Results are predicted for the monitoring station locations only for ease of comparison. Predictions for other receptor locations are provided in Appendix A.

Table 18: Predicted Maximum SO2(g/m3) concentrations in 2013 without TGT

|  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Receptor Name | Predicted Concentrations | | | | | | Predicted No of Exceedences | | |
| 24 hour mean (100%ile, g/m3) | 24 hour mean (99.18%ile, g/m3) | 1hour mean (100%ile, g/m3) | 1hour mean (99.73%ile, g/m3) | 15min mean (100%ile, g/m3) | 15min mean (99.9%ile, g/m3) | 24 hour mean | 1hour mean | 15min mean |
| Grangemouth AURN (Inchyra Park) | **143.8** | 115.3 | 338.5 | 169.2 | **373.6** | **317.8** | 2 | 0 | **36** |
| Grangemouth Moray | **130.8** | 106.0 | 288.6 | 149.2 | **330.0** | 238.0 | 1 | 0 | 15 |
| Grangemouth MC | 79.7 | 64.8 | 242.2 | 139.0 | **284.1** | 185.5 | 0 | 0 | 7 |

The results indicate that the predicted concentration in 2013 without the TGT in operation would result in a small reduction in the predicted 15-minute mean concentrations and the number of exceedences at each of the three monitoring locations when compared with the 2010 baseline.

### 2013 with TGT

Predicted annual mean emissions from the refinery with the TGT in operation were modelled and the results are presented in Table 19. Predictions are presented for the monitoring stations only. Predictions for other receptor locations are provided in Appendix A.

Table 19: Predicted Maximum SO2(g/m3)Concentrations with the TGT

|  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Receptor Name | Predicted Concentrations | | | | | | Predicted No of Exceedences | | |
| 24 hour mean (100%ile, g/m3) | 24 hour mean (99.18%ile, g/m3) | 1hour mean (100%ile, g/m3) | 1hour mean (99.73%ile, g/m3) | 15min mean (100%ile, g/m3) | 15min mean (99.9%ile, g/m3) | 24 hour mean | 1hour mean | 15min mean |
| Grangemouth AURN (Inchyra Park) | 107.1 | 86.3 | 261.0 | 126.7 | **291.8** | 245.8 | 0 | 0 | 29 |
| Grangemouth Moray | 93.4 | 82.2 | 237.5 | 113.9 | **282.2** | 211.5 | 0 | 0 | 7 |
| Grangemouth MC | 65.9 | 51.8 | 191.8 | 113.2 | 224.0 | 163.5 | 0 | 0 | 0 |

The results indicate that with the TGT in operation, exceedences of the objective level are still predicted at the Grangemouth AURN (Inchyra Park), however the number of predicted exceedences has reduced markedly from 36 to 29. The highest predicted 15-minute mean concentration at the site is predicted to have reduced by approximately 22% as a result of the introduction of the TGT. Maximum predicted 1-hour mean and 24-hour mean concentrations at Grangemouth AURN (Inchyra Park) are predicted to reduce by 23% and 26% respectively following introduction of the TGT. No exceedences of the 1-hour mean or 24-hour mean objective levels are predicted post-TGT.

At Grangemouth Moray, seven exceedences of the 15-minute mean objective are predicted post-TGT introduction. The maximum 15-minute mean objective level is predicted to reduce by 15%. No exceedences of the 1-hour mean objective level are predicted with a reduction of approximately 18% also predicted in maximum 1-hour mean concentrations. No exceedence of the 24-hour mean objective is predicted, with a reduction of 29% in the maximum predicted 24-hour mean concentration predicted.

At Grangemouth MC no exceedences of any objective are predicted post-TGT. Reductions in the 15-minute, 1-hour and 24-hour mean concentrations of approximately 21%, 21% and 17% respectively are predicted.

# 

# Modelling uncertainties and limitations

The modelling study was undertaken using various input data used to define local meteorology and topography/topology effects on wind flow and atmospheric conditions, which will in turn influence the dispersion of emissions from the petrochemical complex. Sensitivity analysis was undertaken of the input data utilised, however there are a number of inherent limitations in the study which should be considered.

The model requires meteorological data measured on an hourly sequential basis, which is available from a number of local sites. The most reliable (in terms of data capture and QA/QC) is the Met Office measured data from Gogarbank, a site approximately 20 km east of Grangemouth. This data may not accurately reflect local conditions. The local monitoring sites are located adjacent to air quality monitoring stations or in the case of GMC on top of the roof of a building. Wind flows measured at these sites may be affected by local topology and not all required meteorological parameters are measured. The meteorological data used in the study therefore requires some compromises in selecting the best datasets.

Furthermore, whichever meteorological dataset is utilised it should be noted that the data considered are hourly average data, which are used to predict hourly mean pollutant concentrations from which predictions of 15-minute mean concentrations are derived. The model may underestimate the effect of fluctuations in meteorological conditions on pollutant dispersal and hence resulting concentrations.

A similar approach is required for consideration of emissions data. For the baseline scenario hourly variable emissions data are considered based on historic measurements for the site. The measurements indicate a substantial peak to mean ratio on emissions at differing times of the year. As hourly average emissions are considered the study also potentially underestimates emissions which could occur over a lesser 15-minute averaging period.

For consideration of future scenarios, no hourly variable emissions data are available, therefore it is necessary to consider future annual average emissions and benchmark against baseline average emissions. Such an approach allows determination of the predicted change in concentrations, however may underestimate the magnitude of predicted levels.

Due to the limitations of the proprietary dispersion model used in the stud a number of other compromises have been made regarding input data.

The study does not include reference to the buildings in the study area. There are a number of buildings and complex orography at the site that may influence the concentrations recorded at certain locations due to their impact on wind patterns and dispersion of pollutants. It is assumed that buildings are unlikely to be an issue influencing the dispersion of pollutants at the site and have been sufficiently accounted for by the inclusion of a variable surface roughness file, so have not been considered in this study. The site is also located in a coastal location and beyond the surface roughness file coastal factors have not been included in the analysis.

It is also not possible to model both ‘calms’ and ‘terrain’ together and so the models have been analysed to assess which factor assists in most faithfully reproducing the recorded concentrations at the expense of the other factor being removed from the model.

# CONCLUSIONS

## Baseline Scenario

Modelling was undertaken of both time varying and annual mean emissions under normal operating conditions during 2010.

The results from the baseline model using the time varying emission profile indicated that the model under predicted but performed well when predicted the magnitude of exceedences of the 15-minute mean objective at all three monitoring locations.

The results from the baseline model using the annual mean emission profile generally under predicted pollutant concentrations when compared against measured data. The modelling results also adequately predicted the magnitude of the exceedences of all three SO2 objectives at all three air quality monitoring locations.

## Future Scenario

Modelling was undertaken of predicted emissions during 2013 with the TGT and without the TGT to determine the benefit to air quality.

Modelling predictions of 2013 without the TGT indicates that the 15-minute mean objective would continue to be breached based on projected emissions data.

Modelling predictions of 2013 with the TGT installation indicates that the number of exceedences of the   
15-minute mean objective would reduce markedly. Predicted concentrations at Grangemouth AURN (Inchyra Park) and Grangemouth Moray would continue to be in excess of the objective level, however the number of predicted exceedences would be below that allowed under the objective. No exceedences are predicted at Grangemouth MC. Overall, maximum concentrations are predicted to reduce markedly as a result of the TGT introduction.

Potential for exceedence of the NAQS 15-minute mean objective level will remain after the introduction of the TGT, however overall maximum concentrations will be reduced and the extent of the potential area of exceedence of objectives is likely to be reduced.

Report Signature Page

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Post-TGT Modelling Predictions



Figures

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| GA Logo Small_RGB from Phil |

1. IPPC H1 Horizontal Guidance Note – Environmental Appraisal and Assessment of BAT, Scottish Environment Protection Agency, 2003 [↑](#footnote-ref-1)
2. http://www.ene.gov.on.ca/envision/gp/5165e.pdf [↑](#footnote-ref-2)
3. www.falkirk.gov.uk [↑](#footnote-ref-3)