Sulphur Dioxide (SO_2) Emissions Modelling for the New LNG Plant at Delimara Power Station, Malta
Phase 1

P1521

A Report Prepared for
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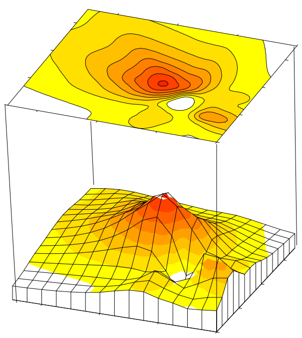

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1 INTRODUCTION

Atmospheric Dispersion Modelling (ADM) Ltd has been commissioned by Adi Associates Environmental Consultants Ltd to undertake dispersion modelling of emissions to atmosphere from the new Liquefied Natural Gas (LNG) power station at Delimara, Malta.

An air quality assessment for the proposed power station was completed in August 2013 and included full assessment of emissions of oxides of nitrogen (NO_x/NO_2) and particulate matter (PM_{10} and $PM_{2.5}$) [1]. The report stated emissions of sulphur dioxide (SO_2) would be negligible and therefore was not included in the assessment.

It has subsequently transpired that LNG sulphur (S) fuel content could be up to 30 mg Nm^{-3} (273 k, 101.3 kPa) and therefore should be considered.

This study updates the previous work and includes modelling for sulphur dioxide (SO_2) at the guaranteed maximum fuel sulphur content.

Predictions are made for routine emissions from the gas turbines operating in combined cycle mode (CCGT) and for emissions from the gas turbines operating in open cycle mode (OCGT). OCGT operating will occur for the first six months.

The sources of emissions to atmosphere modelled in this assessment are:

- Three 75 m high single flue CCGT stacks
- Three 30 m high single flue OCGT stacks

As with all types of modelling there is a degree of uncertainty in the predictions which is due to a number of factors including the accuracy of input data, reliability of meteorological data, the algorithms used to generate the predictions and the assumptions made. It is not possible to determine the overall accuracy of any particular predicted concentration as this will vary and will be related to the statistic predicted (eg long or short term concentrations) and nature of the emissions (eg whether effected by building downwash or terrain).

(1) ERSLI (December 2013) Delimara Gas and Power Combined Cycle Gas Turbine and Liquefied Natural Gas receiving, storage , and re-gasification facilities. Delimara Power Station.

2 REGULATIONS

2.1 INTRODUCTION

The section described the targets used for the determination of sulphur dioxide (SO_2) emission limits for combined cycle gas turbine (CCGT) and open cycle gas turbine (OCGT) operation.

2.2 REGULATION 3(3)

Regulation 3(3) of the Industrial Emissions (Large Combustion Plants) Regulations (LN 11 of 2013) state that:

For combustion plants permitted after 07 January 2013, the minimum stack height which shall be established during the initial permitting process, shall be such that the contribution from these combustion plants does not exceed 3% of the limit values in Annex 7 of the Ambient Air Quality Regulations, for the pollutants specified therein.

Schedule 7 (part AII) of the Ambient Air Quality Regulations (LN 478 of 2010 as amended) define the following limit values for SO_2 in ambient air:

- *One day:125 µg/m3, not to be exceeded more than 3 times a calendar year*
- *One hour:350 µg/m3, not to be exceeded more than 24 times a calendar year*

It is considered that the intention of the Regulation 3(3) was that the 3% percentage was to apply to only annual average concentrations. This was assumed to be the case for the previous study that considered the impacts of nitrogen dioxide (NO_2) which compared the annual average concentration with the 3% of the annual average limit value but not compared the hourly average concentrations with 3% of the hourly average limit value.

It is considered that an appropriate limit value for short term impacts (ie 1 hour and 24 hour averaging periods) is 10 times the long term limit value which in this case would be 30% of the short term Ambient Air Quality Regulations. The factor of 10 between long and short term impacts is used by the UK Environment Agency (EA) in their risk assessment guidance [(1)].

However, for the purpose of this study and as instructed by the former Malta Environment & Planning Authority (now the Planning Authority and the Environment & Resources Authority), the 3% of the limit value will be applied to the daily average ambient limit value of 125 μg m^{-3} not to be exceeded more than 3 times per calendar year.

The target for emissions of sulphur dioxide (SO_2) that gives rise to an acceptable impact is therefore 3.75 μg m^{-3} as a daily average not to be exceeded more than 3 times per year which is equivalent to a 3.75 μg m^{-3} as 99.17th percentile of daily averages.

(1) https://www.gov.uk/guidance/air-emissions-risk-assessment-for-your-environmental-permit.

3 METHODOLOGY

3.1 INTRODUCTION

This section describes the methodology and assumptions made for the modelling. Also described are the emissions data used.

3.2 EMISSIONS DATA

Table 3.1 shows the parameters which will describe physical properties of emissions to atmosphere from the stacks, as required for definition of the emissions in dispersion modelling terms.

Table 3.1 Stack Emissions and Physical Properties

Parameters	CCGT			OCGT		
Number of stacks	3			3		
Stack Reference	A1, B1, C1			A0, B0, C0		
Number of flues per stack	1			1		
UTM Grid Reference (Sector 33 S, WGS 84 datum, used in modelling)	A1	459683	3965627	A0	459671	3965607
	B1	459669	3965617	B0	459685	3965616
	C1	459655	3965606	C0	459699	3965626
UTM Grid Reference (Sector 33 S, ED 50 datum)	A1	459765	3965809	A0	459754	3965823
	B1	459751	3965799	B0	459740	3965813
	C1	459737	3965789	C0	459726	3965803
Stack height (metres)	75			30		
Flue gas mass flow rate (kg s^{-1})	132.6			127.7		
Flue gas emission temperature (deg C)	95.3			564		
Percentage water (% v/v)	8.34			8.34		
Percentage oxygen in wet gas (% v/v)	12.98			12.98		
Exit velocity (m s^{-1})	21.4			33.1		
Internal flue exit diameter (metres)	2.90			3.45		
Actual volumetric flow rate per flue ($Am^3 s^{-1}$)	141.4			309.4		
Normalised flow rate per flue ($Nm^3 s^{-1}$) [(a)]	109.7			105.7		
(a) Corrected to 273 k, dry and 15% v/v O_2 (dry).						

Modelling is undertaken assuming a sulphur (S) fuel concentration of 30 mg Nm^{-3} (273 k, 101.3 kPa) for both combined cycle and open cycle operation.

Table 3.2 shows the emission concentration and emission rates used for this assessment.

Table 3.2 Sulphur Dioxide (SO_2) Pollutant Emission Concentration and Rates

Parameter	Value	
Fuel sulphur (S) content (mg Nm^{-3}) (a)	30	
Fuel flow at maximum load (kg s^{-1})	2.517	
Fuel density (kg Nm^{-3}) (a)	0.78	
Fuel flow rate (Nm^3 s^{-1}) (a)	3.227	
Sulphur (S) emission rate (mg s^{-1})	96.8	
Sulphur dioxide (SO_2) emission rate (mg s^{-1})	193.6	
	CCGT	**OCGT**
Exhaust gas flow Rate (Nm^3 s^{-1}) (b)	109.7	105.7
Sulphur dioxide emission conc (mg Nm^{-3}) (b)	1.77	1.83

(a) Correct to 273 k, 101.3 kPa
(b) Corrected to 273 k, dry, 15% v/v O_2 (dry), 101.3 kPa.

Table 3.2 shows that at the guaranteed maximum fuel sulphur (S) content of 30 mg Nm^{-3} (273 k, 101.3 kPa) this is equivalent to a sulphur dioxide (SO_2) emission concentration of 1.77 mg Nm^{-3} for CCGT and 1.83 mg Nm^{-3} for open cycle (273 k, dry,15% v/v O_2 (dry), 101.3 k Pa).

3.3 FACTORS AFFECTING DISPERSION

There are a number of factors that affect how emissions disperse once released to atmosphere. The four factors having the greatest effect on dispersion are:

- physical characteristics of the emissions
- climate
- terrain
- building downwash

3.3.1 Physical Characteristics of the Emissions

Provided that exhaust gases have sufficient velocity at stack exit to overcome the effects of stack tip downwash, which is almost certainly the case for velocities of 15 m s^{-1} or more, the physical characteristics of the flue gases will determine the amount of plume rise and, hence, the affect on ground level pollutant concentrations. The degree of plume rise usually depends on the greater of the thermal buoyancy or momentum effects. In the case of emissions from the proposed facility, it will be the thermal effects that determine how high the plume will eventually rise. The exit velocities of 21 m s^{-1} and 33 m s^{-1} are sufficient to overcome the effects of stack tip down wash.

3.3.2 Climate

The most important meteorological parameters governing the atmospheric dispersion of pollutants are wind speed, wind direction and atmospheric stability.

- **Wind direction** determines the broad transport of the plume and the sector of the compass into which the plume is dispersed.

- **Wind speed** can affect plume dispersion by increasing the initial dilution of pollutants and inhibiting plume rise.

- **Atmospheric stability** is a measure of the turbulence of the air, particularly of the vertical motions present. For dispersion modelling purposes, one method of classifying stability is by the use of Pasquill Stability categories, A to F. Another is by reference to the surface heat flux present at the ground.

Dispersion models, such as ADMS and AERMOD, do not allocate the degree of atmospheric turbulence into six discrete categories. These models use a parameter known as the Monin-Obukhov length which, together with the wind speed, describes the stability of the atmosphere.

Building Downwash

The presence of buildings can significantly affect the dispersion of the atmospheric emissions. Wind blowing around a building distorts the flow and creates zones of turbulence that are greater than if the building were absent. Increased turbulence causes greater plume mixing; the rise and trajectory of the plume may be depressed generally by the flow distortion. Downwash leads to higher ground level concentrations closer to the stack than those present in the absence of a building.

It is commonly accepted that downwash effects only occur for emissions from stacks that are less than 2.5 to 3 times the height of the building structures. The structures also have to be sufficiently close to the source for their influence to be significant. The US Environmental Protection Agency suggests that the zone of influence around a building extends for a distance of no more than five times the lesser of the structures height or width. The dispersion model ADMS, however, calculates the effect of buildings out to sixty times the building height.

For the 75 m high main stacks only buildings or structures taller than 30 m will effect dispersion sufficiently to warrant inclusion in the modelling. For the 30 m high by-pass stacks used for open cycle operation buildings or structures taller than 12 m will effect dispersion sufficiently to warrant inclusion in the modelling. There are no buildings higher than 12 m in the Delimara Power Station. The highest structures on the site are the three Heat Recovery Steam Generators (HRSGs) at the base of the main stacks that may have a small effect on dispersion of emissions from the 30 m high by-pass stacks used in open cycle operation. The effects of the HRSGs on dispersion have been included in the modelling.

Table 3.3 shows the building dimensions included in the modelling to simulate the downwash effects of the HRSGs.

Table 3.3 Dimensions of Buildings Included in the Modelling

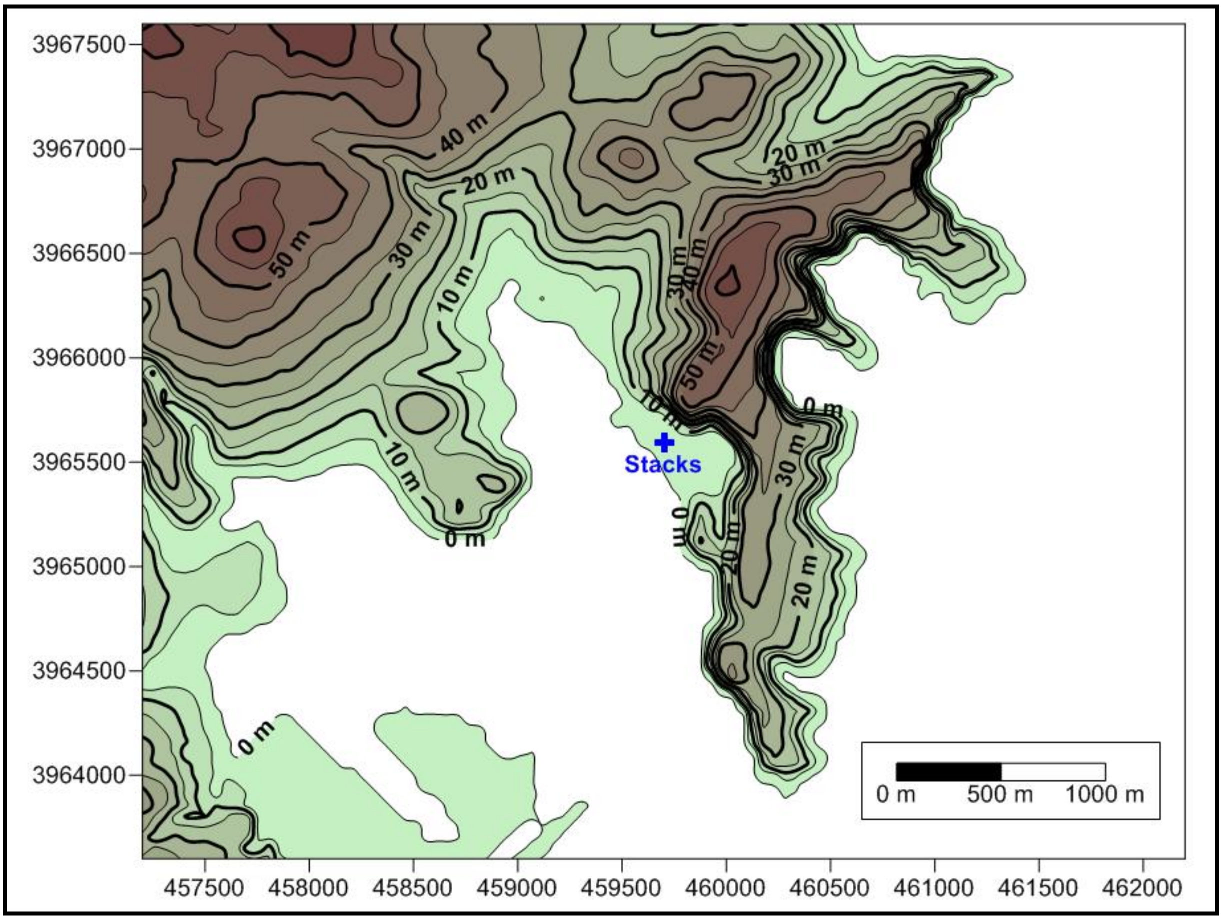
Building	UTM Grid Reference (metres)		Height (m)	X Length (m)	Y Length (m)	Angle (deg)
HRSG 1	459709	3965609	17	17	5	47.5
HRSG 2	459682	3965588	17	17	5	47.5
HRSG 3	459695	3965598	17	17	5	47.5

3.3.3 Nature of the Surface

Terrain

The effects of terrain on dispersion in the region of the facility have been included in the modelling. **Figure 3.1** shows the terrain elevations included in the modelling. The terrain data are UTM coordinates Sector 33 S referenced to WGS 84 datum.

Figure 3.1 Terrain Elevations Included in Modelling (m)



Roughness

The nature of the surface of the terrain can have a significant influence on dispersion by affecting the velocity profile with height and the amount of atmospheric turbulence. To account for the nature of the site and surrounding area, a surface roughness length of 0.3 m to 0.5 m depending on the wind direction has been assumed for the dispersion modelling.

3.3.4 Selection of Suitable Dispersion Model

The dispersion models which are widely used to predict ground level pollutant concentrations are based on the concept of the time averaged lateral and vertical concentration of pollutants in a plume being characterised by a *Gaussian* (1) distribution and the atmosphere is characterised by a number of discrete stability classes. So called 'new generation' dispersion models such as AERMOD and ADMS have been developed which replace the description of the atmospheric boundary layer as being composed of discrete stability classes with an infinitely variable measure of the surface heat flux, which in

(1) A Gaussian distribution has the appearance of a bell shaped curve. The maximum concentration occurs on the centre line.

turn influences the turbulent structure of the atmosphere and hence the dispersion of a plume.

The following are details for two of the commercially available dispersion models that are able to predict ground level concentrations arising from emissions to atmosphere from elevated point sources (ie stacks) which are routinely used for modelling and assessment work.

- *AERMOD*: The US **A**merican Meteorological Society and **E**nvironmental Protection Agency **R**egulatory Model Improvement Committee developed the dispersion **MOD**del called *AERMOD* which incorporates the latest understanding of the atmospheric boundary layer. AERMOD is the US EPA regulatory dispersion model.

- *UK Atmospheric Dispersion Modelling System (ADMS)*: This is a dispersion model developed by the UK consultancy CERC. The model allows for the skewed nature of turbulence within the atmospheric boundary layer.

In many respects the models are quite similar and in many situations generate similar predictions of ground level concentrations. AERMOD was selected as the model for use in this assessment because of its wide spread international acceptability. US EPA version 15181 of AERMOD was used for this assessment.

3.3.5 Meteorological Data

A necessary input to the dispersion model is the meteorological data. These data are important in determining the location of the maximum concentrations and their magnitude. The closest location for which there is observation of all the parameters required for modelling is Malta International Airport, Luqa which is considered to be representative of the location of the proposed development. Luqa is about 5 km to the west of the proposed facility.

Figure 3.2, 3.3 and **3.4** are the 2011-2015 wind roses of the meteorological data used in this assessment, from Luqa. The figures show that the prevailing wind direction is from the north west.

Figure 3.2 Windrose for 2011 and 2012 from Luqa

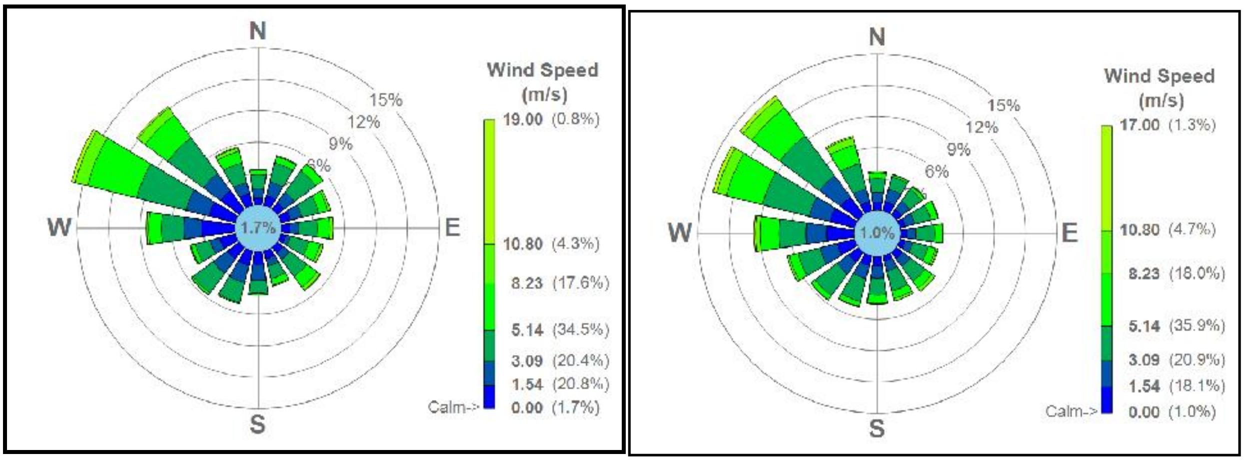


Figure 3.3 Windrose for 2013 and 2014 from Luqa

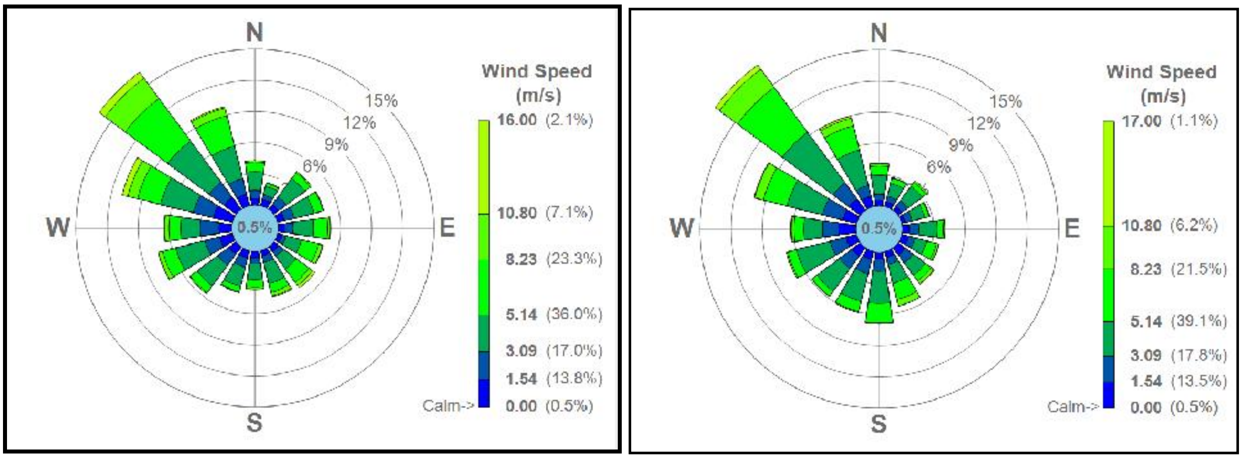
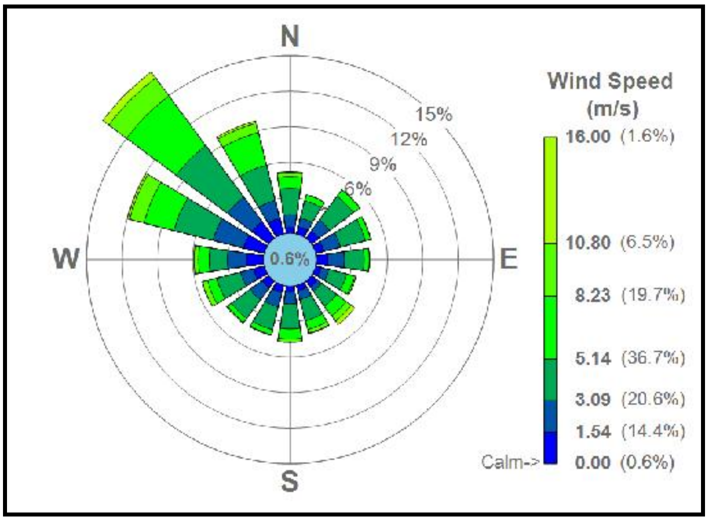


Figure 3.4 Windrose for 2015



3.3.6 Modelling Assumptions

Receptor Grid Spacing

The receptor grid used for this assessment was 5 km by 4 km with a grid spacing of 50 m to allow for predictions to be made at the point of maximum impact.

4 ASSESSMENT OF IMPACTS

4.1 INTRODUCTION

This section describes the predicted ground/sea level concentrations of sulphur dioxide (SO_2) occurring from both combined and open cycle operation. Predictions are presented for the guaranteed maximum fuel sulphur (S) content of 30 mg Nm^{-3} (273 k, 101.3 kPa) which is equivalent to a sulphur dioxide (SO_2) emissions rate of 194 mg s^{-1}.

4.2 COMBINED CYCLE GAS TURBINE (CCGT) OPERATION

Table 4.1 shows the maximum predicted ground or sea level concentration of sulphur dioxide (SO_2) occurring as a consequence of emissions to atmosphere from the facility operating in combined cycle mode for each of the five years of meteorological data.

Table 4.1 AERMOD Maximum Predicted Ground/Sea Level Concentrations of Sulphur Dioxide (SO_2, $\mu g\,m^{-3}$) for Fuel Sulphur (S) Concentration of 30 mg Nm^{-3} for Combined Cycle Gas Turbine (CCGT) Operation

Year	Annual Average	99.17^{th} Percentile of Daily Average	99.73th Percentile of Hourly Average
2011	0.038	0.22	0.66
2012	0.035	0.19	0.64
2013	0.037	0.21	0.66
2014	0.037	0.22	0.64
2015	0.038	0.22	0.66
Ambient Limit Value	**-**	**125**	**350**
Compliance with Reg. 3(3)	**-**	**3.75**	**-**

Table 4.1 shows that 2015 meteorological data gives rise to the maximum ground/sea level 99.17% percentile of daily average concentrations. The grid maximum for 2011 to 2015 of 0.22 $\mu g\ m^{-3}$ is substantially less than that required for compliance with Regulation 3(3) which is 3.75 $\mu g\ m^{-3}$.

The following figures are presented to show the distribution of ground/sea level concentrations of the sulphur dioxide (SO_2), assuming a fuel sulphur (S) concentration of 30 mg Nm^{-3}. Predictions are presented for 2015 which gives rise to the maximum impact for daily average connotations.

- **Figure 4.1;** Annual Average
- **Figure 4.2**; 99.17^{th} percentile of daily averages

Figure 4.1 AERMOD Predicted Annual Average Ground/Sea Level Concentrations of the Sulphur Dioxide (SO_2); 2015 Meteorological Data ($\mu g\ m^{-3}$); Assuming Fuel Sulphur (S) Emission Concentration of 30 mg Nm^{-3} equivalent to 194 mg s^{-1} Emissions of Sulphur Dioxide (SO_2) Combined Cycle Gas Turbine Operation (CCGT)

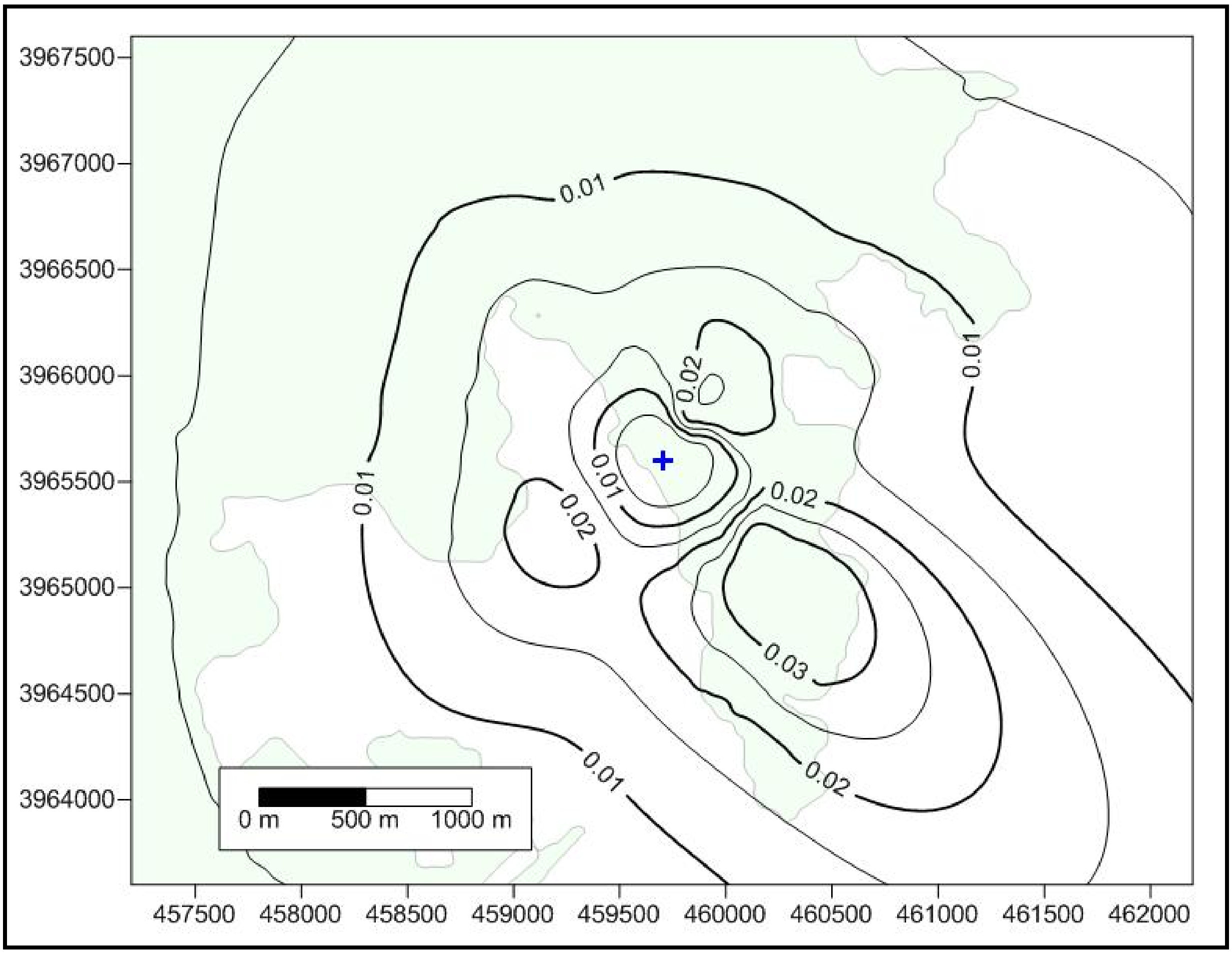
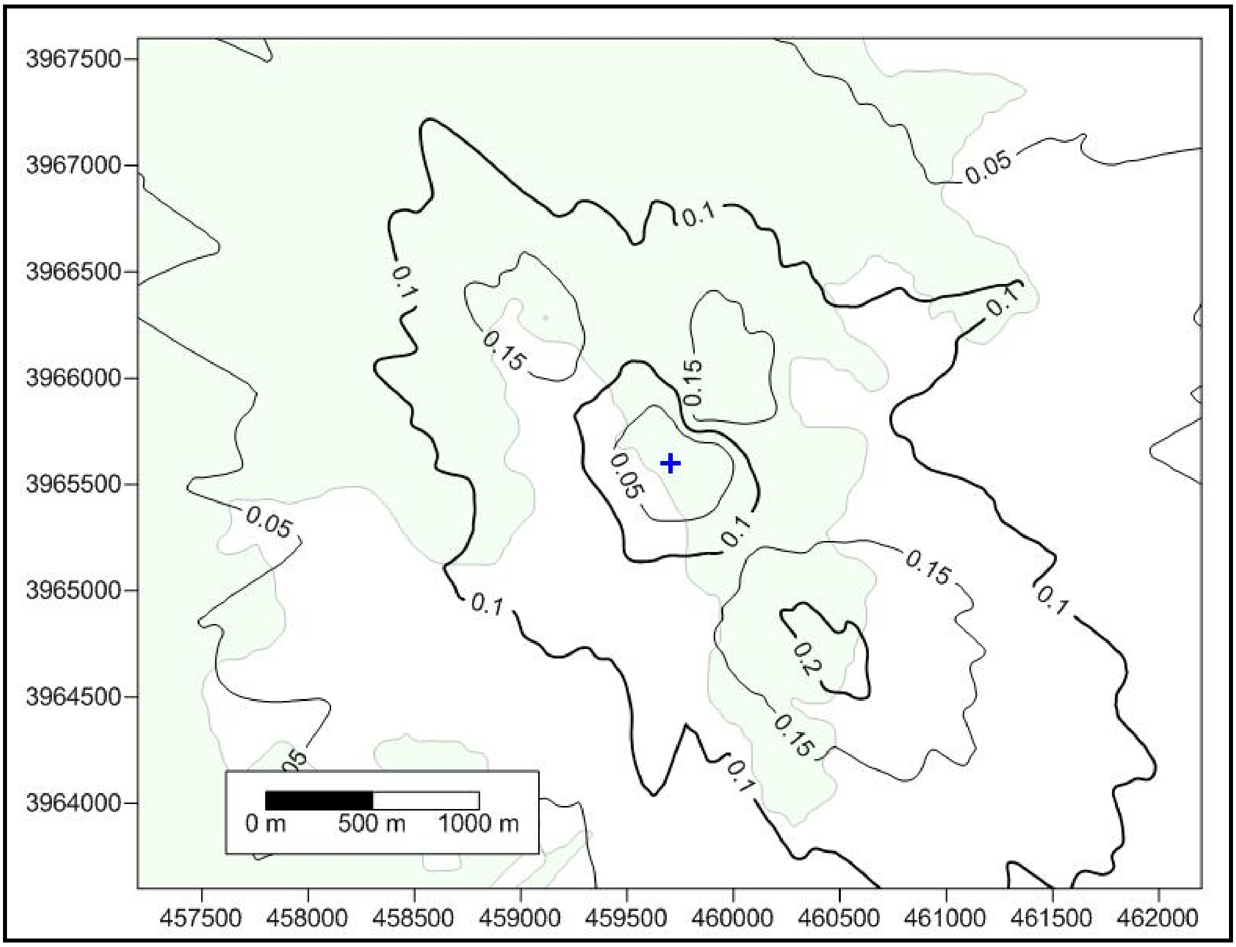


Figure 4.2 AERMOD Predicted 99.17th Percentile of Daily Average Ground/Sea Level Concentrations of the Sulphur Dioxide (SO_2); 2015 Meteorological Data ($\mu g\ m^{-3}$); Assuming Fuel Sulphur (S) Emission Concentration of 30 mg Nm^{-3} equivalent to 194 mg s^{-1} Emissions of Sulphur Dioxide (SO_2) Target: 3.75 $\mu g\ m^{-3}$ Combined Cycle Gas Turbine Operation (CCGT)



4.3 OPEN CYCLE GAS TURBINE (OCGT) OPERATION

For the first six months, the facility will operate in open cycle model with emissions from the gas turbine being released to atmosphere from the 30 m high by-pass stacks.

Table 4.2 shows the maximum predicted ground or sea level concentration of sulphur dioxide (SO_2) occurring as a consequence of emissions to atmosphere from the facility operating in open cycle mode for each of the five years of meteorological data.

Table 4.2 AERMOD Maximum Predicted Ground/Sea Level Concentrations of Sulphur Dioxide (SO_2, $\mu g\,m^{-3}$) for Fuel Sulphur (S) Concentration of 30 mg Nm^{-3} for Open Cycle Gas Turbine (OCGT) Operation

Year	Annual Average	99.17th Percentile of Daily Average	99.73th Percentile of Hourly Average
2011	0.036	0.27	0.80
2012	0.044	0.38	1.26
2013	0.049	0.44	1.70
2014	0.049	0.38	1.27
2015	0.039	0.39	1.06
Ambient Limit Value	**-**	**125**	**350**
Compliance with Reg. 3(3)	**-**	**3.75**	**-**

Table 4.2 shows that 2013 meteorological data gives rise to the maximum ground/sea level 99.17% percentile of daily average concentrations. The grid maximum for 2013 of 0.44 $\mu g\ m^{-3}$ is substantial less than required for compliance with Regulation 3(3) which is 3.75 $\mu g\ m^{-3}$.

The following figures are presented to show the distribution of ground/sea level concentrations of the sulphur dioxide (SO_2), assuming a fuel sulphur (S) concentration of 30 mg Nm^{-3}. Predictions are presented for 2013 which gives rise to the maximum impact for daily average connotations.

- **Figure 4.3;** Annual Average
- **Figure 4.4**; 99.17th percentile of daily averages

Figure 4.3 AERMOD Predicted Annual Average Ground/Sea Level Concentrations of the Sulphur Dioxide (SO_2); 2013 Meteorological Data ($\mu g\ m^{-3}$); Assuming Fuel Sulphur (S) Emission Concentration of 30 mg Nm^{-3} equivalent to 194 mg s^{-1} Emissions of Sulphur Dioxide (SO_2) Open Cycle Gas Turbine Operation (OCGT)

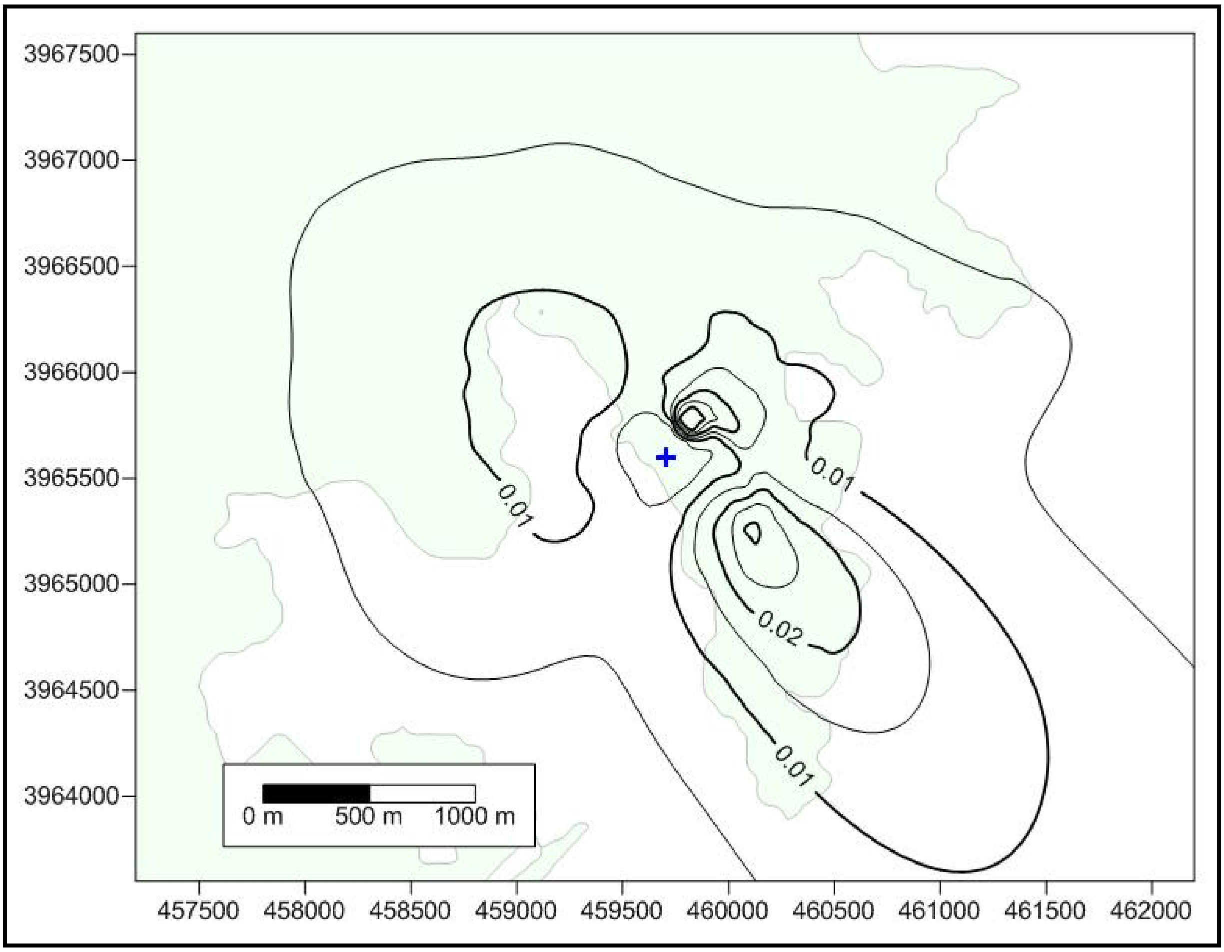
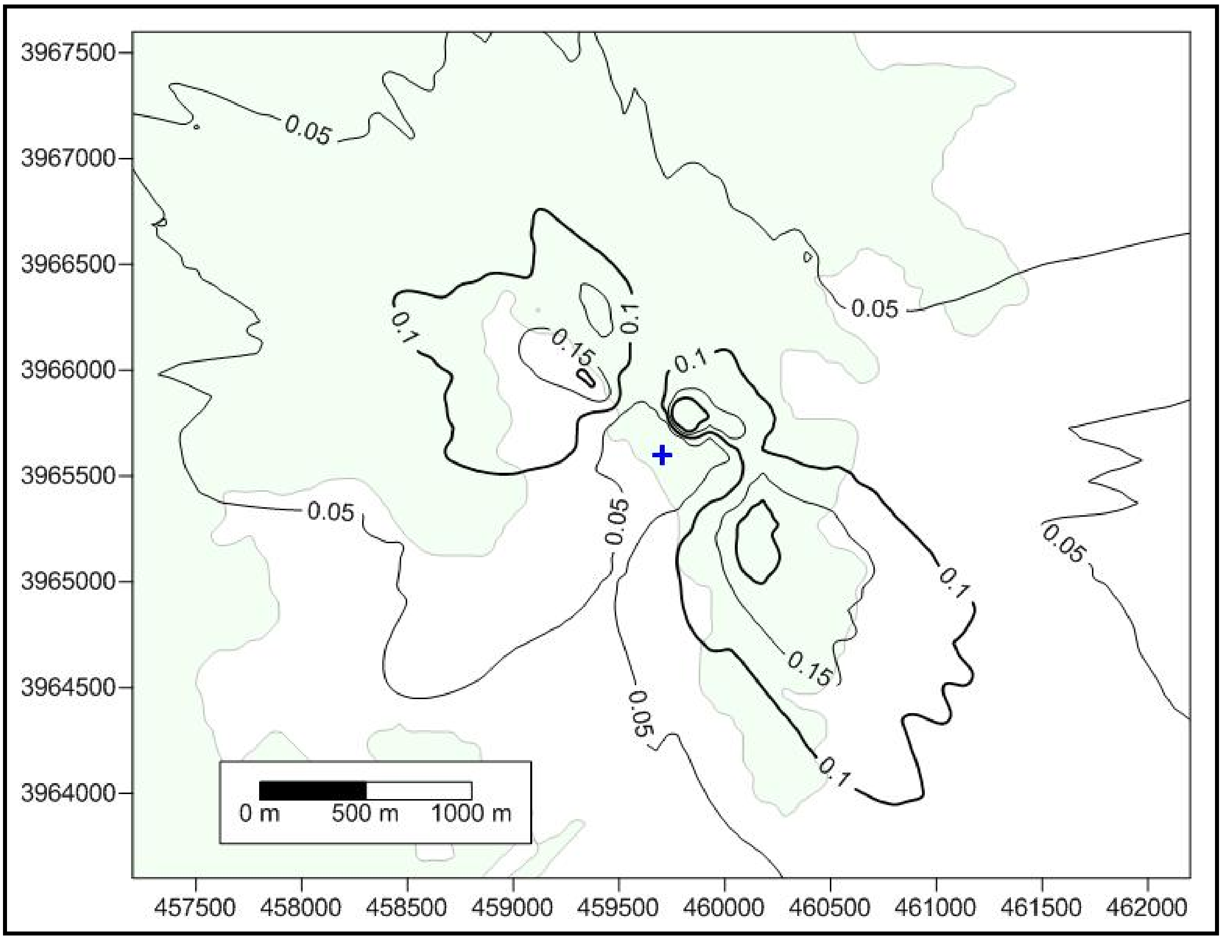


Figure 4.4 AERMOD Predicted 99.17th Percentile of Daily Average Ground/Sea Level Concentrations of the Sulphur Dioxide (SO_2); 2013 Meteorological Data ($\mu g\ m^{-3}$); Assuming Fuel Sulphur (S) Emission Concentration of 30 mg Nm^{-3} equivalent to 194 mg s^{-1} Emissions of Sulphur Dioxide (SO_2) Target: 3.75 $\mu g\ m^{-3}$ Open Cycle Gas Turbine Operation (OCGT)



5 DISCUSSION AND CONCLUSIONS

5.1 INTRODUCTION

This section provides a discussion and conclusions.

5.2 REGULATION 3(3)

It is considered that the intention of Regulation 3(3) was that the 3% criteria should to apply to annual average limit value concentrations and not to short term value concentrations.

For the purpose of this study, the 3% criteria will be applied to the daily average ambient limit value of 125 μg m^{-3} not to be exceeded more than 3 times per calendar year. It is considered that this is a conservative interpretation of the requirements of Regulation 3(3). The former MEPA instructed the Consultants to use this interpretation.

5.3 COMBINED AND OPEN CYCLE GAS TURBINE (CCGT/OCGT) OPERATION

Table 4.1 and **Table 4.2** show the maximum predicted 99.17th percentile of daily average ground/sea level concentrations do not approach the target of 3.75 μg m^{-3} and therefore the emissions from the gas turbines are complaint with Regulation 3(3)

5.4 SUMMARY AND CONCLUSIONS

Atmospheric Dispersion Modelling (ADM) Ltd has been commissioned by Adi Associates to undertake dispersion modelling of emissions to atmosphere from the new LNG power station at Delimara, Malta.

The modelling shows that emissions to atmosphere at the guaranteed maximum fuel sulphur (S) content of 30 mg Nm^{-3} (273 k, 101.3 kPa) are compliant with Regulation 3(3) and therefore no further mitigation measures are required.