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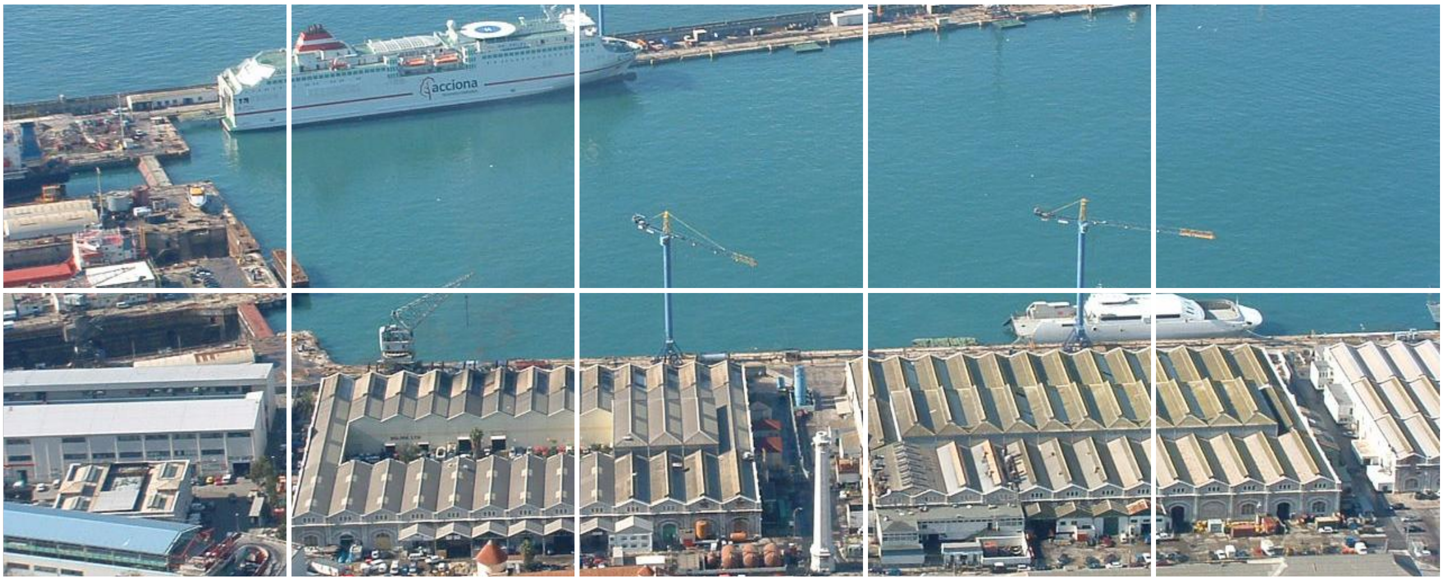

Dispersion modelling of MOD and OESCO power station discharges

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Executive summary

AEA Energy & Environment manage a programme of passive nitrogen dioxide monitoring using diffusion tubes on behalf of the Environmental Agency, Gibraltar. The results of the first two years of the monitoring programme have highlighted a significant area of Gibraltar that is exposed to annual average concentrations of nitrogen dioxide that is above the EU limit value of 40 $\mu g\ m^{-3}$. Measurements suggest that several areas are exposed to concentrations in excess of the limit value + margin of tolerance (a trigger for action prior to 2010).

In order to inform our understanding of the elevated measured concentrations a modelling study has been undertaken to investigate the MOD and OESCO Ltd power generation facilities contribution to the measured concentrations.

The complex terrain in the region of the OESCO Ltd and MOD power stations on Gibraltar presents a serious challenge for dispersion modelling. The flow model predicts that a zone of recirculating airflow develops in the area of Rosia Road and this limits the dispersion model's capability to predict concentrations in the area during these conditions. Model runs were therefore carried out with and without the effects of complex terrain.

The model predicted that, even in the absence of complex terrain effects, the power station emissions result in concentrations of nitrogen dioxide greater than the annual average limit value of 40 $\mu g\ m^{-3}$ in the Jumper's area. Model runs that took complex terrain effects into account indicated that plume grounding would lead to hourly average concentrations greater than the limit value of 200 $\mu g\ m^{-3}$ on the slopes of the rock.

The diesel generators used in the power stations are relatively old. Modern diesel engines that follow best available techniques emit approximately one tenth of the oxides of nitrogen emissions. The model results indicate that a 90% reduction in oxides of nitrogen emissions would be just sufficient to meet the annual average limit value and also to meet the hourly limit value.

Dispersion of pollutants from the power stations could be improved by increasing the height of the discharge stacks. The model results show that increasing the stack height to 25 m would be sufficient to meet the annual mean and hourly mean limit values in the absence of complex terrain effects. However, the model runs with complex terrain indicate that plume grounding may continue to lead to hourly average concentrations greater than the limit value of 200 $\mu g\ m^{-3}$ on the slopes of the rock.

Road traffic emissions from Rosia Road also contribute to pollutant concentrations. Simple model results indicate that, in the absence of complex terrain effects and the increased emissions from vehicles travelling up hill, these emissions would not increase roadside concentrations much above background levels. Sensitivity studies suggest that roadside concentrations could approach those observed at Rosia Road and South Barracks Road if the effects of increased emissions from vehicles climbing up hill and the effects of street canyons are taken into account.

Table of contents

1 Introduction

AEA Energy & Environment manage a programme of passive nitrogen dioxide monitoring using diffusion tubes on behalf of the Environmental Agency, Gibraltar. The results of the first two years of the monitoring programme, 2005 and 2006, highlighted consistently high concentrations of nitrogen dioxide in the vicinity of Jumper's on Rosia Road. The concentrations measured in and around this area exceeded the EU limit value plus the margin of tolerance for annual mean nitrogen dioxide concentrations.

Road traffic is often the most significant contributor to roadside and kerbside nitrogen dioxide concentrations. However, the Jumper's location is close to two of the main power generation facilities in Gibraltar and it has been suggested that the generation plant contributes significantly to the local concentrations. The Environmental Agency, Gibraltar contracted AEA Energy & Environment to investigate further the measured high concentrations of nitrogen dioxide. The investigation comprises an expansion of the monitoring activities in the vicinity of Jumper's area and a dispersion modelling study of the area. This report describes the modelling study.

The modelling study was carried out using the dispersion model ADMS3.3. ADMS3.3 is a practical dispersion model that uses an up-to-date description of the atmospheric boundary layer. Modules within the model allow the effects of complex terrain and buildings to be taken into account. Various approaches can be taken in modelling what is a complex real world situation, each involving some compromises because the modelling of pollutant dispersion over Gibraltar's complex terrain represents a considerable challenge. Sensitivity studies have therefore been carried out to assess the sensitivity of the model predictions to the modelling approach adopted and the meteorological input data used.

In addition to using the model to represent the current situation (the base case) the model has been used to assess the effects of alternative scenarios representing options for process changes on the generation plant with a view to assessing the potential for reductions in nitrogen dioxide concentrations. Two scenarios have been investigated:

- Reducing the emissions from the generation plant
- Increasing the discharge stack heights from the generation plant

The model is used to assess the effects of these alternative scenarios.

Section 2 of this report provides a summary of recent measurements of nitrogen dioxide concentrations in Gibraltar. Section 3 of the report describes the model inputs. Section 4 presents the results of the modelling study and Section 5 discusses the contribution made by the power generation facility to the measured exceedences of the EU limit value. Section 6 presents the conclusions of the modelling study and sets out recommendations that arise from this study.

2 Nitrogen dioxide monitoring

2.1 Air quality objectives

Gibraltar will comply with the European Air Quality objectives as detailed in the European Council Directives 1996/62/EC, 1999/30/EC, 2000/69/EC, 2002/3/EC and 2004/107/EC.

These Directives have been transposed into Gibraltar Law by the Public Health (Air Quality Limit Values) Rules 2002 as amended by the Public Health (Air Quality Limit Values) (Amendment) Rules 2003 and the Public Health (Air Quality) (Ozone) Rules 2004.

The European Union Limit Values for nitrogen dioxide are shown in Table 1.

Table 1: Limit Values for nitrogen dioxide

	Averaging period	Limit value	Margin of tolerance[1]	Date by which value is to be met
Hourly limit for the protection of human health	1 hour	200 $\mu g\ m^{-3}$ not to be exceeded more than 18 times a calendar year	50% on the entry into force of the Directive in 1999, reducing on 1 January 2001 and every 12 months thereafter by equal annual percentages to reach 0% by 1 January 2010	1January 2010
Annual limit for the protection of human health	Calendar year	40 $\mu g\ m^{-3}$		

[1] The concept of a margin of tolerance provides a trigger for action in the period prior to the date by which the Limit Value must be met. The margin of tolerance is reduced each year and reduced to zero on the 01 January 2010 at which time the Limit Value must be met.

The Limit Value + Margin of Tolerance that applies for nitrogen dioxide for each year until 2010 is set out in Table 2.

Table 2: Limit Values + Margin of Tolerance for nitrogen dioxide

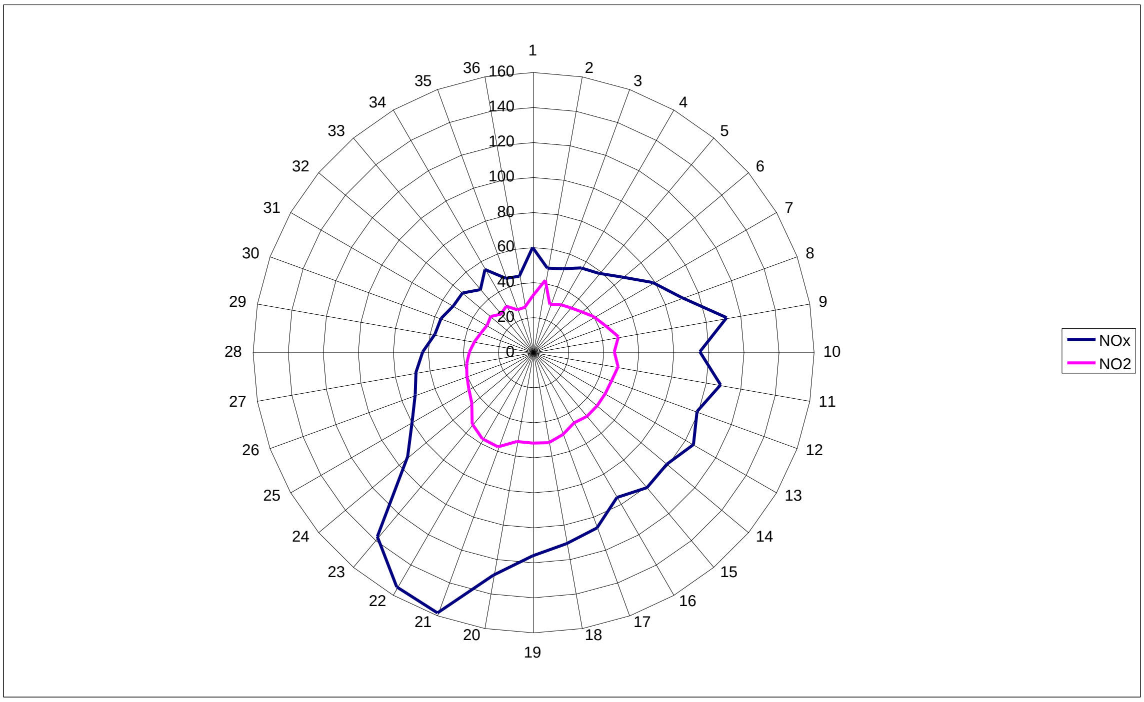
Year	2005	2006	2007	2008	2009	**2010**
Concentration ($\mu g\ m^{-3}$)	50	48	46	44	42	**40**

2.2 Continuous monitoring

Nitrogen dioxide is monitored automatically by ozone chemiluminescence at two locations in Gibraltar at a roadside site on Rosia Road and at a background site at Bleak House. The annual mean nitrogen dioxide concentrations at the two sites in 2006 were 42 $\mu g\ m^{-3}$ at Rosia Road and 24 $\mu g\ m^{-3}$ at Bleak House. The 99.8 th percentile of hourly concentrations, corresponding to 19th highest hourly concentration during the year, were 124 $\mu g\ m^{-3}$ at Rosia Road and 103 $\mu g\ m^{-3}$ at Bleak House. The annual mean limit value was thus exceeded at Rosia Road during 2006 but the hourly limit value was met at the site. Both limit values were met at Bleak House. Continuous monitoring in Gibraltar first started in February 2005: the partial 2005 data sets reveal identical mean concentrations and similar 99.8 th percentile of hourly concentrations to the full 2006 data sets.

Fig.1 shows a pollution rose for the Rosia Road location. It shows the average oxides of nitrogen concentration and the average nitrogen dioxide concentration for each 10^{o} wind direction band measured at Rosia Road. The highest observed concentrations occur when the wind comes from SSW i.e. from the general area of the two main power generation facilities in Gibraltar.

Fig,.1: Average oxides of nitrogen and nitrogen dioxide concentrations, $\mu g\ m^{-3}$ for each 10^o wind direction band at Rosia Road



2.3 Passive monitoring

Nitrogen dioxide was also monitored by passive diffusion tube at 14 locations in Gibraltar throughout 2006. The annual average concentrations at these sites are shown in Table 3. Two of the diffusion tube sites are collocated with the continuous monitors at Rosia Road and Bleak House. The concentrations measured by diffusion tubes at these sites are higher than those measured by the automatic reference method. The 2006 diffusion tube measurements have therefore been adjusted to take account of the diffusion tube over-read using the bias adjustment factor calculated at Rosia Road.

Table 3: Diffusion tube measurements 2006

Site	Concentration, µg m^{-3}	
	Unadjusted	Bias adjusted[2]
Jumpers	69	57
George Don House	47	39
Devils Tower Road	54	45
Water Gardens	51	42
Glacis Road	58	48
Harbour Views	39	32
Main Street No. 7	42	35
Queensway	42	35
Prince Edwards Road	49	40
Rosia Road	51	42
Red Sands Road	55	45
South Barracks Road	61	51
Bleak House	33	27
Lime Kiln Road	49	40

[2] Bias adjustment based on the 2006 Rosia Road continuous monitoring collocation study

The annual limit value (40µg m^{-3}) and the annual mean limit value + margin of tolerance for 2006 (48µg m^{-3}) was exceeded at several of these sites during 2006, with particularly high concentrations measured at Jumpers. Most of the sites where the limit value was exceeded are kerbside sites on relatively busy roads. However, the Jumpers, South Barracks Road, Red Sands Road and Rosia Road sites are also close to two of the main power generation facilities in the dockyard area adjacent to Jumpers.

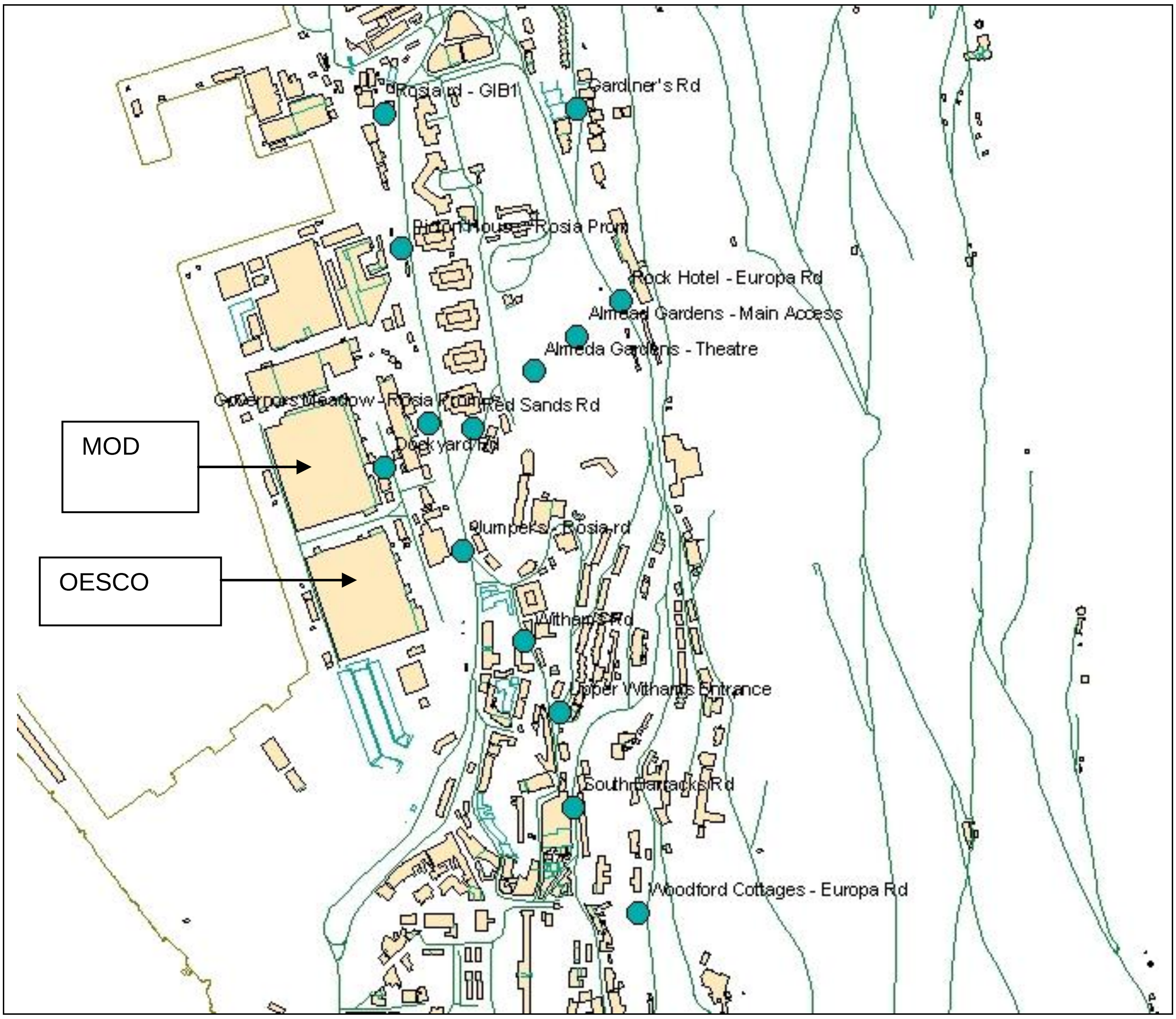
In February 2007 additional diffusion tubes were installed near to the power generation facilities to provide more spatial detail of actual concentrations. Insufficient data have been collected so far to provide a basis for reliable assessment. Fig. 2 shows the location of diffusion tube sites in the area of the power generation facilities and Table 3 lists the measured concentrations (without any bias adjustment) for February and March 2007.

Table 4: Diffusion tube measurements, 30 January – 26 March2007

Site	Unadjusted Concentration, µg m-3
Rosia Road	48
Jumpers	69
Red Sands Road	54
South Barracks Road	60
Picton House - Rosia Promenade	46
Upper Withams Entrance	64
Withams Road	58
Almeda Gardens - Theatre	44
Almeda Gardens - Main Access	39
Rock Hotel - Europa Road	55
Gardiners Road	38
Governors Meadow - Rosia Promenade	58
Dockyard Road	59
Woodford Cottages - Europa Road	60

The measurements shown in Table 4 suggest that the limit value is likely to be exceeded at nearly all the locations in the area of the power generation facilities.

Fig. 2: Location of diffusion tubes in the area adjacent to the two dockyard power generation facilities.



3 Modelling approach and inputs

The impact of the emission discharges from the two dockyard power generation facilities is modelled using ADMS 3.3, a practical dispersion model that uses an up-to-date description of the atmospheric boundary layer.

The actual ambient concentration of nitrogen dioxide that is experienced at any receptor location in Gibraltar is a function of emissions, from all sources of oxides of nitrogen, dispersion of those emissions after they leave the source and the chemistry that occurs between the emission point and the receptor location.

Disperse sources of oxides of nitrogen provide a background concentration upon which more local sources such as the power generation facilities are superimposed. The 2006 monitoring data from the Bleak House continuous station has been used to provide the best estimate of the background concentration for Gibraltar.

Modules within the model allow the dispersion effects of complex terrain and buildings to be taken into account. The modelling of the dispersion of pollutants over Gibraltar's complex terrain represents a considerable challenge for any model and various approaches can be taken in modelling this complex situation, each involving some compromises. Sensitivity studies were therefore carried out to assess the sensitivity of the model predictions to the modelling approach and the meteorological data.

The contribution of road traffic local to the power generation facilities were assessed to identify how significant a contribution to ambient nitrogen dioxide concentrations is made by road traffic.

3.1 Emissions sources

Electricity is generated at three main power plants on Gibraltar. These are operated by the Ministry of Defence, OESCO Ltd and Gibelec Ltd. The Ministry of Defence and OESCO Ltd stations are located in the dockyard area to the west of Rosia Road below Jumpers, while the Gibelec Ltd power station is located on Gibraltar's North Mole. The Ministry of Defence and OESCO Ltd power stations have the greatest potential to affect the nitrogen dioxide concentrations in the Rosia Road area and are considered within this study. They are the nearest stations to the area of highest measured nitrogen dioxide concentrations.

Traffic on Rosia Road also contributes to oxides of nitrogen emissions. The contribution to oxides of nitrogen emissions from the traffic was also investigated.

3.2 Emissions

3.2.1 OESCO Ltd

OESCO Ltd operate seven diesel engines, discharging through eleven stacks as shown in Table 5.

Table 5: OESCO Ltd Emission points

Emission Point	Description	Engine Size
A1	Engine No. 1 Stack	2.5 MW
A2	Engine No. 2 Stack	1.8 MW
A3	Engine No. 3 Stack	2.5 MW
A4	Engine No. 4 Stack 4N	5.1 MW
A5	Engine No. 4 Stack 4S	
A6	Engine No. 5 Stack 5N	5.1 MW
A7	Engine No. 5 Stack 5S	
A8	Engine No. 6 Stack 6N	5.1 MW
A9	Engine No. 6 Stack 6S	
A10	Engine No. 7 Stack 7N	5.1 MW
A11	Engine No. 7 Stack 7S	

Inspeccion y Control measured oxides of nitrogen concentrations and discharge flowrates for these stacks on behalf of OESCO Ltd. The gas flowrates were determined following standard UNE77225:2000, equivalent to ISO 10780:1994. Oxides of nitrogen concentrations were determined following standard UNE 77218:1996, equivalent to ISO 10369:1993. The results are summarised in Table 6.

Table 6: Oxides of nitrogen measurements at OESCO Ltd

SET No.	% LOAD	NOx mg Nm^{-3}	Corrected to 15% O_2	O_2 %	CO_2 %	Moisture %	Temp degrees C	GAS FLOW $Nm^3 h^{-1}$	NOx discharge rate, g s^{-1} as NO_2
1		Assume results for Engine 3 which have the same size and capacity							
2	90	1385	825	11	7	8	417	11700	4.50
3	90	1581	1002	11.6	7	8	382	15500	6.81
4N	90	2185	1315	11.1	5.5	8	403	16600	10.08
4S	90	1876	1165	11.4	7.5	8	430	14400	7.50
5N	90	1705	977	10.6	6.5	8	421	14700	6.96
5S	90	1628	924	10.5	6	8	435	16200	7.33
6N		Assume results for Engines 4 or 5 which have the same size and capacity							
6S		Assume results for Engines 4 or 5 which have the same size and capacity							
7N	90	2412	1599	12	6.5	8.9	407	20100	13.47
7S	90	2445	1639	12.1	5	8.8	403	20100	13.65
1		Assume results for Engine 3 which have the same size and capacity							
2	60	1626	1141	12.5	4.5	8	345	7400	3.34
3	60	1660	1100	12	7	8	361	12100	5.58
4N	60	2218	1437	11.8	5.5	8	363	13300	8.19
4S	60	1944	1318	12.2	5.5	8	371	11500	6.21
5N	60	2002	1341	12.1	5	8	342	11600	6.45
5S	60	1659	1030	11.4	4	8	378	12300	5.67
6N		Assume results for Engines 4 or 5 which have the same size and capacity							
6S		Assume results for Engines 4 or 5 which have the same size and capacity							
7N	60	2402	1728	12.7	5.5	8	362	15500	10.34
7S	60	2382	1755	12.9	5	9	359	14200	9.40
1	30	No Data							
2	30	No Data							
3	30	No Data							
4N	30	1878	1439	13.2	3.5	8	283	7300	3.81
4S	30	1156	1100	14.7	2.5	8	254	7000	2.25
5N	30	1145	1145	15	3	8	222	6000	1.91
5S	30	1517	1133	13	4	8	308	8600	3.62
6N		Assume results for Engines 4 or 5 which have the same size and capacity							
6S		Assume results for Engines 4 or 5 which have the same size and capacity							
7N	30	1991	1780	14.3	3.5	8	278	9800	5.42
7S	30	1968	1843	14.6	3	8	250	10600	5.79

OESCO Ltd operate the diesel engines in response to electricity demand. Engines are taken out of service to allow efficient operation and for maintenance. Table 7 shows the number of hours run by each engine and load factor for each of the engines in recent years. Table 7 also shows an average loading calculated as the ratio of the actual power generated in a year compared to the theoretical maximum power generation.

Table 7: Engine utilisation at OESCO Ltd.

	2003/2004		2004/2005		2005/2006		
Engine	Hours Run	Load factor	Hours Run	Load factor	Hours Run	Load factor	Average loading
1	3469	73.7	5071	70.08	3392	69.8	0.323
2	3220	64.52	1465	73.62	1163	73.31	0.153
3	3140	73.94	2456	79.74	4155	77.14	0.285
4	3058	72.13	4892	80.6	4753	74.18	0.368
5	5639	81.96	4527	84.25	4911	83.68	0.477
6	6076	85.49	2915	76.59	4070	77.74	0.403
7	-	-	-	-	1406	61.04	0.098

Table 8 shows the annual average rate of emission used for dispersion modelling. The emission rate was estimated from the measured emissions under 90 % load and the average loading. Table 8 also shows the easting and northing grid reference of each of the emission points and the discharge velocity calculated on the basis of the measured gas flow and discharge temperature for a 90% loading and discharge diameters of 0.71 m for A1-A9 and 0.61m for A10 and A11.

Table 8: Location and rate of emissions of OESCO discharges

Emission Point	Annual average emission rate, g/s	Discharge velocity, m s^{-1}	Easting, m	Northing, m
A1	2.44	26.1	288260	4001005
A2	0.76	20.7	288265	4000995
A3	2.15	26.1	288268	4000990
A4	4.12	28.8	288277	4000963
A5	3.07	26.0	288280	4000957
A6	3.69	26.2	288283	4000950
A7	3.89	29.5	288285	4000943
A8	4.51	28.8	288290	4000935
A9	3.36	26.0	288293	4000930
A10	1.47	47.6	288295	4000925
A11	1.49	47.3	288297	4000920

The stacks discharge at a height of 1.3 m above the roof level of 12.2 m.

3.2.2 Ministry of Defence

The Ministry of Defence operate six diesel engines discharging through six stacks. The engine sizes are listed in Table 9.

Table 9: Ministry of Defence engine sizes

Emission Point	Engine Size
7	2.16 MW
8	2.16 MW
9	2.16 MW
10	2.16 MW
12	4.68 MW
14	3.8 MW

The Institute of Naval Measurement (INM) carried out stack emissions monitoring but standard methods were not used and it was not possible to measure either the discharge flowrate or the total oxides of nitrogen concentrations. An emission factor of 3 g MJ^{-1}, estimated from the measurements on similar diesel engines at OESCO has therefore been used to estimate emissions from the MOD engines. Similarly a discharge rate of 2 Nm^3 MJ^{-1} has been used to estimate the discharge flowrate. The MOD diesel engines have a total generating capacity of 17.12 MW. Typically the electricity demand is 5-7 MW. For modelling purposes, it has been assumed that generators 7, 12 and 14 are running at 66% loading.

Discharge temperature of 400^{o}C has been assumed, typical of this type of diesel engine. The stacks discharge approximately at the level of the roof ridges (12 m).

Table 10 shows the discharge characteristics of each of the modelled stacks.

Table 10: Discharge characteristic of modelled MOD stacks

Stack	Easting, m	Northing, m	Discharge flowrate $Nm^3 h^{-1}$	Emission rate, g s^{-1}	Discharge velocity, m s^{-1}
7	288335	4001068	10264	4.3	16
8	288330	4001067	10264	0	16
9	288325	4001066	10264	0	16
10	288320	4001065	10264	0	16
12	288285	4001185	22239	9.3	24
14	288322	4001035	18058	7.5	19

3.2.3 Rosia Road traffic

Preliminary modelling runs indicated that Rosia Road was located in an area of recirculating air flow, the result of the steep terrain. The ADMS model is not able to calculate concentrations near to roads in these circumstances. A simpler model, the Highways Agency Design Manual for Roads and Bridges (DMRB) was used therefore to investigate the potential contribution of emissions from traffic on Rosia Road to local concentrations. An annual average daily traffic flow of 10,000 vehicles per day was nominally assumed with 3% heavy-duty vehicles. It was further assumed that the vehicle fleet emissions technology was broadly comparable with the UK vehicle fleet. The roads on Gibraltar are generally steeply inclined so that most driving is done in low gear. There is no detailed emission data for vehicles climbing hills, thus the approach recommended in the UK Technical Guidance LAQM.TG(03) was adopted. The method accounts in a simple way for the increased power output from the engines required to climb the hill. The effective emission factor is thus:

$$EF_2 = EF_1 \times \frac{V_1}{V_2}$$

where EF_1 is the emission factor for vehicles travelling with high engine load on flat terrain (V_1=100 kph) ; EF_2 is the emission factor for vehicles travelling at speed V_2=20 kph up hill.

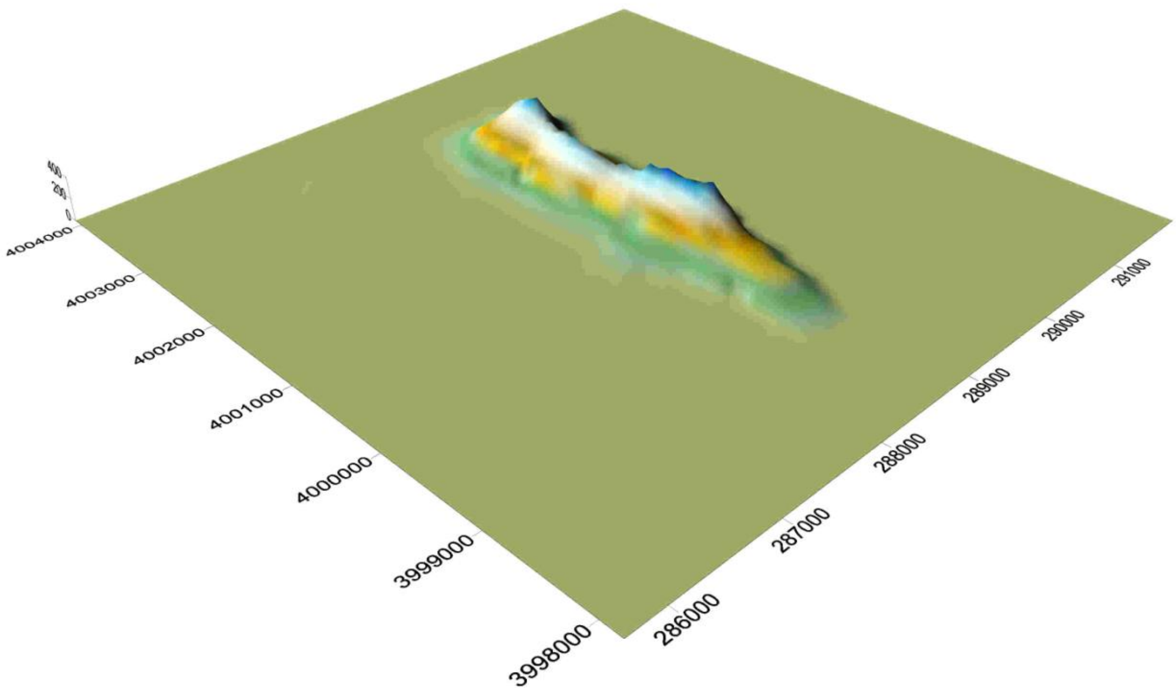
The road is sheltered on one or both sides by large buildings, close to the road. The closeness of the buildings gives rise to a potential street canyon effect. The advice given in the UK Technical Guidance LAQM.TG(03) was followed; this suggests that the predicted annual mean nitrogen dioxide road traffic component from DMRB should be multiplied by a factor 2. This should then be added to the background concentration (in this case from Bleak House) to give the total predicted concentration.

3.3 Terrain

The terrain surrounding the power generation facilities is complex. The power stations are close to the coast on the west and the land rises steeply to the east. The ADMS 3.3 dispersion model has the facility to take account of complex coastline and terrain effects. Ideally, the hills should have moderate slope (say less than 1 in 3) but the model is useful even when this criterion is not met. Model runs were carried out with and without complex terrain to investigate the sensitivity of the modelled concentrations to complex terrain.

Spot heights were digitised from the Military Survey 1:2500 map of Gibraltar at 50 m height and 200 m northing intervals. The digitised map was then interpolated onto a 64 x 64 node rectangular grid extending from 288400, 3997800 to 291950, 4004100 at 100 m spacing between nodes. The height of sea nodes was set to 0 m. Fig. 3 shows the modelled terrain.

Fig. 3: Gibraltar terrain model



For the purpose of the modelling the surface roughness of landside areas was set to 1 m: for areas of sea the surface roughness was set to 0.001 m.

3.4 Buildings

Dispersion from the diesel engine discharges is affected by the presence of nearby buildings.

The MOD generator, HM Naval Base and OESCO Ltd buildings are located on the dock area immediately below the Rosia Road Promenade, with the building roofs approximately level with the Promenade. Model runs were carried out in which the buildings were included as part of the terrain. The effective stack heights for these model runs were the heights above the roof ridges.

Close to the buildings, the MOD and OESCO Ltd buildings potentially have the most significant effect on dispersion. Separate model runs were therefore carried out for flat terrain, but taking the buildings into account. The two buildings were treated in ADMS3.3 as rectangular blocks. The position of the centre of the blocks, their dimensions and the angle with respect to north is shown in Table 11. The MOD building was assessed to be the "main building" influencing dispersion from MOD stacks 7-12: The OESCO building was the "main building" for the OESCO discharges and MOD stack 14.

Table 11: Buildings affecting dispersion

	Grid reference of building centroid		Length , m	Width, m	Angle to north	Height, m
	Easting, m	Northing, m				
MOD	288280	4001115	125	102	162	12.2
OESCO	288330	4000970	125	102	162	12.2

ADMS3.3 has the capability to model the buildings and the complex terrain together. However, the model cannot take account of buildings that are located in "reverse flow" areas where the ground level wind moves in the opposite direction to the general wind. Preliminary model runs showed that reverse flow occurred in the area of the MOD and OESCO buildings for many hours of the year.

3.5 Meteorological data

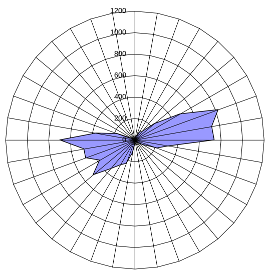
Meteorological data for the period 2002-2006 for Gibraltar Airport was obtained from Trinity Consultants. The data provides hourly sequential records of the wind speed and direction, temperature and cloud cover. Fig.4 shows the frequency of winds from each direction observed at the airport and the average wind speed in each direction. The most frequent winds are from the south-west and north-east. Average wind speeds are typically 6-7 m s^{-1} in these directions. By contrast the wind speed measured on the 7 m meteorological mast at the Rosia Road air quality monitoring site is much smaller, typically less than 1 m s^{-1}. The wind speeds predicted by the ADMS terrain module at the Rosia Road site are also substantially less than those predicted at the airport. For example, for winds (10 m above ground) from the north-east (70^o from north) at the Airport with a wind speed of 7 m s^{-1}, the predicted wind speed (10 m above ground) at Rosia Road was 0.85 m s^{-1}. The modelled wind direction at Rosia Road depends to a considerable degree on the height above ground. Table 12 shows the modelled wind direction at Rosia Road when there are north-east winds at the airport, it can be seen that the wind direction is reversed close to the ground.

Table 12: The dependence of modelled wind direction at Rosia Road on height above ground

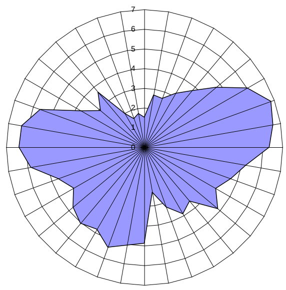
Height above ground, m	Wind speed, m s^{-1}	Wind direction, degrees from north
0	4.6	256
1	1.9	267
10	0.85	27
30	2.9	61
80	5.3	66
200	7.6	68

Fig. 4: Wind roses at the airport , Rosia Road and Bleak House

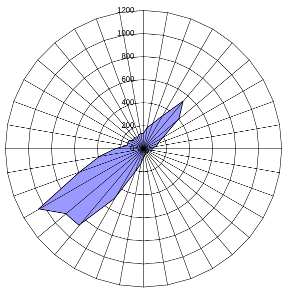
Airport: frequency of wind direction



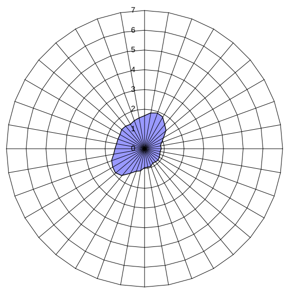
Airport: average wind speeds



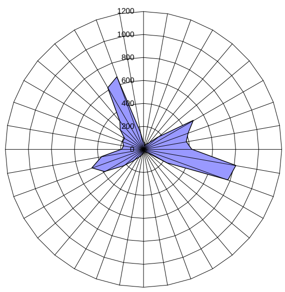
Rosia Road: frequency of wind direction



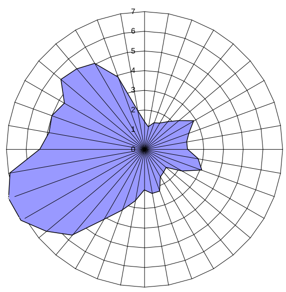
Rosia Road: average wind speeds



Bleak House: frequency of wind direction



Bleak House: average wind speeds



3.6 Receptor grids

The model was used to predict ground level concentrations resulting from emissions from the electricity generation on a rectangular receptor grid extending 500 m in each direction from the generating plant, with receptors at 50 m intervals.

3.7 Chemistry

Oxides of nitrogen emitted from the power generation diesel engines and from road traffic reacts with ozone in the air to form nitrogen dioxide. The rate of reaction depends on the concentrations of the reacting gases and on the temperature and available solar radiation. These chemical reactions were modelled in the ADMS 3.3 model runs for 2006 taking account of hourly measured oxides of nitrogen, nitrogen dioxide and ozone concentrations from the Bleak House monitoring site. It was assumed that 10% of the oxides of nitrogen emissions were present as nitrogen dioxide: this is the ADMS default value. Monitoring at Bleak House started part way through 2005 and so data is not available for complete years before 2006.

3.8 Scenarios

The Environment Agency Sector Guidance Note for combustion activities specifies a benchmark emission limit for compression ignition engines for oxides of nitrogen of 150 mg m^{-3} at 15% oxygen, dry, 273 K and 101325 Pa pressure. This is approximately 10-20% of the emission concentrations measured at the OESCO plant. The benchmark emission limit could be achieved if new engines were installed and so represents the best possible improvement that could be obtained by means of changes to the engine installation alone. A 90% reduction in engine emissions from the OESCO and MOD plant has therefore been considered as one possible improvement scenario. The contribution to oxides of nitrogen concentrations at the receptors from the generators is proportional to the rate of emission and so the contribution for this scenario can be obtained by scaling the baseline model results. However, the contribution to nitrogen dioxide concentrations is not proportional to emissions and so additional runs were carried out for 2006.

Some improvement in dispersion could be obtained by discharging through taller stacks. The greatest benefit would be obtained where the discharges are grouped together in a single stack. It has been assumed therefore that the discharges from the OESCO plant can be discharged at 400^{o}C through a single stack, 25 m tall with diameter 1.4 m at a velocity of 15 m s^{-1}. It has also been assumed that the MOD stacks are increased in height to 25 m: however, it has been assumed that the MOD discharges will remain through individual stacks because it is not practicable to discharge these emissions through a single stack.

3.9 Model runs

Table 13 summarises the model runs carried out. Model runs without complex terrain provide an indication of the impact of the power stations in flat terrain. These model runs should be considered representative of the impact at the optimum location. An installation is unlikely to be satisfactory if predicted concentrations under these conditions exceed the limit values. Model runs carried out with complex terrain represent our best attempt to simulate the effects of Gibraltar's terrain.

Table 13: Summary of main model runs

	Emission sources	Year	Complex terrain	Buildings	Chemistry
1	Generators	2002	✓	×	×
2		2003	✓	×	×
3		2004	✓	×	×
4		2005	✓	×	×
5		2006	✓	×	✓
6	Generators	2002	×	✓	×
7		2003	×	✓	×
8		2004	×	✓	×
9		2005	×	✓	×
10		2006	×	✓	✓
21	10 % Generator emissions	2006	×	✓	✓
22	10 % Generator emissions	2006	✓	×	✓
31	25 m stacks	2002	✓	×	×
32		2003	✓	×	×
33		2004	✓	×	×
34		2005	✓	×	×
35		2006	✓	×	✓
36	25 m stacks	2002	×	✓	×
37		2003	×	✓	×
38		2004	×	✓	×
39		2005	×	✓	×
40		2006	×	✓	✓

4 Results

The results of the dispersion modelling are presented in this section. Modelled concentrations at the diffusion tube locations in the area adjacent to the power generation facilities are listed in a series of tables. The tables show the modelled oxides of nitrogen concentrations for each meteorological data set and modelled nitrogen dioxide concentrations for 2006. The tables are listed as follows:

Table 14: Modelled contributions from the power generation facilities to annual average oxides of nitrogen concentrations at monitoring locations, $\mu g\ m^{-3}$: baseline
Table 15: Modelled contributions from the power generation facilities to 99.8th percentile of hourly oxides of nitrogen concentrations at monitoring locations, $\mu g\ m^{-3}$: baseline
Table 16: Modelled nitrogen dioxide concentrations at monitoring locations , $\mu g\ m^{-3}$ resulting from power generation facilities emissions: baseline
Table 17: Modelled nitrogen dioxide concentrations at monitoring locations, $\mu g\ m^{-3}$ resulting from power generation facilities emissions: 90% reduction in emissions
Table 18: Modelled contributions from power generation facilities emissions to annual average oxides of nitrogen concentrations at monitoring locations, $\mu g\ m^{-3}$: 25 m stacks
Table 19: Modelled contributions from power generation facilities emissions to 99.8th percentile of hourly oxides of nitrogen concentrations at monitoring locations, $\mu g\ m^{-3}$: 25 m stacks
Table 20: Modelled nitrogen dioxide concentrations at monitoring locations resulting from power generation facilities emissions, $\mu g\ m^{-3}$: 25 m stack height.

Table 21 shows the concentrations resulting from road traffic predicted at the kerbside (5 m from the road centreline) using the DMRB model for a range of scenarios.

The results of the power station modelling are shown as contour plots (isopleths) of modelled nitrogen dioxide concentrations superimposed on a map of the area near to the power stations:

Fig. 5: Annual mean nitrogen dioxide concentrations, base case with buildings, run 10c
Fig. 6: Annual mean nitrogen dioxide concentrations, base case complex terrain, run 5c
Fig. 7: 99.8th percentile hourly nitrogen dioxide concentrations, base case with buildings, run 10c
Fig. 8: 99.8th percentile hourly nitrogen dioxide concentrations, base case with complex terrain, run 5c
Fig. 9: Annual mean nitrogen dioxide concentrations, 90 % reduction in emissions with buildings, run 21c
Fig. 10: Annual mean nitrogen dioxide concentrations, 90 % reduction in emissions with complex terrain, run 22c
Fig. 11: 99.8th percentile hourly nitrogen dioxide concentrations, 90% reduction in emissions with complex terrain, run 22c
Fig. 12: Annual mean nitrogen dioxide concentrations, 25 m stacks with buildings, run 40c
Fig. 13: Annual mean nitrogen dioxide concentrations, 25 m stacks with complex terrain, run 35c
Fig. 14: 99.8th percentile hourly nitrogen dioxide concentrations, 25 m stacks with buildings, run 40c

Fig. 15: 99.8th percentile hourly nitrogen dioxide concentrations, 25 m stacks with complex terrain, run 35c

4.1 Baseline

Table 14: Modelled contributions to annual average oxides of nitrogen concentrations at monitoring sites, μg m^{-3}: baseline

	Complex terrain					Buildings				
Met. Data Year	2002	2003	2004	2005	2006	2002	2003	2004	2005	2006
Run no.	1	2	3	4	5	6	7	8	9	10
Rosia rd - GIB1	31	24	20	18	21	21	18	13	11	16
Jumper's - Rosia rd	23	20	24	20	22	177	167	171	143	153
Red Sands Rd	38	30	30	30	32	189	161	143	131	153
South Barracks Rd	10	13	7	5	7	7	9	8	7	7
Picton House - Rosia Prom	45	34	29	29	33	67	54	42	38	51
Upper Withams Entrance	26	27	19	20	21	41	41	41	36	38
Withams Rd	16	16	16	14	15	76	76	78	66	70
Almeda Gardens - Theatre	67	54	62	60	63	121	104	96	87	100
Almead Gardens - Main Access	43	39	45	43	40	90	77	70	64	74
Rock Hotel - Europa Rd	23	17	23	22	21	69	59	53	49	57
Gardiner's Rd	45	40	40	40	36	38	31	24	23	29
Governors Meadow - Rosia Prom	56	45	38	38	44	169	142	115	107	134
Dockyard Rd	70	54	43	44	52	142	115	87	82	108
Woodford Cottages - Europa Rd	9	11	6	3	5	3	4	4	3	3

Table 15: Modelled contributions to 99.8th percentile oxides of nitrogen concentrations at monitoring sites, $\mu g\ m^{-3}$: baseline

	Complex terrain					Buildings				
Met. Data Year	2002	2003	2004	2005	2006	2002	2003	2004	2005	2006
Run no.	1	2	3	4	5	6	7	8	9	10
Rosia rd - GIB1	637	637	608	622	618	324	356	327	285	341
Jumper's - Rosia rd	864	872	1048	826	1173	652	653	653	646	651
Red Sands Rd	900	874	966	918	919	784	781	782	780	784
South Barracks Rd	2123	2280	917	548	939	259	301	283	295	282
Picton House - Rosia Prom	688	628	675	632	639	522	510	510	504	519
Upper Withams Entrance	1960	1962	1419	1696	1992	464	453	454	471	475
Withams Rd	1471	1215	1158	1249	1150	589	589	592	591	589
Almeda Gardens - Theatre	5337	5031	5212	5249	5554	503	500	503	500	502
Almead Gardens - Main Access	4788	4719	5365	4740	4488	409	406	406	405	406
Rock Hotel - Europa Rd	3036	1845	3058	2466	2470	339	333	338	332	336
Gardiner’s Rd	4388	3947	4043	4484	3585	285	277	274	272	279
Governors Meadow - Rosia Prom	1161	1072	1148	1097	1013	1026	1027	1024	1014	1030
Dockyard Rd	1262	1149	1154	1205	1133	958	952	951	950	955
Woodford Cottages - Europa Rd	992	1783	490	321	443	168	230	209	226	201

Table 16: Modelled nitrogen dioxide concentrations at monitoring sites, $\mu g\ m^{-3}$: baseline

Run no	Complex terrain 5c		Buildings 10c	
	Annual mean	99.8 th percentile hourly	Annual mean	99.8 th percentile hourly
Rosia rd - GIB1	30	163	29	129
Jumper's - Rosia rd	29	198	51	174
Red Sands Rd	32	180	53	187
South Barracks Rd	25	163	26	112
Picton House - Rosia Prom	32	167	37	153
Upper Withams Entrance	27	270	33	136
Withams Rd	27	199	38	159
Almeda Gardens - Theatre	33	620	47	157
Almead Gardens - Main Access	31	521	43	145
Rock Hotel - Europa Rd	29	313	40	137
Gardiner’s Rd	31	425	34	125
Governors Meadow - Rosia Prom	34	194	49	208
Dockyard Rd	35	212	42	197
Woodford Cottages - Europa Rd	25	125	25	107

4.2 Scenario #1 - 90% reduction in emissions

Table 17: Modelled nitrogen dioxide concentrations at monitoring sites, $\mu g\ m^{-3}$: 90% reduction in emissions

Run no	Buildings 21c		Complex terrain 22c	
	Annual mean	99.8 th percentile hourly	Annual mean	99.8 th percentile hourly
Rosia rd - GIB1	25	96	25	97
Jumper's - Rosia rd	28	97	25	97
Red Sands Rd	28	99	25	99
South Barracks Rd	24	94	24	106
Picton House - Rosia Prom	26	97	26	97
Upper Withams Entrance	25	94	24	111
Withams Rd	26	94	24	106
Almeda Gardens - Theatre	28	100	26	127
Almead Gardens - Main Access	27	99	25	121
Rock Hotel - Europa Rd	27	98	25	109
Gardiner's Rd	26	96	25	125
Governors Meadow - Rosia Prom	28	98	26	96
Dockyard Rd	26	98	26	97
Woodford Cottages - Europa Rd	24	94	24	101

4.3 Scenario #2 - 25 m stacks

Table 18: Modelled contributions to annual average oxides of nitrogen concentrations at monitoring sites, $\mu g\ m^{-3}$: 25 m stacks

	Complex terrain					Buildings				
Met. Data Year	2002	2003	2004	2005	2006	2002	2003	2004	2005	2006
Run no.	1	2	3	4	5	6	7	8	9	10
Rosia rd - GIB1	8	6	6	5	6	13	11	9	7	10
Jumper's - Rosia rd	1	1	1	1	1	59	56	59	47	50
Red Sands Rd	4	3	3	3	3	78	67	56	51	62
South Barracks Rd	1	1	1	0	0	4	5	4	4	4
Picton House - Rosia Prom	10	7	6	6	7	37	30	23	20	28
Upper Withams Entrance	1	0	1	1	1	23	24	25	21	21
Withams Rd	1	1	1	1	1	40	41	42	34	37
Almeda Gardens - Theatre	4	3	3	3	3	72	62	56	51	58
Almead Gardens - Main Access	5	4	4	4	4	58	50	45	41	47
Rock Hotel - Europa Rd	15	12	14	14	13	48	40	36	33	38
Gardiner's Rd	13	10	11	11	12	28	23	18	17	21
Governors Meadow - Rosia Prom	5	3	3	3	3	61	50	40	37	47
Dockyard Rd	3	2	2	2	2	49	39	30	28	36
Woodford Cottages - Europa Rd	2	3	1	1	1	2	2	2	2	2

Table 19: Modelled contributions to 99.8th percentile oxides of nitrogen concentrations at monitoring sites, µg m^{-3}: 25 m stacks

	Complex terrain					Buildings				
Met. Data Year	2002	2003	2004	2005	2006	2002	2003	2004	2005	2006
Run no.	1	2	3	4	5	6	7	8	9	10
Rosia rd - GIB1	274	268	268	250	279	244	254	231	210	240
Jumper's - Rosia rd	91	66	149	79	82	354	352	353	351	347
Red Sands Rd	250	218	261	237	225	432	431	428	427	431
South Barracks Rd	60	93	88	49	50	140	213	169	199	176
Picton House - Rosia Prom	325	278	298	291	285	332	328	333	319	328
Upper Withams Entrance	52	48	103	55	59	302	300	302	301	301
Withams Rd	53	54	103	50	55	358	358	356	358	357
Almeda Gardens - Theatre	209	207	219	194	212	344	338	338	342	341
Almead Gardens - Main Access	210	204	212	204	211	285	282	281	284	283
Rock Hotel - Europa Rd	2329	1946	2348	2326	1933	250	244	245	247	246
Gardiner's Rd	1414	1382	1434	1421	1830	200	200	198	196	199
Governors Meadow - Rosia Prom	293	239	258	271	256	556	538	538	533	533
Dockyard Rd	244	142	169	187	172	558	543	538	535	537
Woodford Cottages - Europa Rd	376	397	140	89	169	110	168	147	149	147

Table 20: Modelled nitrogen dioxide concentrations at monitoring sites, µg m^{-3}: 25 m stack height

Run no	Complex terrain 5c		Buildings 10c	
	Annual mean	99.8 th percentile hourly	Annual mean	99.8 th percentile hourly
Rosia rd - GIB1	26	118	28	113
Jumper's - Rosia rd	24	98	34	119
Red Sands Rd	25	111	38	139
South Barracks Rd	24	96	25	103
Picton House - Rosia Prom	26	120	32	127
Upper Withams Entrance	24	96	29	116
Withams Rd	24	97	32	124
Almeda Gardens - Theatre	25	107	39	136
Almead Gardens - Main Access	26	108	38	132
Rock Hotel - Europa Rd	27	263	36	127
Gardiner's Rd	27	237	32	117
Governors Meadow - Rosia Prom	25	114	35	148
Dockyard Rd	25	107	31	144
Woodford Cottages - Europa Rd	24	111	24	100

4.4 Traffic

Table 20: DMRB predictions of kerbside nitrogen dioxide concentrations

Case	Effective annual average daily traffic flow	Effective speed, kph	Nitrogen dioxide concentration, μg m^{-3} [3]
No hills, no street canyon effects	10000	20	27.6
No hills, with street canyon effects	10000	20	31.1
With hills, no street canyon effects	50000	100	32.3
With hills, with street canyon effects	50000	100	40.5

[3] Note this is the predicted nitrogen dioxide concentration as a result of road traffic 5m from the centreline of the road. This includes a background contribution of 24 μg m^{-3} NO_2 (the Bleak House 2006 annual average concentration).

Fig. 5: Annual mean nitrogen dioxide concentrations, base case with buildings, run 10c

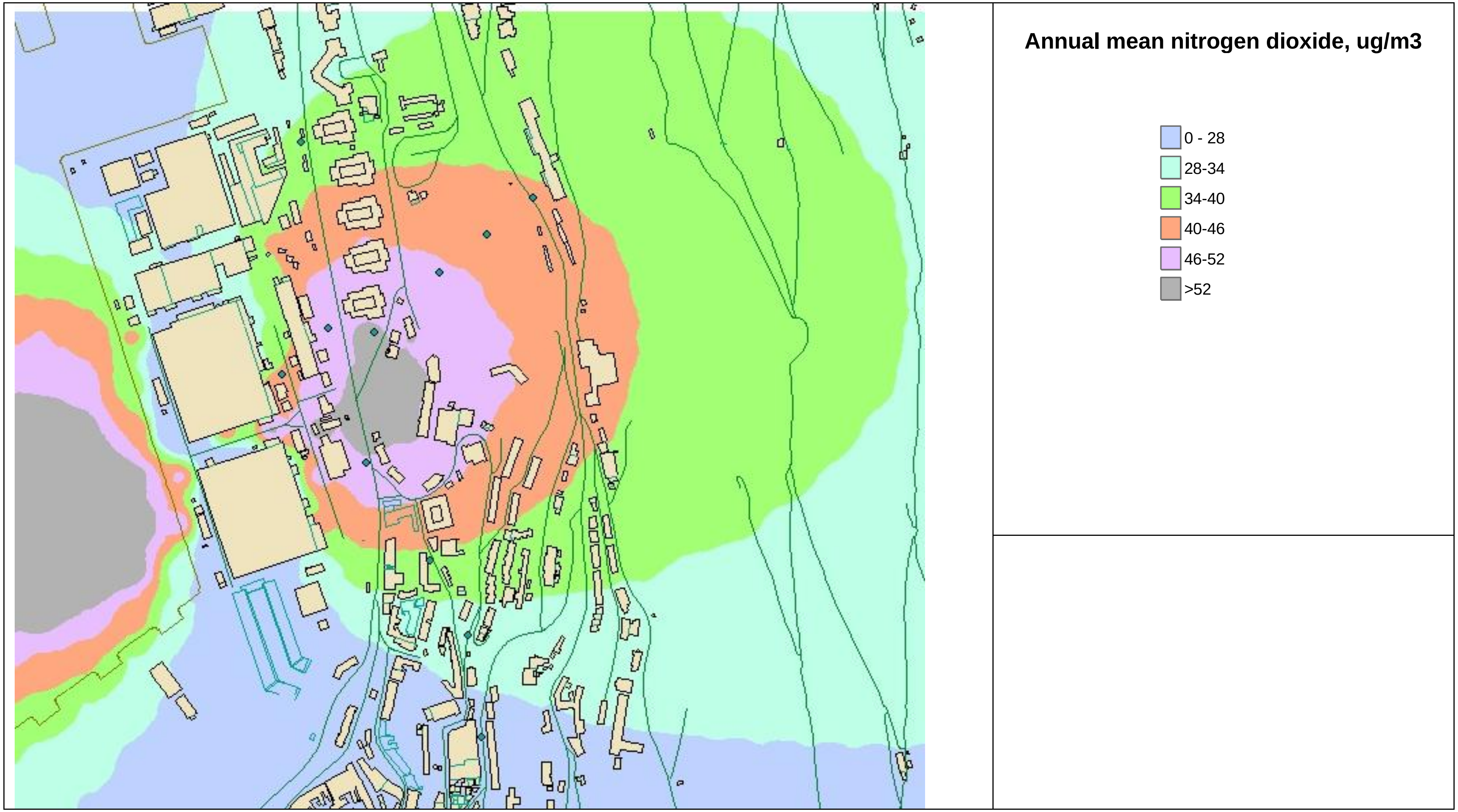


Fig. 6: Annual mean nitrogen dioxide concentrations, base case complex terrain, run 5c

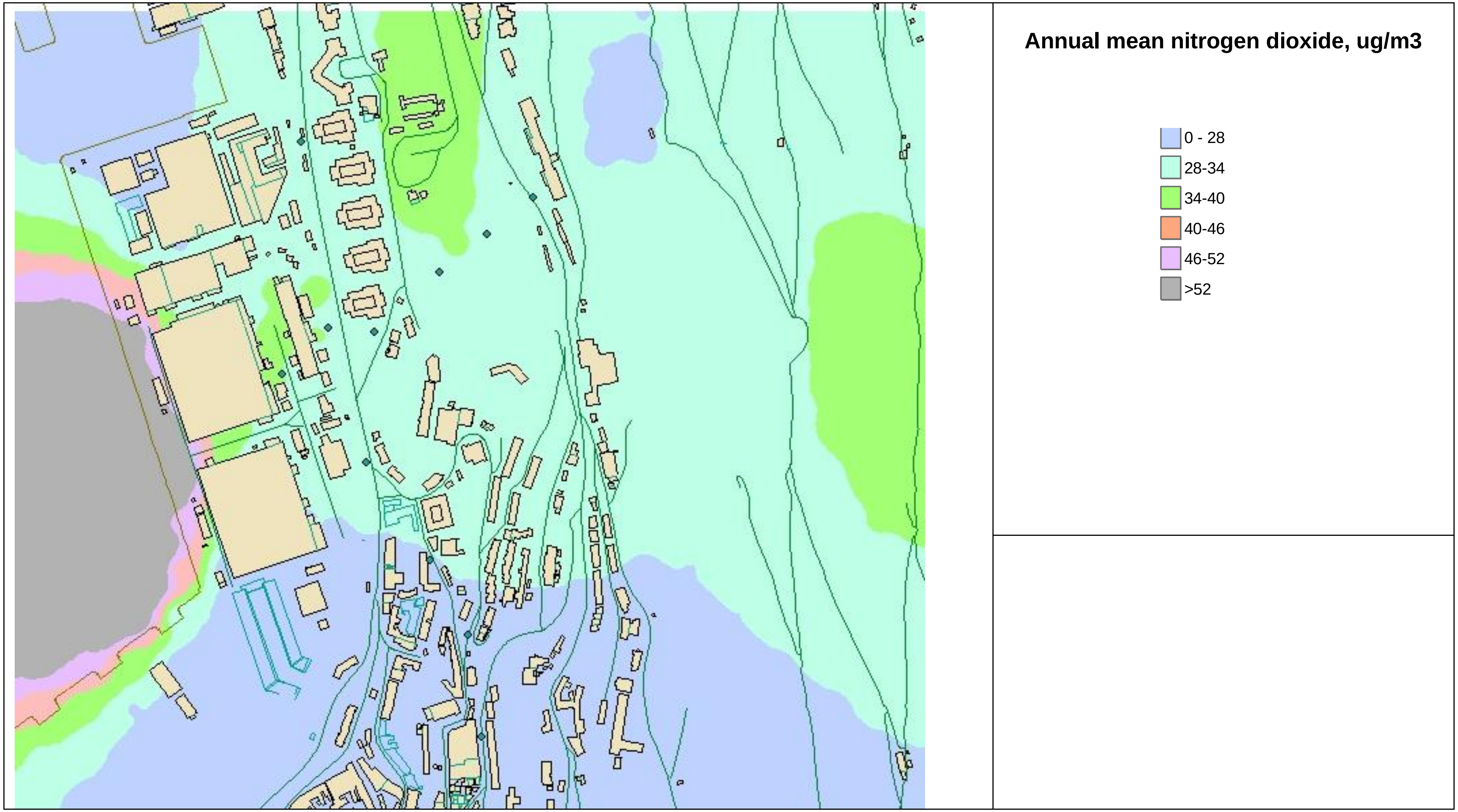


Fig. 7: 99.8th percentile hourly nitrogen dioxide concentrations, base case with buildings, run 10c

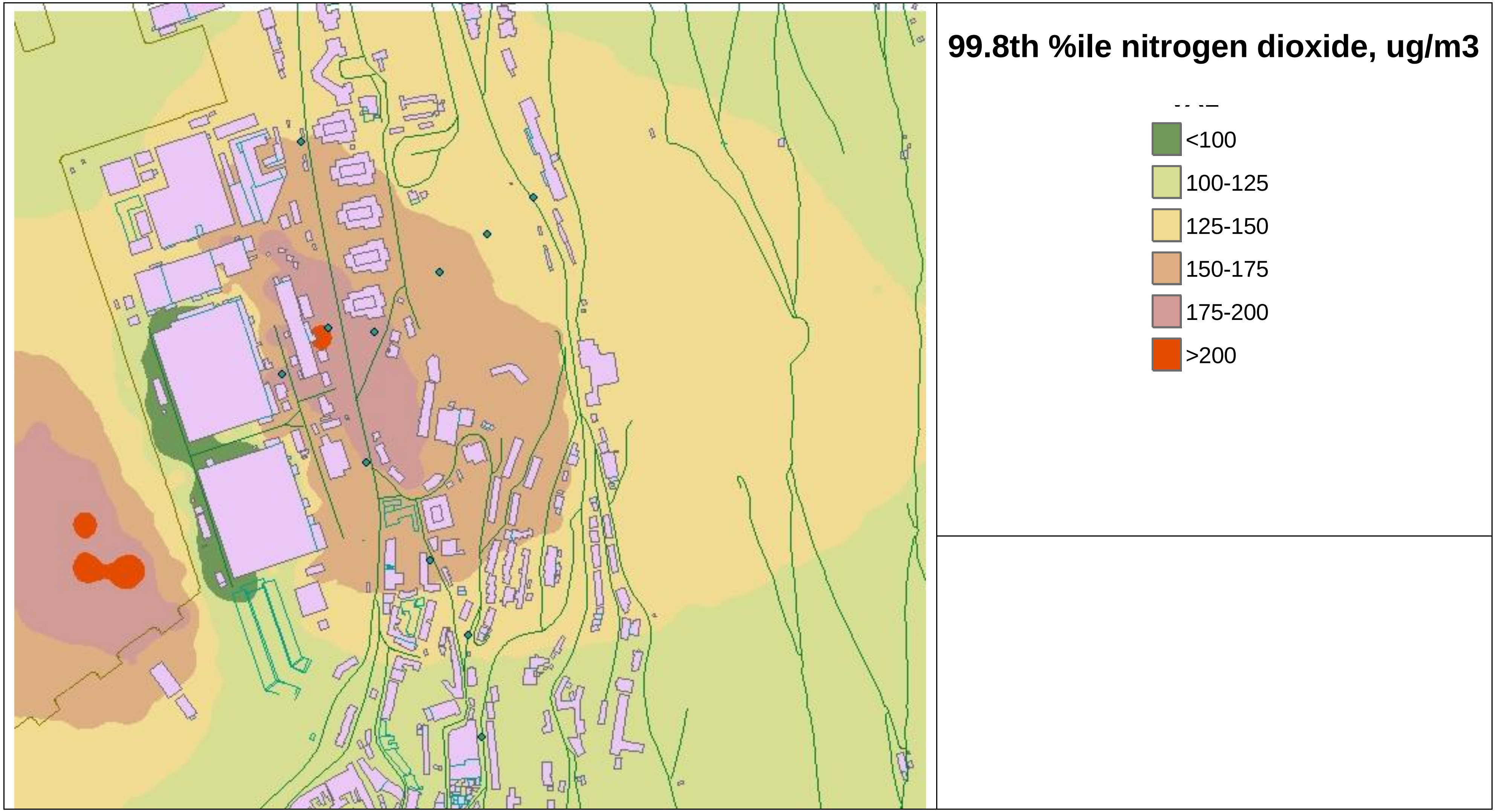


Fig. 8: 99.8th percentile hourly nitrogen dioxide concentrations, base case with complex terrain, run 5c

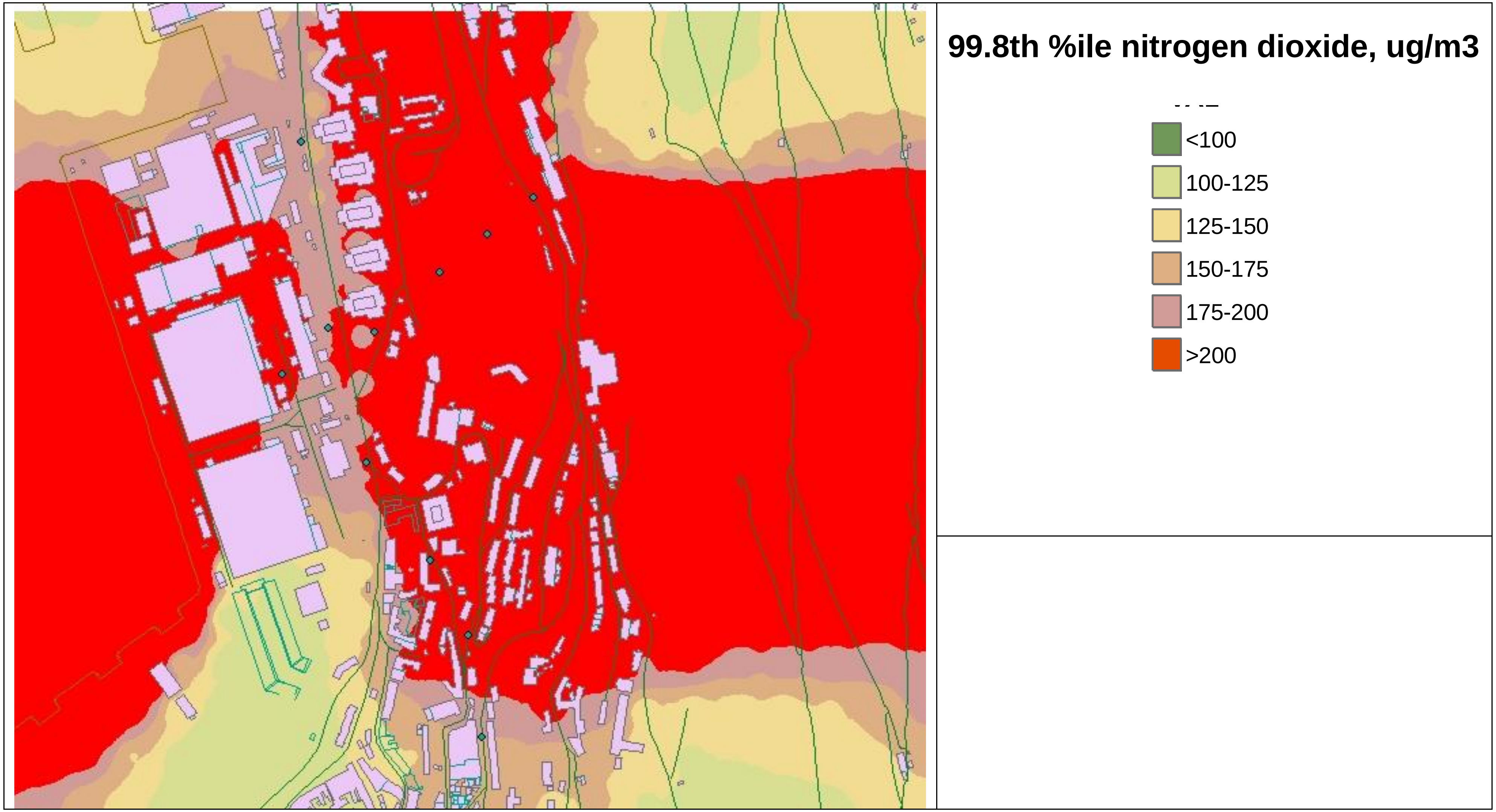


Fig. 9: Annual mean nitrogen dioxide concentrations, 90 % reduction in emissions with buildings, run 21c

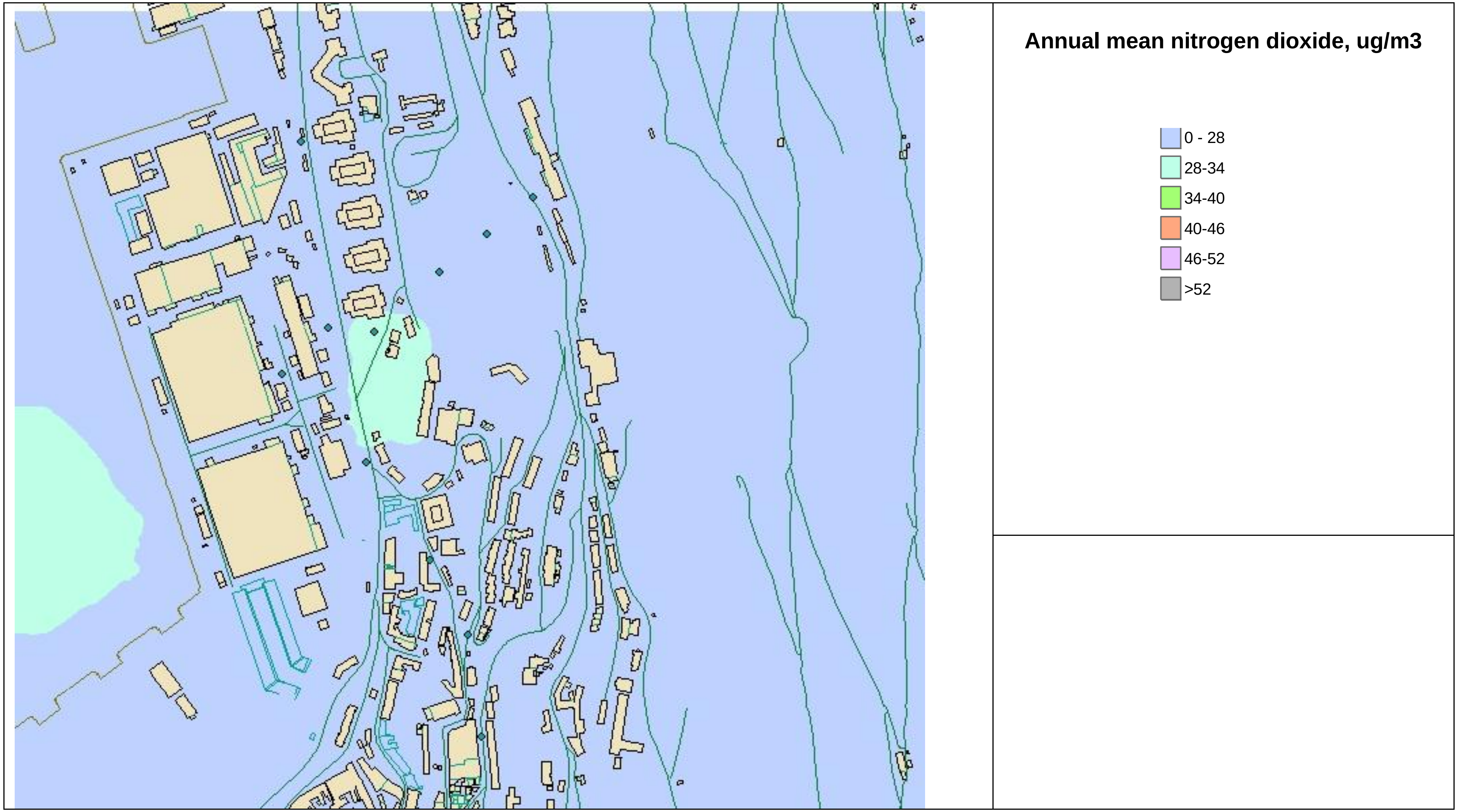


Fig. 10: Annual mean nitrogen dioxide concentrations, 90 % reduction in emissions with complex terrain, run 22c

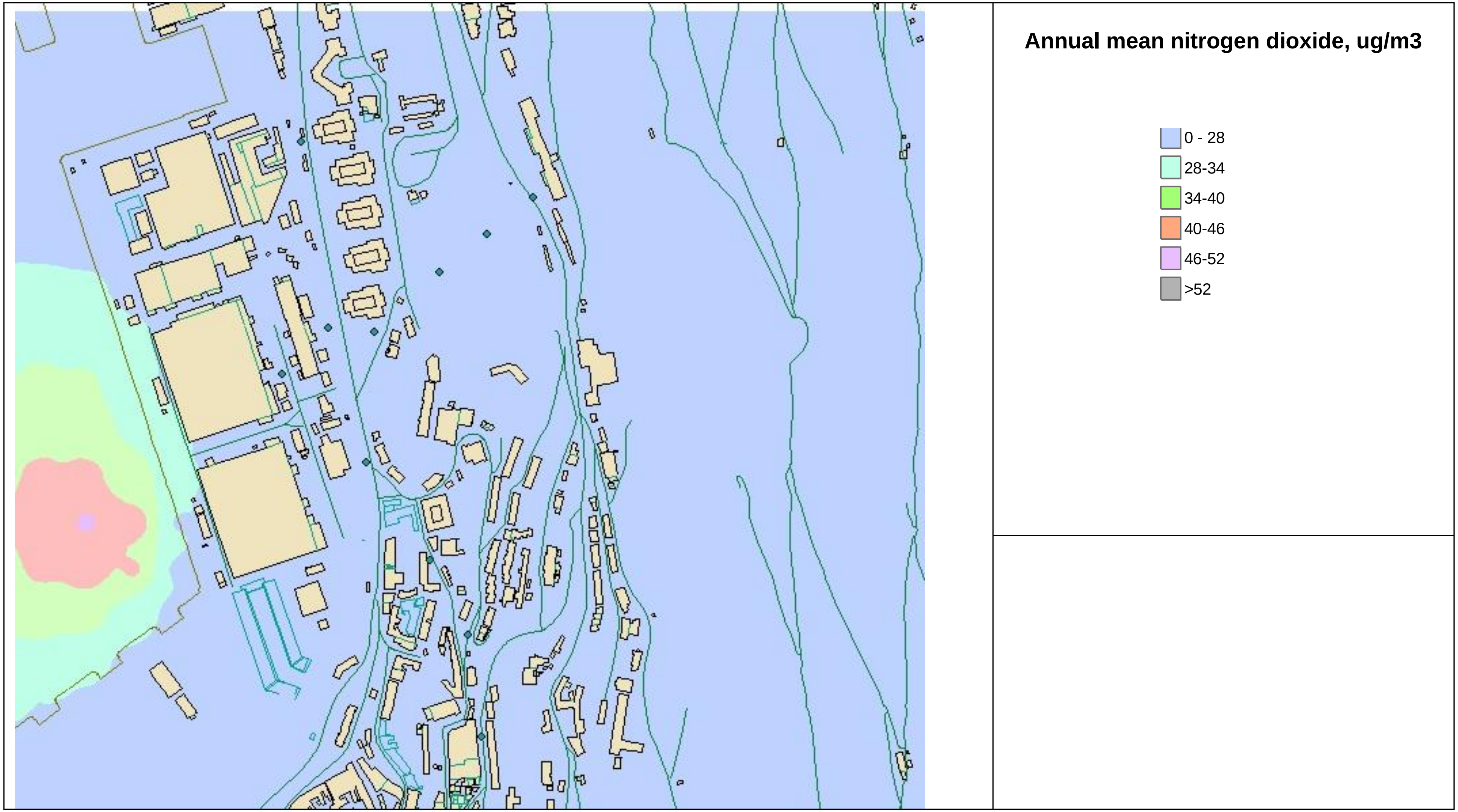


Fig. 11: 99.8th percentile hourly nitrogen dioxide concentrations, 90% reduction in emissions with complex terrain, run 22c

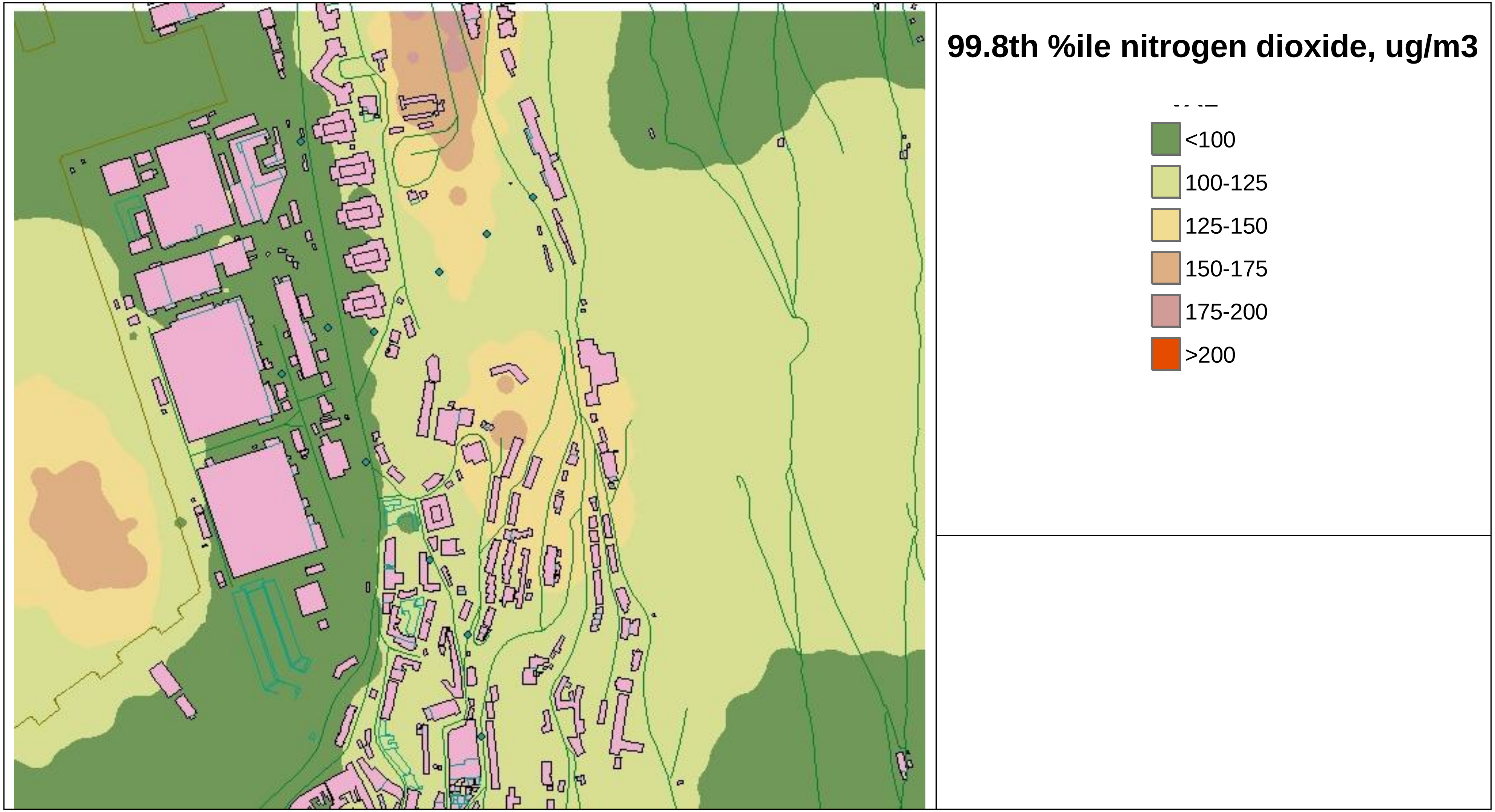


Fig. 12: Annual mean nitrogen dioxide concentrations, 25 m stacks with buildings, run 40c

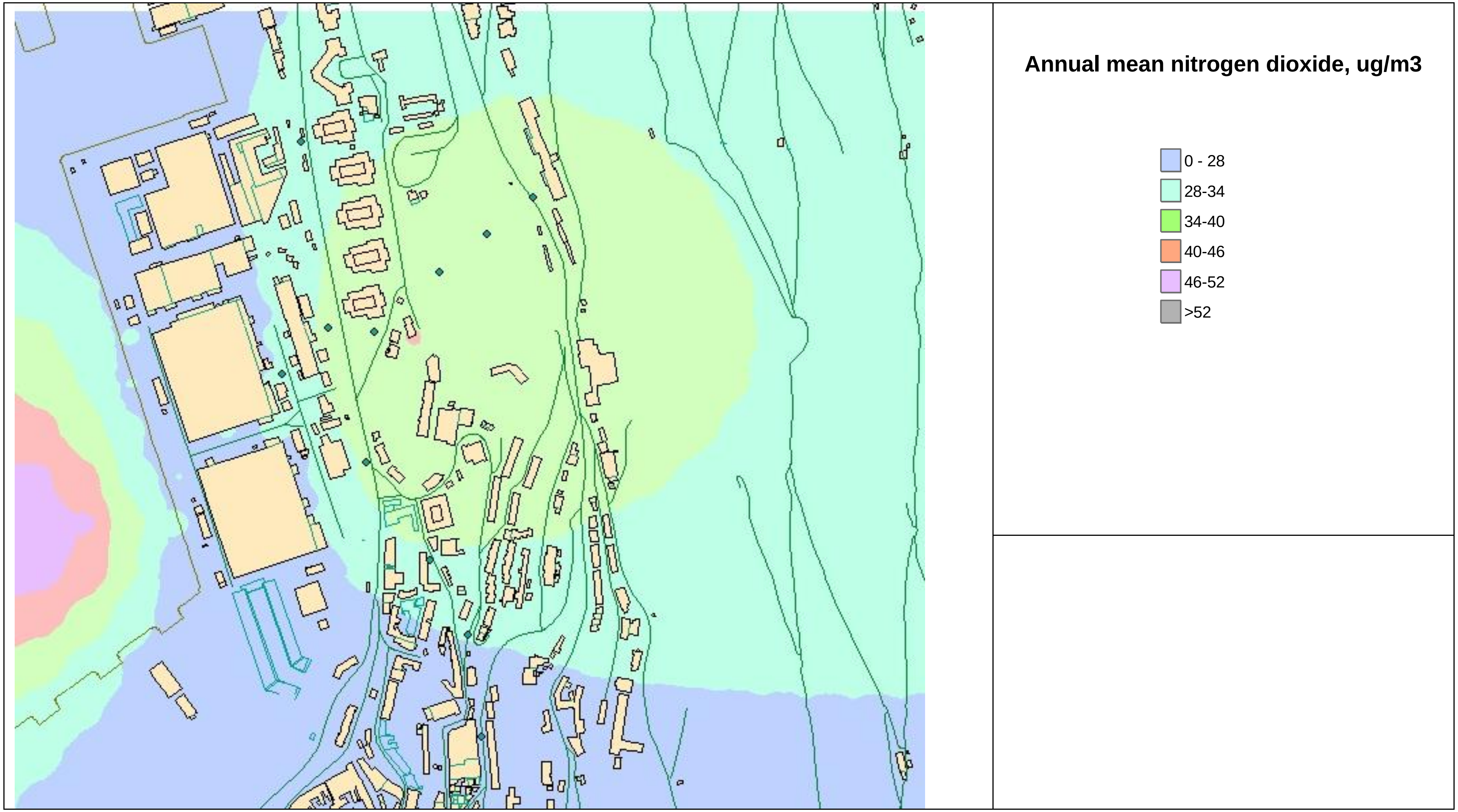


Fig. 13: Annual mean nitrogen dioxide concentrations, 25 m stacks with complex terrain, run 35c

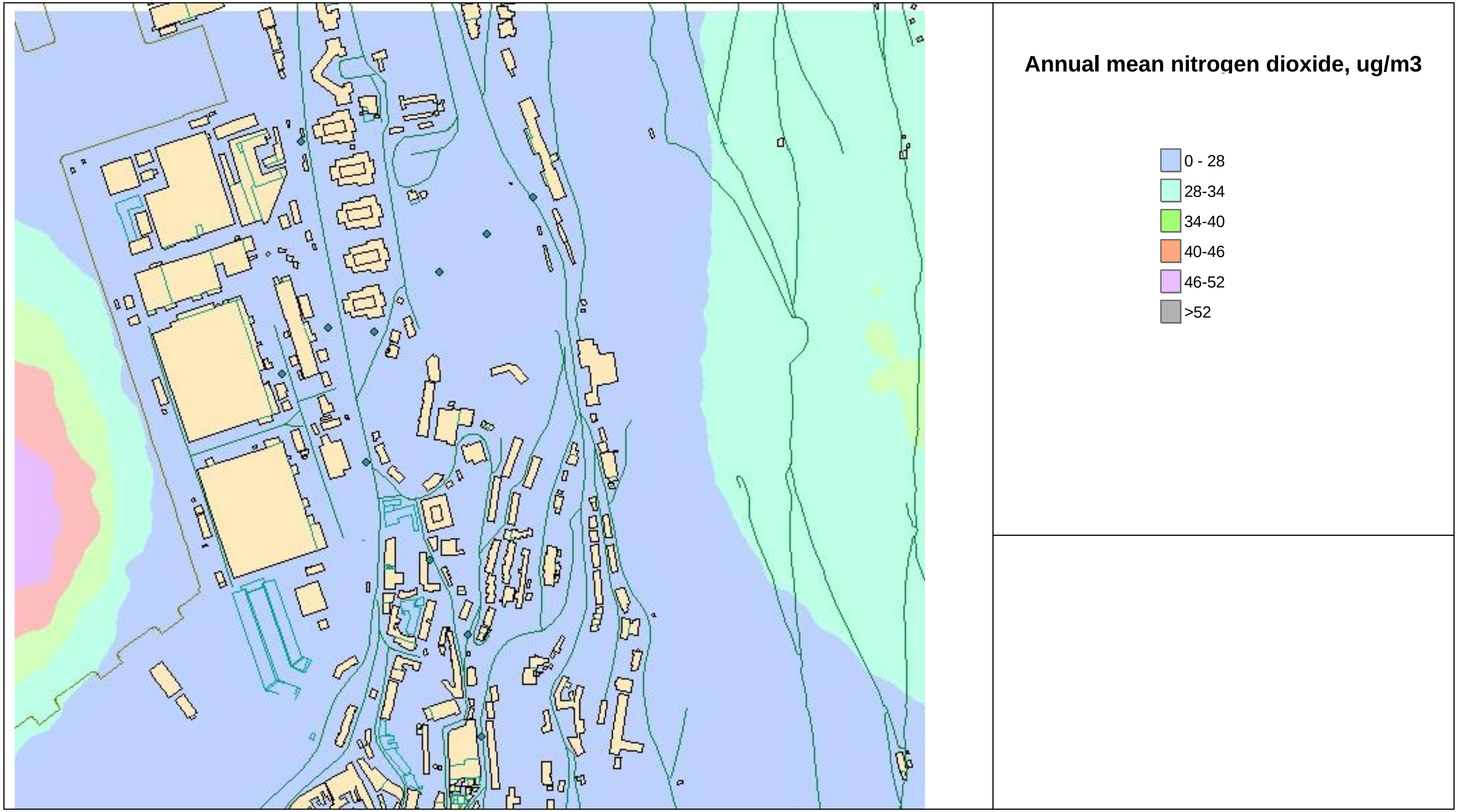


Fig. 14: 99.8th percentile hourly nitrogen dioxide concentrations, 25 m stacks with buildings, run 40c

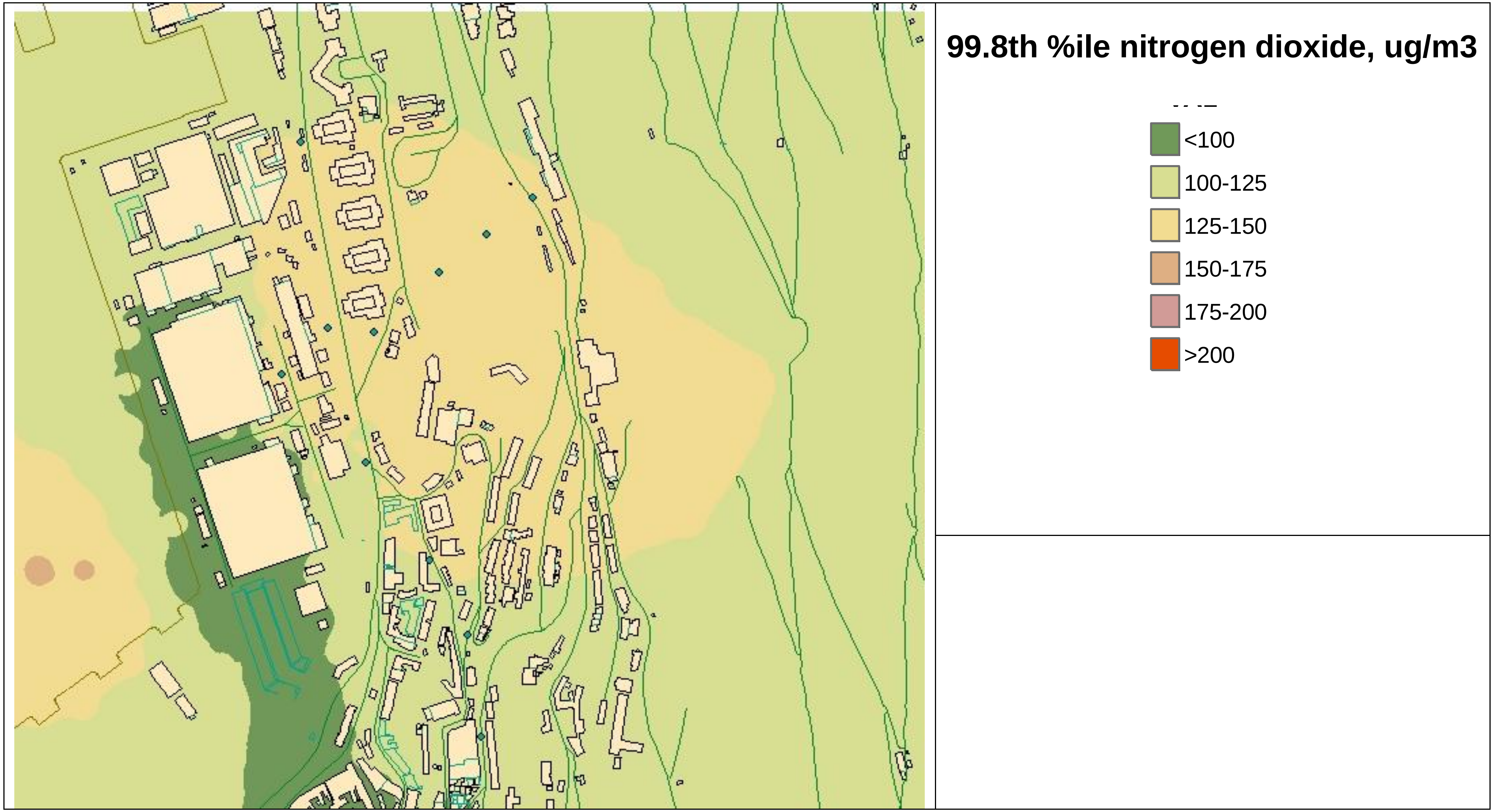
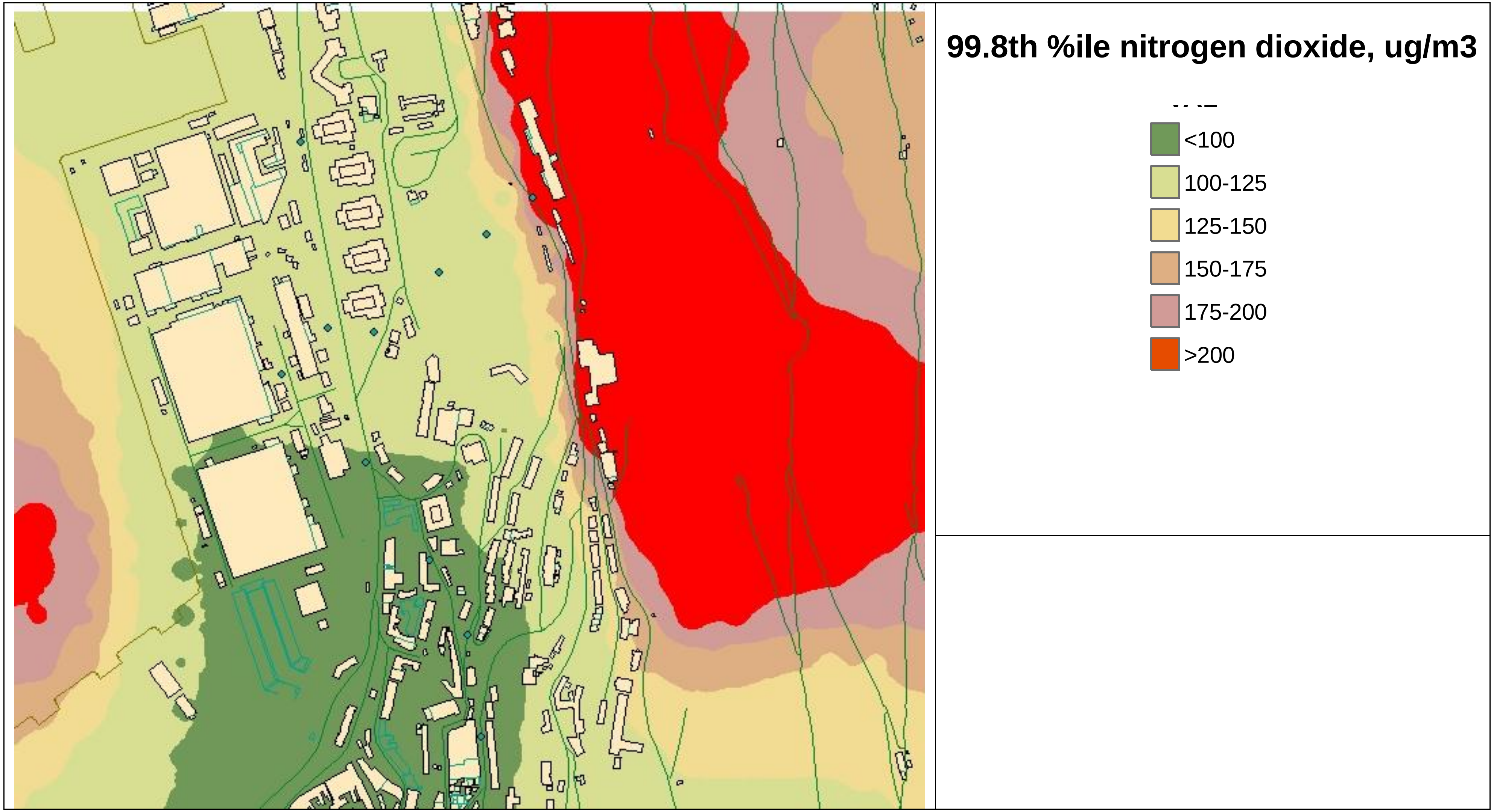


Fig. 15: 99.8th percentile hourly nitrogen dioxide concentrations, 25 m stacks with complex terrain, run 35c



5 Discussion

5.1 Baseline Modelling

Fig. 5 shows the predicted annual average nitrogen dioxide concentration in the vicinity of the power generation facilities, taking the effect of the buildings but ignoring the effects of Gibraltar's complex terrain. The predicted concentrations are likely to represent the power generation impact in a 'optimum location for the plant' (i.e. on flat terrain). High ground level concentrations, in excess of the limit value are predicted close to the plant in the area of Jumpers. The modelled concentration at the Jumpers diffusion tube site of 51 $\mu g\ m^{-3}$ is less than the observed concentration of 57 $\mu g\ m^{-3}$, which is at a roadside site potentially influenced by road vehicles not taken into account in the model. The modelled concentrations at South Barracks Road and Rosia Road (26 $\mu g\ m^{-3}$ and 29 $\mu g\ m^{-3}$), which are further from the power generation facilities, are much lower than the measured concentrations (51 $\mu g\ m^{-3}$ and 42 $\mu g\ m^{-3}$). It is likely that the nitrogen dioxide concentrations at these sites are dominated by road vehicle emissions.

Fig. 6 shows the annual average nitrogen dioxide concentrations predicted by the ADMS model taking the complex terrain into account, but ignoring the buildings. The predicted concentrations in the Jumpers area are well below the limit value of 40 $\mu g\ m^{-3}$ and much lower than the measured concentration at the location This underprediction is a limitation of the ADMS model. Under a wide range of meteorological conditions, a zone of recirculating air flow is predicted in the Jumpers area. The ADMS model does not allow pollutant emitted outside the recirculating zone to enter the zone, but rather directs the modelled air flow above the recirculating zone. Thus for these conditions low ground level concentrations are predicted. The nature of Gibraltar's complex terrain means that recirculating flow occurs for a significant number of hours every year, resulting in underprediction of actual concentrations. This is an artefact of the model, rather than a true representation of the reality.

Fig. 7 shows the predicted 99.8th percentile of hourly nitrogen dioxide concentrations taking the effect of the buildings but ignoring the effects of Gibraltar's complex terrain. The predicted concentrations are less than the hourly limit value of 200 $\mu g\ m^{-3}$ except in small areas within the dockyard or in the dock itself.

Fig. 8 shows the predicted 99.8th percentile of hourly nitrogen dioxide concentrations taking the complex terrain into account, but ignoring the buildings. The model predicts occasional plume grounding events leading to exceedence of the limit value over a wide area. The model predicts a 99.8 th percentile concentration of 163 $\mu g\ m^{-3}$ at the Rosia Road site which is greater than the observed value of 123 $\mu g\ m^{-3}$, but not excessively so. The high hourly concentrations arise from occasional plume grounding, the result of meteorological conditions that prevent the plume rising over the rock. The model's treatment of recirculating flows leads to an effective increase in the plume height thus it is likely that the grounding events predicted are higher up the rock than actually occurs in practice.

It was not appropriate to include traffic emissions in the ADMS model because the roads and receptors are located in a zone of recirculating air flow for a significant number of hours each year. Simple modelling of the traffic emissions using the DMRB model indicates that, in the absence of the complex terrain, steep hills and street canyon effects, the expected traffic flows of around 10,000 vehicles per day (which may well be a significant over estimate for this road) would not result in roadside concentrations much above background levels. The sensitivity studies suggest that roadside concentrations could approach those observed at Rosia Road and South Barracks Road if the effects of increased emissions from vehicles climbing up hill and the effects of street canyons are taken into account. However, it is not possible to draw firm conclusions from the modelling of traffic emissions.

Model runs were carried out with 5 years of meteorological data. Examination of Tables 14, 15, 18 and 19 indicate that while there are significant year-to-year variations in predicted concentrations at receptors, the overall pattern of predicted concentrations remains broadly the same. The variation between years is generally less than the variation between receptors.

5.2 Scenario Modelling

5.2.1 Scenario #1 – 90% Reduction in Emissions

90 % reduction in emissions from the power generation plant, potentially achievable by employing new engines following best available technology would be sufficient to reduce predicted concentrations to below nitrogen dioxide limit values.

Predicted annual mean concentrations, shown in Fig. 9 for flat terrain with buildings are less than the annual mean limit value of 40 $\mu g\ m^{-3}$. Similarly, Fig. 10 for the case with complex terrain shows that the limit value is met at all relevant locations, although the predicted concentration exceeds 40 $\mu g\ m^{-3}$ in the dock itself.

Fig. 11 shows that the predicted 99.8th percentile of hourly concentrations for complex terrain is less than the limit value of 200 $\mu g\ m^{-3}$ at all receptor locations although the limit value is approached where the hill rises steeply between Europa Road and Gardiners Road. The predicted 99.8th percentile of hourly concentrations for the flat terrain with buildings case was less than 100 $\mu g\ m^{-3}$ at all locations.

5.2.2 Scenario #2 – 25m stacks to aid pollutant dispersion

The addition of 25m stacks to aid pollutant dispersion from the power generation plant would largely be sufficient to reduce predicted concentrations to below nitrogen dioxide annual limit values BUT there may remain a risk of breaching the hourly limit value.

For flat terrain, increasing the stack heights to 25 m would be almost sufficient to reduce predicted concentrations to below nitrogen dioxide limit values. Fig. 12 and 13 shows that the predicted annual mean concentration is less than 40 $\mu g\ m^{-3}$ at all locations except within the dock and a small area below Almeda Gardens (Fig 12: flat terrain with buildings).

Fig. 14 shows that the predicted 99.8th percentile of hourly mean concentrations, for flat terrain with buildings, are also less than the limit value of 200 $\mu g\ m^{-3}$. Fig. 15, for the complex terrain case, shows that there is a substantial risk of plume grounding on the hillside, sufficient for concentrations to exceed the hourly limit value, despite the increased stack heights.

6 Conclusions

The nitrogen dioxide monitoring programme for 2005 and 2006 has highlighted a significant area of Gibraltar that is exposed to annual average concentrations that are above the EU limit value of 40 $\mu g\ m^{-3}$. Measurements suggest that several areas are exposed to concentrations in excess of the limit value + margin of tolerance (a trigger for action prior to 2010).

In order to inform our understanding of the elevated measured concentrations, a modelling study has been undertaken to investigate the MOD and OESCO Ltd power generation facilities contribution to the measured concentrations.

The complex terrain in the region of the OESCO Ltd and MOD power stations on Gibraltar presents a serious challenge for dispersion modelling. The slopes of the rock are steeper than the usual range of application of the ADMS3.3 dispersion model. The flow model predicts that a zone of recirculating air flow develops in the area of Rosia Road and this limits the dispersion model's capability to predict concentrations in the area during these conditions. Model runs were therefore carried out with and without the effects of complex terrain.

The model predicted that, even in the absence of complex terrain effects, the power station emissions result in concentrations of nitrogen dioxide greater than the annual average limit value of 40 $\mu g\ m^{-3}$ in the Jumper's area. Model runs that took complex terrain effects into account indicated that plume grounding would lead to hourly average concentrations greater than the limit value of 200 $\mu g\ m^{-3}$ on the slopes of the rock.

The diesel generators used in the power stations are relatively old. Modern diesel engines that follow best available techniques emit approximately one tenth of the oxides of nitrogen emissions. The model results indicate that a 90% reduction in oxides of nitrogen emissions would be just sufficient to meet the annual average limit value and also to meet the hourly limit value.

Dispersion of pollutants from the power stations could be improved by increasing the height of the discharge stacks. The model results show that increasing the stack height to 25 m would be sufficient to meet the annual mean and hourly mean limit values in the absence of complex terrain effects. However, the model runs with complex terrain indicate that plume grounding may continue to lead to hourly average concentrations greater than the limit value of 200 $\mu g\ m^{-3}$ on the slopes of the rock. Consideration should be given to the installation of a single continuous monitor to better elucidate the actual impact of plume grounding on short term nitrogen dioxide concentrations in the area affected by the power generation facility emissions. The current diffusion tube network cannot provide information on short term concentrations.

Road traffic emissions from Rosia Road also contribute to pollutant concentrations. Simple model results indicate that in the absence of complex terrain effects and the increased emissions from vehicles travelling up hill these emissions would not increase roadside concentrations much above background levels. The sensitivity studies suggest that roadside concentrations could approach those observed at Rosia Road and South Barracks Road if the effects of increased emissions from vehicles climbing up hill and the effects of street canyons are taken into account.