CUADRILLA BALCOMBE LIMITED

APPENDIX A

GEOLOGICAL SUMMARY, LOG

AND

CROSS SECTION

Cuadrilla Balcombe Limited
November 2013

Lower Stumble Hydrocarbon Exploration Site.
Planning Application
Prepared by Phil Mason.

Cuadrilla Resources Limited
Cuadrilla House
Stowe Court
Stowe Street
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Cuadrilla

Geological Summary of the Lower Stumble Prospect

The Lower Stumble prospect is located on an east-west tending anticlinal structure of Alpine origin in the centre of the Weald Basin, southeast of Crawley and 5km northwest of Hayward's Heath near the village of Balcombe in West Sussex.

The anticline is one of a number of small scale structures in the central Weald and has a length of about 4km and wavelength of 2km. The anticline lies to the north, on the down thrown side of a major E-W striking fault (Borde Hill Fault) which forms the northern boundary of the Cuckfield Horst. There are a number of smaller faults mapped at surface but these converge with the Borde Hill Fault at depth such that the structure at deeper structural levels is relatively simple

Balcombe-2 is located at the same place as the Balcombe-1 exploration well drilled by Conoco in 1986. The original objectives were the Portland sandstone, Ashdown Sands and Kimmeridge Clays. A number of oil and gas shows were recorded in the exploration well but none proved to be economic at the time.

The target formation for the Balcombe-2z exploration well is the Middle Kimmeridge Micrite at approximately 2500 ft below the surface. Cuadrilla drilled, cored, and logged the middle Kimmeridge Micrite in the Balcombe 2 vertical exploration well. Because the initial core and log results from Balcombe 2 proved promising, the drilling of Balcombe 2z, a horizontal exploration well within the Micrite, was executed. Hydrocarbon shows and good hole conditions were encountered within the horizontal drilling of the Micrite. The horizontal drilling stayed solely within the Micrite formation and no significant faults or structures were encountered. A simplified geological log and cross section of the Balcombe 2z borehole can be found at Figure AO1, Appendix A.

GEOLOGICAL LOG & LATERAL CROSS SECTION

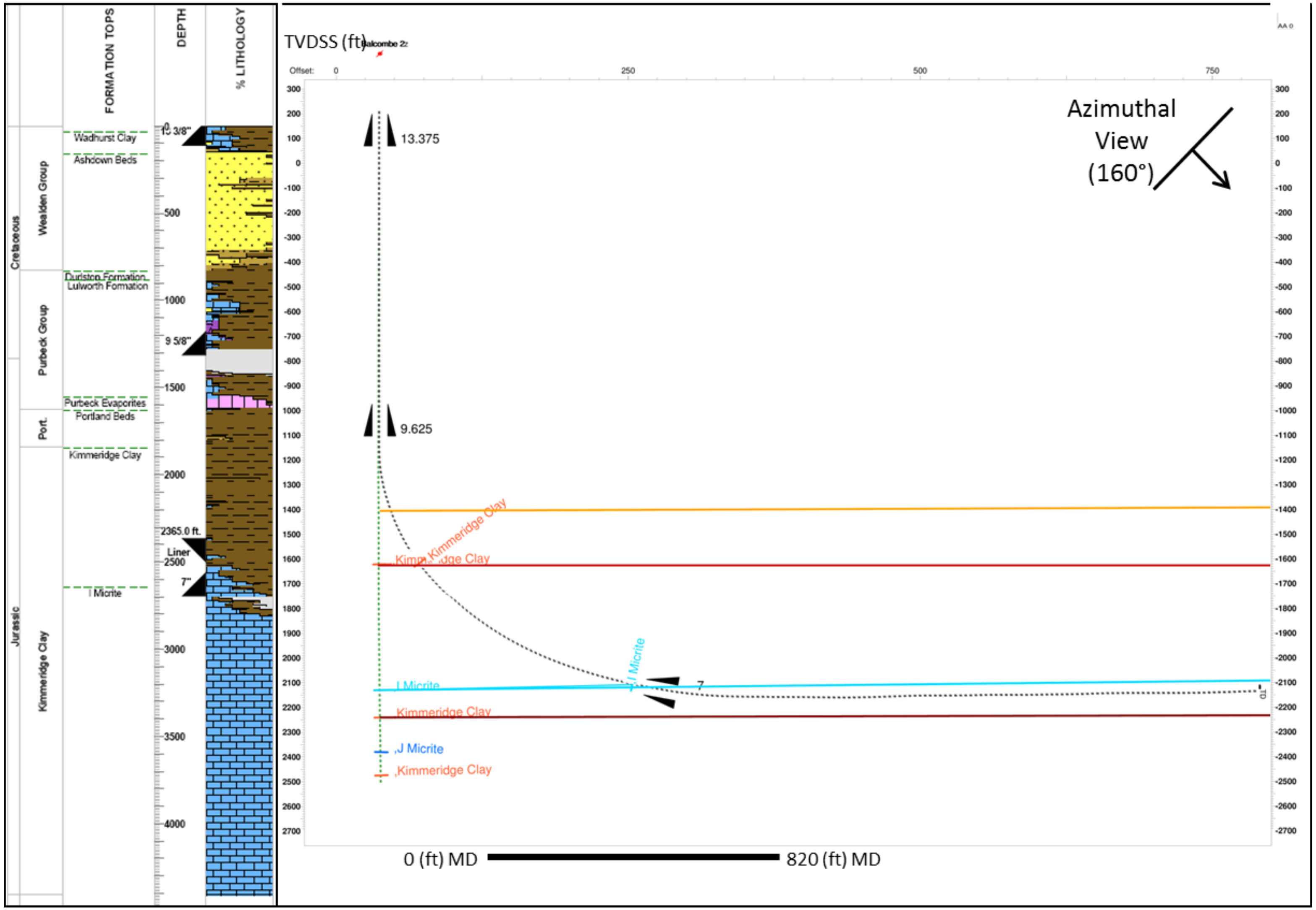

FIGURE A01

CUADRILLA BALCOMBE LIMITED

APPENDIX B

TESTING OPERATIONS

AND

TRANSPORT LOADS

Cuadrilla Balcombe Limited
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BALCOMBE – 2Z EXPLORATION WELL TEST

Well: Balcombe – 2z

Type of Test: Constant pressure drawdown-build up test

Test Duration: The well flow test will be carried out until stable flow conditions are reached, estimated to require approximately 7 days of flow (after initial well clean up). This is followed by a well shut-in period, for which pressure gauges installed in the well will be read after 3 times the duration of the flow test (approximately 3 – 5 weeks) to evaluate whether further shut-in is needed (no more than 60 days of shut-in in total). This makes for a total test duration of between 9 and 16 weeks, including the shut-in period during which pressure gauges are left in the well.

Pre-Test Operations:

(1) Mobilize and rig up well test equipment comprising (multi-phase test separator, slickline unit service rig and associated pumps and tanks, coiled tubing and nitrogen pumping equipment, oil and water stock tanks, and equipment to handle and pump 9.9% hydrochloric acid/90.1% water solution (20 cu. m)

(2) Rig up the service rig and coiled tubing unit. Conduct completion operations as required and run the coiled tubing into the end (toe) of the horizontal well section (lateral) .

(3) Conduct a diluted acid wash along the length of the lateral using approximately 20 cubic meters of HCl (9.9%)

(4) Circulate spent diluted acid out of well, and into disposal tank at surface.

(5) Continue to clean the well bore with coiled tubing and nitrogen until the well starts to produce oil to the stock tank at a rate that can sustain a well test. Remove the coiled tubing from the well.

(6) Install the pressure gauges in the well using slickline.

(7) If the well will not flow naturally, artificially lift the well for the flow test: the option for best achieving flow will be decided based on initial clean-up results, and available options include swabbing with wireline or pumping with a rod pump. “Swabbing” uses rubber cup seals lowered on a steel cable into the tubing to raise and remove fluid from the well in order to reduce hydrostatic pressure. Rod pumping involves installing a pump into the well that is then driven via a rod string by an electric-powered pump jack mounted immediately adjacent to the well at surface.

(8) Shut in the well and for the pressure build-up.

Additional operations to the above may include electric logging (either tubing-conveyed or wireline-conveyed with a well tractor), comprising both openhole logs and cement evaluation logs for the 7" casing, and modifications to the installed completion to accommodate requirements of the well test and suspension. Well perforating and subsequent cementing may also be required. Preparatory and plug and abandonment or well suspension operations would be expected to take between 4 and 8 weeks, in addition to the well testing operations. All in-hole (subsurface) operations are subject to unforeseen delays and mechanical issues which may require remedial steps to be taken; hence the time span of such operations is only **intended to be** indicative.

Exploration Well Test Procedure:

(1) Following preparatory operations, open the well and commence artificial lifting, directing the flow through to the well test separator.

(2) Measure oil, water and gas at regular intervals. Oil and water will be placed in separate tanks for measurement, and the measurement of the oil tank must also determine the small amounts of water that may accumulate below the oil. Oil will then be taken to a refinery facility, and waste water will be taken to a licensed waste facility. Natural gas flow rates will be measured through a digital flow meter at the separator. After measurement the natural gas will be burned at the flare stack, except during the very early stages of the well clean-up when the flow stream at the flare stack is predominantly non-combustible CO_2 gas or nitrogen gas.

(3) Collect oil, water and gas samples every 12 hours at the separator.

(4) Continue producing the well until stable flow conditions are reached after about 7 days as needed to establish a reliable production rate.

(5) When stable flow conditions are achieved, shut in the well to start the pressure build-up test.

   (i) Continue with the pressure build up test for a period at least 3 times longer than the duration of the flow period. At that point retrieve the downhole gauges to analyse the data collected up to that point in time. If further build up is required, rerun the gauges into the hole and shut-in up to 60 additional days (as needed)

   (ii) At the end of the test, retrieve the pressure gauges and download the memory pressure gauges to obtain the flowing and shut-in bottom hole pressures.

(6) Conduct additional well operations to secure the well and evaluate the test results. The further options for the well will then depend on the results.

LOWER STUMBLE TESTING OPERATION VEHICLE MOVEMENTS 115 DAY PERIOD

ACTIVITY	NUMBER OF DAYS	DAILY RANGE		TOTALS	AVERAGE PER DAY
Mobilization/ Dilute Acid Wash	7	HGV	2-17	54	8
		Car/Van	12-22	116	17
Flow Test	14	HGV	2-8	69	5
		Car/Van	16-22	240	17
Pressure Monitoring/ Shut In	62	HGV	0-4	10	1
		Car/Van	12-18	540	9
Sealing Well (Plugging & Abandoning)	27	HGV	0-11	35	6
		Car/Van	18-18	108	18
Demobilization/ Resstore Site	4	HGV	5-16	42	11
		Car/Van	6-18	48	12

The number of days to complete these operations are estimates based on typical operations and do not account for unforeseen delays.

CUADRILLA BALCOMBE LIMITED

APPENDIX D

NOISE IMPACT APPRAISAL

Cuadrilla Balcombe Limited
November 2013

Lower Stumble Hydrocarbon Exploration Site.
Planning Application
Prepared by Phil Mason.

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Noise Impact Appraisal
Testing of Balcombe-2z Oil Well
Lower Stumble Exploration Site

Report ref.

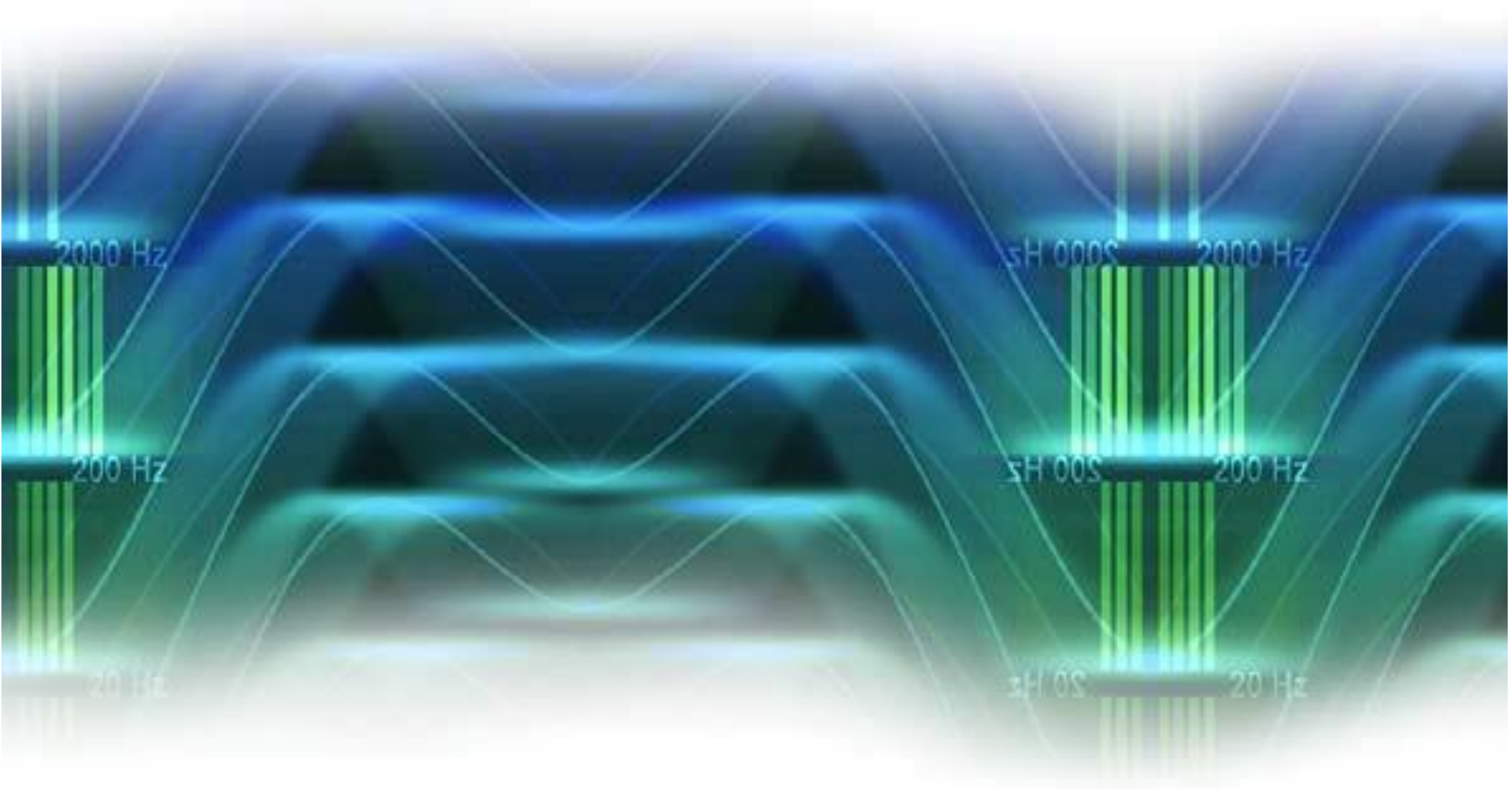
PJ3171/13181

Date

September 2013

Issued to

Cuadrilla Resources Limited



Issued by

Peter Jackson MSc MIOA
Principal Consultant

Spectrum
ACOUSTIC CONSULTANTS

SECTION	TITLE	PAGE

1. INTRODUCTION

Cuadrilla Resources Limited is planning to complete testing operations at their Balcombe–2z oil well, located at the Lower Stumble exploration site, in Balcombe West Sussex.

Testing (in outline terms) would comprise the following operations:

- Pre-test operations: Involving mobilisation and operation of the work-over (service) rig, to tube, clean out and prepare the borehole.
- Well test operations Involving opening the well and use of a bean pump (nodding donkey pump) to extract and test the flow of oil, water and gas

In terms of plant and equipment requirements, testing operations are significantly less intensive than preceding drilling operations and consequently the expectation would be that such testing operations, would comply with the same noise limits as imposed on the drilling operations at the well site, as previously consented by the planning authority.

To provide additional information to inform the planning application for the testing operations this report provides an appraisal of the potential noise impacts. A quantitative prediction is provided, based on typical noise emission data for the equipment to be used during both pre-test and well test operations. Target noise limits are established, based on relevant standards and guidelines and an assessment is made as to whether or not such targets would be met.

2. ASSESSMENT METHODOLOGY

2.1 NOISE FROM MINERALS EXTRACTION OPERATIONS

The National Planning Policy Framework (NPPF) 2012 provides guidance to Local Planning Authorities, with respect to determining planning applications covering minerals extraction. The noise limits advised in technical guidance notes 30 and 31 of NPPF may be summarised as follows

First aim: Background noise level (L_{A90}) + 10dB(A), for all periods.

However, in the cases where this noise limit restriction imposes an unreasonable burden on operations, the following limits to be applied:

Daytime 0700-1900:	Increase over background L_{A90} to be as near to + 10dB(A) as is practicable, subject to an upper limit of 55dB(A) $L_{Aeq(1\ hour)}$ free-field.
Evening 1900-2200:	Background L_{A90} + 10dB(A).
Night time 2200-0700:	42dB(A) $L_{Aeq(1\ hour)}$ free-field.

Additionally, for periods of up to 8 weeks in a year at specified noise-sensitive properties an increased temporary daytime noise limits of up to 70dB(A) L_{Aeq} 1hour (free field) can be considered to facilitate essential works such as site preparation and restoration.

For the proposed temporary testing operations noise levels will be assessed against noise limits based on the advised absolute noise limits of 55dB(A) daytime and 42dB(A) night time. These limits are in line with those specified in the planning consent covering the preceding drilling operations at the site.

2.2 ROAD TRAFFIC NOISE

Procedures assessing road traffic noise impacts are described the Highways Agency advice note 'Design Manual for Roads and Bridges' (DMRB) volume 11, section 3 part 7: Noise & Vibration (August 2008). This document provides guidance on the appropriate level of assessment to be used when considering the noise and vibration impacts arising from new and improved road projects. Whilst the detailed guidance contained in this document is aimed at assessing both stepped and future changes to traffic noise from new roads and road alterations, the procedure does include the screening and scoping phases that may be applied to other projects, which are likely to produce much less significant changes.

The screening process involves identification of whether change in traffic noise is likely to be significant, with the significance indicator being an increase to existing traffic of 25%, or greater. This change in traffic volume corresponds to a change in noise level of +1dB(A), which represents the smallest increment in noise increase that is regarded as being discernible, in terms of a short term change.

For projects, other than new or altered road schemes, the produced increase to traffic volume is unlikely to reach 25%. Where this is identified in the screening study the guidance suggests that no further assessment is normally required.

For the testing operations, traffic requirements have been forecast as a requirement for 11 additional cars (22 movements) and 1-2 HGV's (3 movements). Such minimal additional traffic would present only a small percentage increase to existing traffic, greatly below the 25% required to be significant I terms of noise. Traffic noise impact has therefore been screened out of a more detailed quantitative assessment.

3. POTENTIAL NOISE IMPACTS

For the planned testing operations at the exploration well site the following temporary noise impacts have been identified for assessment:

- Noise produced during pre-test operations
- Noise produced during well testing operations
- Traffic to the site during testing operations

In order to assess the level of potential noise impact a quantitative prediction for the pre-testing and testing operations is provided. With planned traffic movements to the site being at a very low level, this impact is not included in the scope of a qualitative assessment (as explained in section 2.2).

3.1 SENSITIVE RECEPTOR

For the purpose of defining noise impact, noise level predictions have been made at the closest and therefore most sensitive residential receptor position to the exploration site, at position R1 (Kemps Farm) located 380m north of the site. Figure 1 illustrates the relative positions of the well site and the residential receptor position.

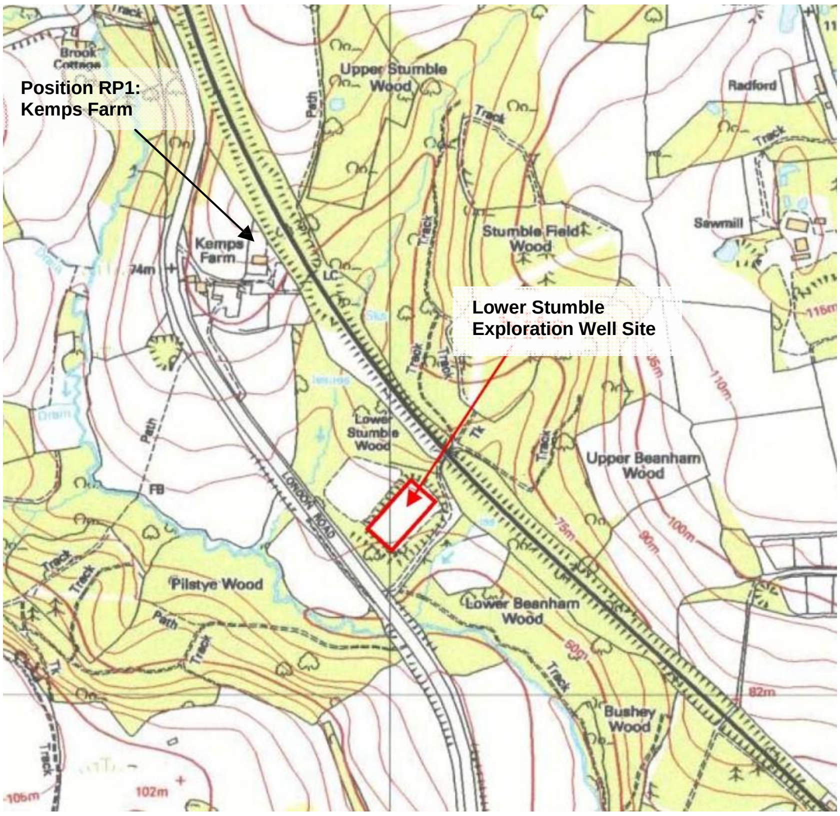


Figure 1: Plan showing Lower Stumble Exploration Well Site and closest residential position RP1.

3.2 PREDICTION METHODOLOGY

To provide an appraisal of the potential impact of testing, in terms of demonstrating compliance with the NPPF advised noise limits, noise level predictions have been made, based on the typical noise levels produced by these operations, using the identified plant items.

Predictions have been made in accordance with guidelines and procedures contained in BS5228-1:2009 'Noise and Vibration Control on Construction and Open Sites. Part 1: Noise'. The procedure involves identifying the main items of plant and equipment and then assigning a sound power level, based on equipment noise data included in an appendix of the Standard, or, as in this case, from available test information on similar plant used on other well sites operations.

Predictions of community noise levels are made by applying corrections to the sound power of each equipment source, to account for the following operational and environmental factors: -

- Typical periods of operation of plant
- Separating distances from source to receiver
- Presence of natural land topography screening or artificial barriers.

3.3 NOISE PRODUCED DURING PRE-TEST OPERATIONS.

The pre-test operations would involve use of a work-over rig, to run in tubing and clean out and prepare the borehole, for the subsequent testing. A generator set would also be used for site power.

Sound power data for the work-over rig has been taken from noise tests conducted at a well site conducting similar work-over operations. The sound power for the site power generator is taken from table C4 of BS5228-1 being indicative of a small enclosed generator set.

The overall LAeq(1 hour) noise level has been predicted at the closest residential location to the well site, at receptor position R1 (Kemps Farm). The results are summarised in table 1 below.

Plant	Sound Power LWA dB	Adjustments dB(A)		Result Lp dB(A)	On time %	Activity LAeq(1hr) dB
		Dist.	Screening			
Work-over rig	102	-60	-5	37	100	37
Site generator	90	-60	-5	25	100	25
Total Plant						37

Table 1: Predicted noise levels from pre-test operations at position R1 (Kemps Farm)

The prediction includes for a -5dB(A) correction to account for the natural screening provided by the land topography and the intervening copse areas, which occlude the direct line of sight between the well site and the house position. The total -65dB(A) noise loss between the well site and the house position has been verified by measurements taken during the recent drilling operations.

The prediction indicates that the pre-test operations would typically produce an LAeq(1 hour) contribution of 37dB(A) at the nearest (most sensitive) residential position.

3.4 NOISE PRODUCED DURING TESTING OPERATIONS

The testing operations would involve operation of the bean pump (nodding donkey), with a small generator set also required for provision of site power. Other equipment such as tanks and separators would provide low noise emission and are therefore not considered.

Depending on the outcome of the testing, there may be a requirement for burning off produced gas, commonly referred to as flaring. Noise produced by flaring is variable, being depending on gas flow rates to the burner and can vary between barely perceptible (with very low gas flows), to a more significant level with high gas flow rates. Should higher gas flows prevail, noise emission can be controlled by enclosing the flare, throttling back the flow during the sensitive night time period, or a combination of both. As the flare noise is unpredictable, but is controllable at source, the potential contribution from this source has not been included in the prediction.

Sound power data for the bean pump (nodding donkey) has been taken from noise tests conducted at an operating well site where this equipment is continuously operated. The sound power for the site power generator is taken from table C4 of BS5228-1 being indicative of a small enclosed generator set.

The overall L_{Aeq}(1 hour) noise level has been predicted at the closest residential location to the exploration site, at receptor position R1 (Kemps Farm). The results are summarised in table 2 below.

Plant	Sound Power L_{WA} dB	Adjustments dB(A)		Result	On time	Activity
		Dist.	Screening	Lp dB(A)	%	L_{Aeq}(1hr) dB
Bean pump	95	-60	-5	30	100	30
Site generator	90	-60	-5	25	100	25
Total Plant						31

Table 2: Predicted noise levels from testing operations at position R1 (Kemps Farm)

The prediction again includes for a -5dB(A) correction to account for the natural screening provided by the land topography and copse. The prediction indicates that the testing operations would typically produce an L_{Aeq}(1 hour) contribution of 31dB(A) at the nearest residential position.

4. MITIGATION

Noise emission during testing operations would be produced by operation of the work-over rig, the bean pump, together with associated plant, including generators. All such plant includes standard mitigation to reduce noise by incorporating high performance acoustic enclosures and silencers into the design.

The proposal is to complete a continuous noise monitoring survey at the Kemps Farm receptor position throughout the pre-test and testing operations, in order to verify that the defined noise limits are being met on a continuous basis. Should noise limits be exceeded additional noise mitigation would be implemented to reduce noise to the acceptable levels.

5. ASSESSMENT OF NOISE IMPACT

5.1 NOISE FROM PRE-TEST OPERATIONS

There are not expected to be significant tonal, or impulsive, characteristics to the predicted noise from the equipment used for pre-test operations. The rating level, as defined in BS4142, would therefore numerically be the same as the predicted specific L_{Aeq} noise level contribution from these operations.

The pre-test operations would be conducted during normal daytime working hours (0700-1900) when the applicable noise limit (in line with NPPF guidance notes) would be 55dB(A). The predictions have demonstrated that at the nearest sensitive residential position to the well site, noise produced by the pre test operations would be well below this daytime limit. In further consideration of the fact that the pre-test operations would be short term, the indication is that there would be a low adverse impact from the aspect of noise and the overall effect of these operations would not be significant.

5.2 NOISE FROM TESTING OPERATIONS

Again, there are not expected to be significant tonal, or impulsive, characteristics to the predicted noise from the equipment used for pre-test operations. The rating level, as defined in BS4142, would therefore numerically be the same as the predicted specific L_{Aeq} noise level contribution from these operations.

The testing operations would be continuous, extending through the night time period (2200-0700), when the applicable noise limit (in line with NPPF guidance notes) would be 42dB(A). Predictions have demonstrated that at the nearest sensitive residential position to the site, noise produced by the testing operations would be well below this night time limit. In further consideration of the fact that the testing operations would be short term, the indication is that there would be a low adverse impact from the aspect of noise and the overall effect of these operations would not be significant.

CUADRILLA BALCOMBE LIMITED

APPENDIX H

AIR DISPERSION REPORT

Cuadrilla Balcombe Limited
November 2013

Lower Stumble Hydrocarbon Exploration Site.
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Technical Report:

Air Dispersion Model of Exploration Drilling and Well Testing at Balcombe Site

Technical Report

Technical Report

Air Dispersion Model of Exploration Drilling and Well Testing at Balcombe Site

Notice

Document History

Revision	Purpose Description	Originated	Checked	Reviewed	Authorised	Date
01	PRE-ISSUE DRAFT	RW	SH	GM	GM	11/06/13

Contents

1. INTRODUCTION

Cuadrilla has been requested by the Environment Agency to submit an application for a mining waste permit to address exploration drilling and well testing activities at the Balcombe site in West Sussex.

The site will include a conventional onshore oil well which does not involve hydraulic fracturing. Flaring will occur continuously on the site over a short period (up to seven days) during well testing and, when in operation, as an emergency measure. The flare will be equipped with a continuous burning pilot flame (propane) and an auto-ignite system to light the pilot, in the event of a flame out.

An air dispersion modelling study is required in order to demonstrate likely ground level concentrations of key potential pollutants.

A photograph of the proposed flare stack design is shown in Figure 1.

Figure 1 – Photograph of flare stack

2. METHODOLOGY

P Dispersion modelling of emissions from the flare has been carried out using the US EPA model AERMOD PRIME version 12060[1]. The model is the result of many years development by the US EPA and the American Meteorological Society. It has been developed as a regulatory model that incorporates the current understanding of atmospheric physical processes. This model is used by regulatory agencies, consultants and industry worldwide to assess the impact of air emissions from point, area, line, flare and volume sources.

AERMOD simulates essential atmospheric physical processes and provides refined concentration estimates over a wide range of meteorological conditions and modelling scenarios. AERMOD includes two data pre-processors for streamlining data input: AERMET, a meteorological pre-processor, and AERMAP, a terrain pre-processor. The model can address both local topography and building downwash effects concurrently, where relevant to the study. The model provides reasonable estimates over a wide range of meteorological conditions and modelling scenarios.

The model has been used to determine potential air quality impacts resulting from a single one-off flaring event of up to seven days duration. Emergency events have not been considered at this stage.

The model was run using five years of hourly sequential meteorological data recorded at Gatwick Airport for the years 2005-2009. A wind rose for Gatwick is presented in Figure 2. The model was set up to report the maximum hourly average and maximum eight hourly average concentrations found at each receptor. As AERMOD was run with a five-year meteorological data file the maximum hourly result at each receptor is therefore the highest in over 43,000 hours processed. The model results presented thus robustly characterise the effects of the plant emissions on ambient concentrations during the most extreme meteorological events.

The primary modelled results are the maximum hourly and eight hourly concentrations found for the duration of the meteorological records, assuming continuous operation of the flare. The results are compared with the national Air Quality Strategy objectives for the protection of human health, as shown in Table 1. There is understood to be no sulphur in the gas, which is predominantly methane, hence the assessment does not address sulphur dioxide.

Table 1 - Air Quality Strategy objectives for the protection of human health

Pollutant	Air quality objective	Concentration (µg/m^3)
Nitrogen dioxide	Maximum 1-hour average (no more than 18 exceedences per year)	200
Carbon monoxide	Maximum daily running 8-hour average	10,000

[1] AERMOD software provided by Trinity Consultants Inc, http://www.breeze-software.com/ .

Ground level concentrations were modelled using Cartesian receptor grids covering at 100 metre resolution an area of 2 by 2 kilometres, with a nested grid of 25 metre resolution (800 by 800 m) nearer to the flare site. Discrete receptors were also specified for certain nearby residential properties. The nearest large group of residential properties lie 780 metres to the north of the site, on Oldlands Avenue, Balcombe. To the north west of the site there are commercial/light industrial premises at Kemps Farm.

Model Inputs

The dry flare gas data provided by Caudrilla lists the following molar composition:

- methane 88.35%
- ethane 4.02%
- propane 4.88%
- i-butane 0.30%
- n-butane 2.45%.

Further information on the flare relief gas characteristics is provided in Table 2. The values in bold type are those provided by Cuadrilla.

Table 2 - Summary of Relief Gas Characteristics

Parameter	Units	Value
Total Relief Gas Flow Rate	kg/hr	**275**
	kmol/hr	14
	MMscfd	0.29
Relief Gas Temperature	°C	**48**
Gas Mol Wt	g/mol	19.13
Gas Net Heat of Combustion	MJ/kmol	938.8
	BTU/scf	1064
Flare Combustion Efficiency	%	98.0
Flare Tip Diameter	M	**2.438**
Heat Release Rate (Net)	MW	3.74
Oxides of nitrogen (NOx) emission factor*	kg/kg	0.0016
Carbon monoxide (CO) emission factor*	kg/kg	0.0087

** estimated using US EPA's AP42 emission factor handbook.*

The dispersion model used the following discharge characteristics for the flare, as shown inTable 2.

Table 3 - Flare Discharge Characteristics

Parameter	Units	Value
Location of stack (National Grid Ref.)	m	531030, 129252
Height of release point above ground	m	13.72
Flare release point diameter	m	2.44
Exhaust gas temperature	°C	800
Heat release	Btu/hr	$1.25x10^{7}$
Radiation loss	%	10
Oxides of nitrogen emission rate	g/s	0.118
Carbon monoxide emission rate	g/s	0.651

Meteorological data

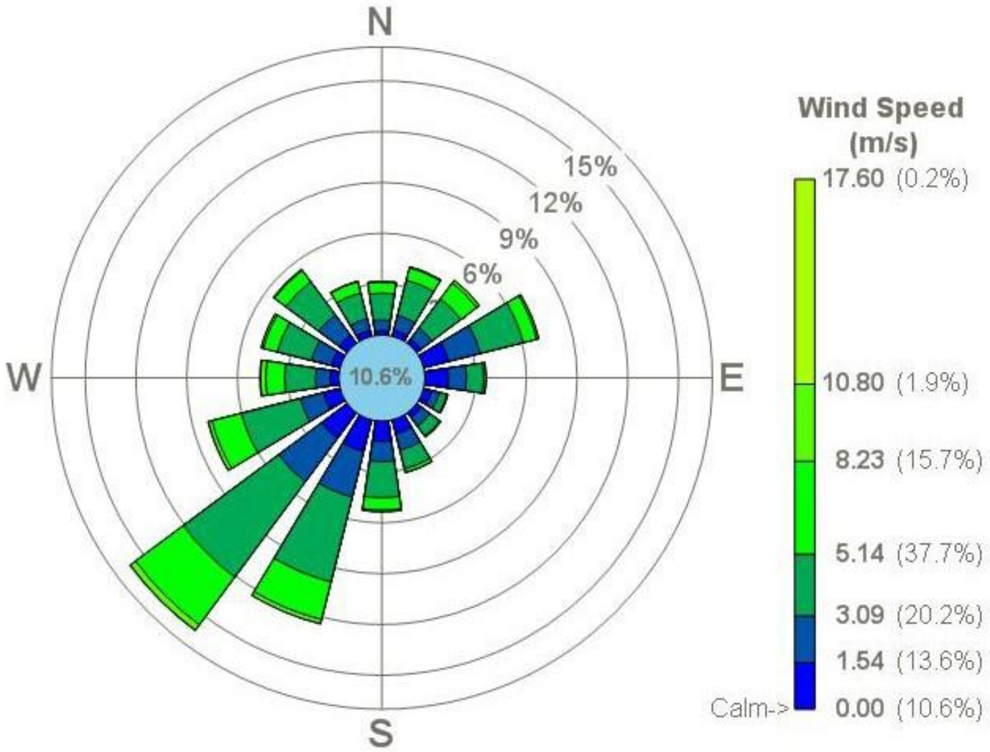
The most appropriate meteorological station with adequate records in the format required for the dispersion modelling study is at Gatwick Airport. This station is located at 51.150 N, 0.183 W and is approximately twelve kilometres to the north north west of the application site at 51.048 N, 0.132 W.

Hourly sequential meteorological data for the five-year period 2005 to 2009 from Gatwick were used in the dispersion modelling. The meteorological data file contains over 43,000 hourly records, and is quite adequate to characterise local meteorology in terms of extreme events conditions.

AERMET, the meteorological pre-processor, was used to process the data and estimate the necessary boundary layer[2] parameters for dispersion calculations in AERMOD. The data were processed to take account of the location and surroundings of the meteorological station and of the modelled facility. These parameters, together with observed near-surface wind and temperature data, were used to model how pollutants disperse in the atmosphere.

The processed meteorological data was used to generate a five-year frequency distribution of wind speed and direction. The data is shown presented as a wind rose diagram in Figure 2.

Figure 2 - Wind Rose Diagram for Gatwick, 2005 to 2009



[2] The atmospheric boundary layer is that region between the earth's surface and the overlying, free flowing atmosphere. The fluxes of heat and momentum drive the growth and structure of this boundary layer. The depth of this layer and the dispersion of pollutants within it are influenced on a local scale by surface characteristics, such as the roughness of the underlying surface, the reflectivity of the surface (albedo) and the amount of moisture available at the surface. From these inputs AERMET calculates severable boundary layer parameters, which in turn influence pollutant dispersion, including surface friction velocity, sensible heat flux, Monin-Obukhov length, daytime mixing layer height and nocturnal surface layer height, and the convective velocity scale.

Were the wind to be equally distributed from each directional sector, the frequency would be 5.6% in each sector excluding calms. It is evident from the data for these years that there is a pronounced prevailing wind from the south west and the adjoining sectors. Winds from these three sectors between the south south west and the west south west occur for over 36% of the time, more than twice as frequent as the evenly distributed case. There is a secondary prevailing wind from the east north east. Winds from the west to the north east sector are relatively infrequent, these seven sectors comprising 30% of total winds. Winds from the five sectors from the east to the south are even less frequent, comprising only 15.5% of the total.

The meteorological data pre-processor AERMET was used to create the site-specific surface and upper air hourly sequential data files required by AERMOD. The AERMET processing takes account of the location and surroundings of the meteorological station itself and of the flare site.

In accordance with the latest US EPA guidance, the near-field land use within a one kilometre radius of the site was evaluated to determine the surface roughness length[3]. Land uses may be specified by directional sector; in this case six sectors were designated as either predominantly urban, cultivated land or deciduous woodland.

The Bowen ratio[4] and albedo[5] were determined by the land use categories within the far-field, a 10 by 10 kilometre square. A determination of the percentages of each type of land use was made based on inspection of maps and aerial photographs. The land use proportions are simply averaged over the area and are independent of distance or direction from the site. The land uses categories within this area were urban 8%, cultivated land 49%, deciduous woodland 36%, coniferous woodland 6% and water 1%.

The pre-processor generates appropriate default annual average values for these parameters based on the land use information. The values used are presented in Table 4 .

Table 4 - Surface Characteristics

Direction Degrees	Land Type	Albedo	Bowen Ratio	Roughness Length
35 - 120	Cultivated land	0.2433	0.867	0.0725
120 - 180	Deciduous woodland	0.2433	0.867	0.9000
180 - 255	Cultivated land	0.2433	0.867	0.0725
255 - 290	Deciduous woodland	0.2433	0.867	0.9000
290 - 330	Cultivated land	0.2433	0.867	0.0725
330 - 35	Deciduous woodland	0.2433	0.867	0.9000

Comparison with Objectives

In undertaking this assessment, reference has been made to the Environment Agency's horizontal guidance document H1 for environmental assessment, Annex F "Air quality". The H1 guidance states that short-term process contributions less than 10% of the environmental standard may be regarded as insignificant.

3 Surface roughness length is a measure of the height of obstacles to wind flow. It is not equal to the physical dimensions of obstacles, but is generally proportional to them.
4 The Bowen ratio is a measure of the amount of moisture at the earth's surface. This influences other parameters which in turn affect atmospheric turbulence.
5 Noon-time albedo is the fraction of incoming solar radiation reflected from the ground when the sun is directly overhead. Adjustments are made in AERMET to incorporate the variation in the albedo with solar elevation angle.

The oxides of nitrogen emissions from combustion processes are released almost entirely in the form of nitrogen monoxide. As the plume travels and mixes with air, the NO slowly oxidises to form NO_2. This slow atmospheric reaction depends upon the availability of both ozone and sunlight to proceed. The plume travel time to the nearest residential receptors is in the order of several minutes only, thus restricting the degree of oxidation. A secondary reaction with oxygen may take place without sunlight, but this is extremely slow and hence is not a relevant consideration in the context of the local study area. Given the lower rate of oxidation at night time, it appears reasonable to assume that long-term average conversion factors would in fact be lower than the short-term daytime factor.

Guidance produced by the Environment Agency's Air Quality Modelling and Assessment Unit (AQMAU)[6] on conversion ratios for NO_x and NO_2 provides a series "screening procedures". The AQMAU note suggests a phased approach, initially a "screening/worst case scenario" using unrealistically high conversion ratios of 50% for short-term and 100% for long-term average concentrations. The second phase of the proposed approach is termed a "worse case scenario" sic and it is recommended that conversion ratios of 35% for short-term and 70% for long-term average concentrations are considered.

The second phase of the AQMAU approach, the "worst case scenario" has been applied in the current assessment and hence the conservative conversion ratio of 35% for short-term results is used when interpreting the modelled results for oxides of nitrogen.

[6] http://www.environment-agency.gov.uk/commondata/acrobat/noxno2conv2005_1233043.pdf

3. RESULTS

Oxides of Nitrogen

The modelled maximum hourly average oxides of nitrogen concentrations are shown below in Figure 3. Note that the value depicted at each receptor grid location is the highest hourly average found in the five years of meteorological data used.

The effects of the emissions on short term concentrations are also quite localised, the highest maximum hourly concentration of 9.5 µg/m^3 occurring on high ground approximately 400 metres to the north east of the flare. There is a secondary maximum of just over 6 µg/m^3 approximately 600 metres to the south west of the stack, again on relatively high ground.

Figure 3 - Maximum Hourly Average Oxides of Nitrogen Concentrations, µg/m^3

BF99_NOx_H 110613

The maximum ground level nitrogen dioxide concentrations (process contributions) at sensitive receptors are shown in Table 4.2 (third column). (The receptor locations are shown in the above figure as blue dots.) The AQMAU “worse case scenario” *sic* assumption was used to estimate nitrogen dioxide concentrations. This applies 35% conversion for the modelled short-term oxides of nitrogen concentration.

Table 1 - Modelled Maximum Hourly NO_x Concentrations and Estimated Total NO_2 Concentrations

Receptor	Grid reference	Maximum Hourly Mean NO_x, $\mu g/m^3$	Estimated Hourly Mean NO_2, $\mu g/m^3$	Concentration as % of AQS objective, $\mu g/m^3$
Kemps Farm	530783, 129550	1.3	0.5	0.2
Bowder's Cottage	531624, 129167	2.5	0.9	0.4
Bowder's Farm	531791, 129259	2.9	1.0	0.5
Holt's Cottages	531651, 129576	6.0	2.1	1.0
Norfolk Cottages	530257, 129479	5.3	1.9	0.9
Glebe Farm	531506, 129938	5.1	1.8	0.9

The estimated nitrogen dioxide concentrations using this conservative procedure demonstrate that all residential receptors where there may be a relevant exposure over a short-term time period the process contributions are 1% or less of the EAL for nitrogen dioxide of 200 $\mu g/m^3$. The H1 guidance states that short-term process contributions less than 10% of the environmental standard may be regarded as insignificant, and hence no further consideration of “predicted environmental concentration” (which includes the existing background concentration) need be carried out.

Carbon Monoxide

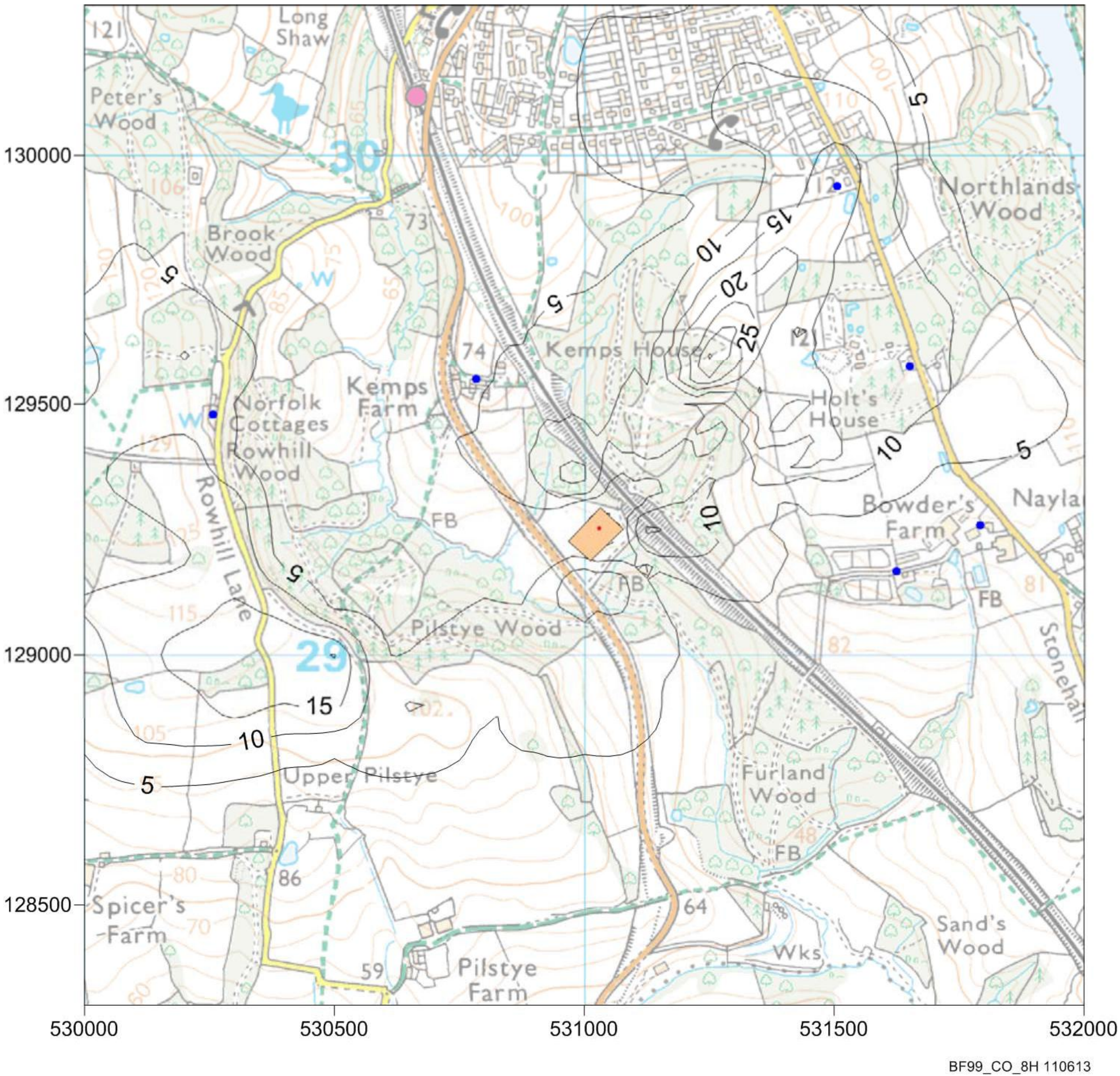
The modelled maximum eight hourly average carbon monoxide concentrations are shown in Figure 4. Again the highest result is on the complex terrain approximately 400 metres to the north east of the stack, where the maximum eight hourly average carbon monoxide concentration is 36 $\mu g/m^3$. This result is just 0.4% of the 10,000 $\mu g/m^3$ air quality objective for carbon monoxide.

The modelled carbon monoxide concentration at a sensitive receptor was 17.6 $\mu g/m^3$ as the maximum eight-hourly average. This maximum eight-hourly average is 0.2% of the AQS objective. These results for carbon monoxide are over an order of magnitude below the H1 assessment threshold of 10% of the environmental standard, thus confirming that these emissions are negligible.

Table 2 - Modelled Eight Hourly Average Carbon Monoxide Concentrations, $\mu g/m^3$

Receptor	Maximum 8 Hourly Mean Concentration, $\mu g/m^3$	Concentration as % of AQS objective, $\mu g/m^3$
Kemps Farm	4.4	<0.1
Bowder's Cottage	3.8	<0.1
Bowder's Farm	2.7	<0.1
Holt's Cottages	10.5	0.1
Norfolk Cottages	8.1	0.1
Glebe Farm	17.6	0.2

Figure 4 - Maximum Eight Hourly Average Carbon Monoxide Concentrations, μg/m^3



4. CONCLUSIONS

The modelled emissions of oxides of nitrogen and carbon monoxide from the proposed natural gas flare at Balcombe will not affect the achievement of the relevant short-term air quality strategy objectives for human health during well testing.

This assessment is based on a number of conservative assumptions: it was assumed that the flare operates continuously for seven days at the upper bound of anticipated operation, (10,000 m^3/day); the assessment used a five year meteorological data set from Gatwick, thus ensuring that the least favourable conditions have been modelled; the interpretation of the modelled oxides of nitrogen concentrations in terms of the resultant increments to ambient nitrogen dioxide concentrations used the highly conservative AQMAU recommendations regarding conversion rates.

The conclusions drawn are therefore robust, as the uncertainty in the modelling is considered to be small in comparison with the overall scale of the safety factors built into the above assumptions.