



Report

Five Fords WwTW AAD - Odour Impact
Assessment of Upgrade Works

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Report number: MOMB16B_16_FINAL
Project code: MOMB16B
Date: 26 July 2016 (July 2016)



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key words:

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Executive Summary

This report presents the findings of an odour assessment of upgrades to Five Fords Wastewater Treatment Works (WwTW). The upgrades at the site relate to the replacement of the existing sludge liming process with a new Thermal Hydrolysis Plant (THP). The study was commissioned by Mott MacDonald Bentley (MMB).

The purpose of the study is to assess how the upgrade is likely to affect odorous emissions and associated odour exposure from the sludge handling and processing areas of the site. As the upgrade only affects specific elements of the operations that relate to sludge processing, it is likely that the odorous emissions from the rest of the works operations will not change. The proposed study therefore focuses on the sludge processing elements of the site only.

The specific objectives of the study are defined as follows:

1. To review the current sludge treatment processes at Five Fords to identify odour sources and estimate the current magnitude of odour emissions from these sources under baseline conditions.
2. To review the proposed upgrade design to identify the new sources of odour that will be introduced, estimate odour emissions, and clarify how the odour emissions from the site are likely to change as a result of the proposed upgrade.
3. To assess the change in off-site odour exposure around the site for the proposed upgrade scenario and evaluate the effect of these upgrades on offsite impact risk and potential adverse impact on the amenity of the area around the site.

The study was informed by previous studies conducted by Odournet UK at a range of WwTW across the UK, including an odour survey of Treborth WwTW which operates a sludge liming process and of Afan WwTW which operates a Thermal Hydrolysis Plant of similar design to that proposed for Five Fords WwTW.

The study focuses on assessing the odour exposure levels which may occur from sludge treatment operations around the site under the following operational conditions:

- Baseline conditions - current operational conditions.
- Proposed upgrade - upgrade conditions with 2 No. odour control units (OCU).

The assessments were performed using mathematical atmospheric dispersion modelling techniques which provided a statistical analysis of the odour exposure levels that are likely to occur around the site for a five year period.

The dispersion modelling was conducted using the US EPA AERMOD dispersion model (version 7.7.1.2). The model was run in accordance with recent guidance issued by the US EPA and guidance relevant to odour assessment published by the Environment Agency.

The dispersion model outputs were compared to assess how odour exposure levels are likely to change as a result of the upgrade. This comparison was conducted using a range of odour impact criteria commonly applied in the UK.

The key findings of the study are as follows:

1. The predicted change in odour emissions from the sludge sources at Five Fords WwTW as a result of the proposed upgrade is an increase of approximately 1%.
2. Despite this slight increase in odour emissions the predicted offsite odour exposure levels for the proposed upgrade, as indicated by dispersion modelling, are predicted to reduce. The area

exposed to commonly used UK odour impact criteria under the baseline and proposed upgrade scenarios are summarised in the table below:

Table 1: Areas covered by each odour impact isopleth for 2010, the worst case year

Odour criteria	Baseline scenario (km ²)	Proposed upgrade (km ²)
C ₉₈ 1 hour ≥ 1.5 ou _E /m ³	0.80	0.64
C ₉₈ 1 hour ≥ 3.0 ou _E /m ³	0.37	0.21
C ₉₈ 1 hour ≥ 5.0 ou _E /m ³	0.20	0.08

3. This reduction in predicted offsite odour exposure is due to the change in the way in which the odour emissions are released, especially in relation to the post-digestion centrifuges and cake storage and handling, where the emissions are released at height allowing for greater dilution and dispersion in the atmosphere.
4. The implementation of the proposed upgrade to the sludge operations at the works is therefore not anticipated to increase the offsite impact risk or to result in an increase in adverse impact on the amenity of the area around the site.

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1 Introduction and scope

1.1 Scope

This report presents the findings of an odour assessment of upgrades to Five Fords Wastewater Treatment Works (WwTW). The upgrades at the site relate to the replacement of the existing sludge liming process with a new Thermal Hydrolysis Plant (THP). The study was commissioned by Mott MacDonald Bentley (MMB).

The purpose of the study is to assess how the upgrade is likely to affect odorous emissions and associated odour exposure from the sludge handling and processing areas of the site. As the upgrade only affects specific elements of the operations that relate to sludge processing, it is likely that the odorous emissions from the rest of the works operations will not change. The proposed study therefore focuses on the sludge processing elements of the site only.

The specific objectives of the study are defined as follows:

1. To review the current sludge treatment processes at Five Fords to identify odour sources and estimate the current magnitude of odour emissions from these sources under baseline conditions.
2. To review the proposed upgrade design to identify the new sources of odour that will be introduced, estimate odour emissions, and clarify how the odour emissions from the site are likely to change as a result of the proposed upgrade.
3. To assess the change in off-site odour exposure around the site for the proposed upgrade scenario and evaluate the effect of the upgrades on offsite impact risk and potential adverse impact on the amenity of the area around the site.

MMB also requested the investigation of the effect of implementing the proposed upgrade but with an alternative odour control strategy, defined by MMB.

The study was informed by previous studies conducted by Odournet UK at a range of WwTW across the UK, including an odour survey of Treborth WwTW which operates a sludge liming process and of Afan WwTW which operates a Thermal Hydrolysis Plant of similar design to that proposed for Five Fords WwTW.

1.2 Structure of report

The report is structured as follows:

- Section 2 describes the methodology undertaken to conduct the assessment.
- Section 3 provides an overview of existing and proposed site operations.
- Section 4 identifies the changing odour sources associated with Five Fords WwTW under the existing and proposed operational conditions.
- Section 5 details the assumptions applied to estimate odour emissions and defines an odour emission hierarchy for the works for the baseline and for the 2 No. upgrade scenarios.
- Section 6 details the results of the odour dispersion modelling and assesses how offsite odour exposure and impact risk is likely to change in comparison to baseline conditions.
- Section 7 summarises the conclusions of the study.

Supporting information is provided in the Annex.

1.3 Quality Control and Assurance

Odournet's odour measurement, assessment and consultancy services are conducted to the highest possible quality criteria by highly trained and experienced specialist staff. All activities are conducted in accordance with quality management procedures that are certified to ISO9001 (Certificate No. A13725).

All sensory odour analysis and odour sampling services are undertaken using UKAS accredited procedures (UKAS Testing Laboratory No. 2430) which comply fully with the requirements of the international quality standard ISO 17025: 2005 and the European standard for olfactometry EN13725: 2003. Where required, Odournet are accredited to conduct odour sampling from stacks and ducts in accordance to ISO 17025: 2005 and EN13725: 2003 under the MCERTS scheme. Odournet is the only company in the UK to have secured UKAS accreditation for all elements of the odour measurement and analysis procedure.

The Odournet laboratory is recognised as one of the foremost laboratories in Europe, consistently out performing the requirements of the British Standard for Olfactometry in terms of accuracy and repeatability of analysis results.

2 Description of approach

2.1 Identification of odour sources and estimation of odour emissions

The odour sources associated with the existing and proposed sludge treatment assets were defined on the basis of an audit of the existing Five Fords WwTW site, and review of information provided by MMB.

Emission estimates (expressed in terms of European odour units) for each source were defined using data collected during previous surveys of sludge liming at Treborth WwTW¹ and a THP process at Afan WwTW². Measurement data from other operational sewage treatment facilities was also used where relevant and appropriate.

In defining emissions from each odour source, consideration was also given to the influence of the following factors:

- Turbulence of aspects of the processes handling odorous liquid and solid material.
- The frequency and duration of release of intermittent activities.

2.2 Odour assessment methodology

The study assessed the odour exposure levels which might occur from sludge treatment operations around the site under the following operational conditions:

- Baseline conditions - current operational conditions.
- Proposed upgrade - Upgrade conditions with 2 No. odour control units (OCU).
- Alternative upgrade - Upgrade conditions with 1 No. OCU.

These assessments were performed using mathematical atmospheric dispersion modelling techniques which provided a statistical analysis of the odour exposure levels that are likely to occur around the site for a the worst case meteorological year of a five year period.

The dispersion modelling was conducted using the US EPA AERMOD dispersion model (version 7.7.1.2). The model was run in accordance with recent guidance issued by the US EPA and guidance relevant to odour assessment published by the Environment Agency.

The predicted odour exposure levels under each operational condition were then compared to assess how odour exposure levels are likely to change as a result of the upgrade. This comparison was conducted using a range of odour impact criteria which are described in more detail below.

2.3 Odour impact criteria

In general terms, odour annoyance is recognised as a symptom that develops as a result of intermittent but regular exposure to odours that are recognisable and have an offensive character. The key factors that contribute to the development of odour annoyance can be usefully summarised by the acronym FIDOL:

- Frequency of exposure.
- Intensity or strength of exposure.
- Duration of exposure.

¹ Odournet Report Reference DCWW13B_13_draft 'Odour impact assessment of Treborth STW'. April 2014.

² Odournet Report Reference DCWW14D_19_draft 'Odour impact assessment of Treborth STW following sludge treatment upgrades'. January 2015.

- Offensiveness.
- Location sensitivity.

In acknowledgement of these factors, a number of odour impact criteria have been developed that enable the odour impact risk of proposed facilities to be predicted using dispersion modelling techniques. These criteria are generally defined in terms of a minimum concentration of odour (reflecting the intensity/strength element of FIDOL) that occurs for a defined minimum period of time (reflecting duration and frequency element of FIDOL) over a typical meteorological year. The concentration element of these criteria can be increased or lowered to reflect variations in the offensiveness of the odours released from a specific type of facility, and the sensitivity of nearby sensitive locations.

There are currently a range of odour criteria applied in the UK to attempt to gain an insight into the probability of odour annoyance developing at a given location. However, there is no firm consensus on which odour impact criteria should be applied for sewage treatment works and the issue is currently a matter of rigorous debate.

In the UK, odour impact criteria are generally expressed in terms of a European odour unit concentration that occurs for more than 2% of the hours of a typical meteorological year, and have been designed for application to permanent residential properties which are considered to be the most sensitive from an impact risk perspective.

The most commonly applied criterion from this perspective is the 'Newbiggin criterion'. This criterion was originally introduced into a public inquiry for a new sewage works at Newbiggin-by-the-sea in 1993, and equates to an odour exposure level of 5 European odour units per cubic metre ($C_{98, 1\text{-hour}} > 5 \text{ ou}_E/\text{m}^3$). The Newbiggin criterion has been successfully applied during numerous planning and odour nuisance assessment studies since 1993 for sewage, waste, food and a range of other industrial and agricultural activities.

Since 2002, a range of indicative odour annoyance criteria have also been applied to assess odour impact risk from residential properties, which have supplemented the use of the Newbiggin criterion. These criteria were introduced in the Horizontal Guidance Note for Odour Management H4 issued by the Environment Agency³ and define three different levels of exposure at which odour impact or annoyance could potentially be expected to occur, for odours with high, moderate and low offensiveness. The indicative criteria are presented in the table below:

Table 2: Odour impact criteria

Relative offensiveness	Indicative criterion	Typical processes
Most offensive	1.5 ou_E/m^3 98 th percentile (hourly average)	Processes involving decaying animals or fish remains; septic effluent or sludge; biological landfill odours
Moderately offensive	3 ou_E/m^3 98 th percentile (hourly average)	Intensive livestock rearing; sugar beet processing; fat frying (food processing); well aerated green waste composting
Less offensive	6 ou_E/m^3 98 th percentile (hourly average)	Brewery; coffee roasting; confectionary; bakery

Odour guidance published by DEFRA in March 2010⁴ also refers to these criteria but in less specific terms. The guidance does not state which criterion should be applied for assessing impact but does suggest that typical criteria fall within the range of $C_{98, 1\text{-hour}} = 1.5 \text{ ou}_E/\text{m}^3$ to $C_{98, 1\text{-hour}} = 5 \text{ ou}_E/\text{m}^3$. Similarly, guidance

³ IPPC H4 Technical Guidance Note "H4 Odour Management", published by the Environment Agency, March 2011.

⁴ Odour Guidance for Local Authorities, published by DEFRA, March 2010.

published by the Institute of Air Quality Management (IAQM)⁵ in May 2014 also refers to these criteria. This guidance does however state that odour impact may occur between $C_{98, 1\text{-hour}} = 1 \text{ ou}_E/\text{m}^3$ and $C_{98, 1\text{-hour}} = 10 \text{ ou}_E/\text{m}^3$ and that professional judgement should be applied to determine criteria on a case by case basis by considering the underlying science, sensitivity of local receptors and developing case law.

There is currently some debate as to which odour criteria currently are the most appropriate for assessing the risk of impact of odorous industries such as sewage treatment, and to what extent the criteria are able to predict occurrence of odour annoyance for different odour types. Whilst there appears to be a substantial body of evidence to support the Newbiggin-by-the-Sea impact criterion for assessing the development of odour annoyance from the sewage sector, the availability of such evidence for the EA criteria is currently somewhat lacking. There is therefore a developing view within the UK odour community that the most stringent EA criteria (i.e. $C_{98, 1\text{-hour}} = 1.5 \text{ ou}_E/\text{m}^3$) may represent an overly precautionary standard in many cases even for highly offensive odours.

Odournet's general experience based on assessment of odours which could generally be classified as moderate to highly offensive (e.g. odours from waste water and sludge handling operations) generally supports this view, and indicates that odour annoyance is a symptom that is most likely to develop at exposure levels between $C_{98, 1\text{-hour}} = 3 \text{ ou}_E/\text{m}^3$ and $C_{98, 1\text{-hour}} = 5 \text{ ou}_E/\text{m}^3$,

This observation is supported to some extent by the findings of recent legal cases relating to odours from sewage treatment works (and a policy statement issued by the Chartered Institute of Water and Environmental Management) as indicated below, although from review of these it is clear that the use of the most stringent criteria EA cannot necessarily be discounted.

- **Appeal by Abbey Homes against St Edmundsbury Borough Council (March 2012).** The Borough Council originally refused planning permission for the erection of 101 dwellings on land between Upthorne Road and Hepworth Road, Stanton, Suffolk, for reasons including the proximity of the site to an existing small rural sewage treatment works and the potential effects on the living conditions of future residents of the dwellings. On the basis of odour dispersion modelling submitted by experts acting for both parties, the inspector considered an appropriate threshold to be more than $C_{98, 1\text{-hour}} = 1.5 \text{ ou}_E/\text{m}^3$, and that $C_{98, 1\text{-hour}} = 3 - 5 \text{ ou}_E/\text{m}^3$ was a more appropriate threshold (the inspector could see no reason to expect a significant loss of amenity to the occupiers of the proposed dwellings where Anglian Water's modelling predicted exposure levels below $C_{98, 1\text{-hour}} = 3 \text{ ou}_E/\text{m}^3$). The appeal was allowed and planning permission was granted.
- **Appeal against Corby Borough Council (2012).** This appeal concerned land at Ashley Road, Middleton, Leicestershire. The inspector concluded in this case "I believe that it is reasonable to take account of the $1.5 \text{ ou}_E/\text{m}^3$ contour map in determining odour impact. In my view areas subject to such concentrations are unlikely to provide a reasonable permanent living environment."
- **Appeal by Lakeland Leisure Ltd. against Allerdale Borough Council, 2012.** This appeal concerned the development of dwellings in Cockermouth, Cumbria in the vicinity of a sewage treatment works. The inspector concluded that development within the area predicted to experience odour exposure levels of $C_{98, 1\text{-hour}} = 3 \text{ ou}_E/\text{m}^3$ or less would be appropriate due to the anticipated medium offensive nature of the odours from the sewage works.
- **Thames Water vs. Dobson 2011.** This nuisance action was brought against Thames Water Mogden Sewage Treatment Works by a group of residents claiming odour nuisance caused by this large municipal sewage works in London. The inspector concluded that he would be reluctant to find nuisance if the modelled odour concentration was only $C_{98, 1\text{-hour}} > 1.5 \text{ ou}_E/\text{m}^3$ but as the odour concentration rises to $C_{98, 1\text{-hour}} = 5 \text{ ou}_E/\text{m}^3$ he considered that this was the area where

⁵ Guidance on the assessment of odour for planning, published by IAQM: April 2014.

nuisance from the works would start and that by the time that $C_{98, 1\text{-hour}} > 5 \text{ ou}_E/\text{m}^3$ or above is reached nuisance would certainly be established.

- **Appeal by JS Bloor (Northampton) Ltd 2010.** This appeal concerned a proposed residential development on land near an existing sewage treatment works in Leighton Linlade. The inspector noted that the water company used a standard of $C_{98, 1\text{-hour}} > 5 \text{ ou}_E/\text{m}^3$ which they indicated would be a “concentration level above which odour might be a potential nuisance”, and stated that the approach seemed reasonable and had been accepted at a previous appeal.
- **Extract from CIWEM policy statement.** CIWEM issued a position statement on odour in 2012 stating that the following framework is the most reliable that can be defined on the basis of the limited research undertaken in the UK at the time of writing:
 - $C_{98, 1\text{-hour}} > 10 \text{ ou}_E/\text{m}^3$ - complaints are highly likely and odour exposure at these levels represents an actionable nuisance;
 - $C_{98, 1\text{-hour}} > 5 \text{ ou}_E/\text{m}^3$, - complaints may occur and depending on the sensitivity of the locality and nature of the odour this level may constitute a nuisance;
 - $C_{98, 1\text{-hour}} < 3 \text{ ou}_E/\text{m}^3$, - complaints are unlikely to occur and exposure below this level are unlikely to constitute significant pollution or significant detriment to amenity unless the locality is highly sensitive or the odour highly unpleasant in nature.

For the purposes of this study, which was aimed at comparing how the off-site odour impact from the site will change following the upgrade, the results of the odour dispersion model were presented in the form of concentration isopleths which were plotted on a plan of the area surrounding the WwTW and encompassed the following specific odour exposure levels:

- $C_{98 \text{ 1 hour}} \geq 1.5 \text{ ou}_E/\text{m}^3$.
- $C_{98 \text{ 1 hour}} \geq 3 \text{ ou}_E/\text{m}^3$.
- $C_{98 \text{ 1 hour}} \geq 5 \text{ ou}_E/\text{m}^3$.

An analysis was also conducted to estimate the area of land that fell within each odour exposure band for each scenario.

3 Description of works operations

3.1 Site location

Five Fords Wastewater Treatment Works (WwTW) is located to the south-east of Wrexham in a predominantly rural location. There are however a number of urban areas located in the vicinity of the works, with the nearest receptors located to the South West and North East of the site. Figure 1 below shows the location of the works.

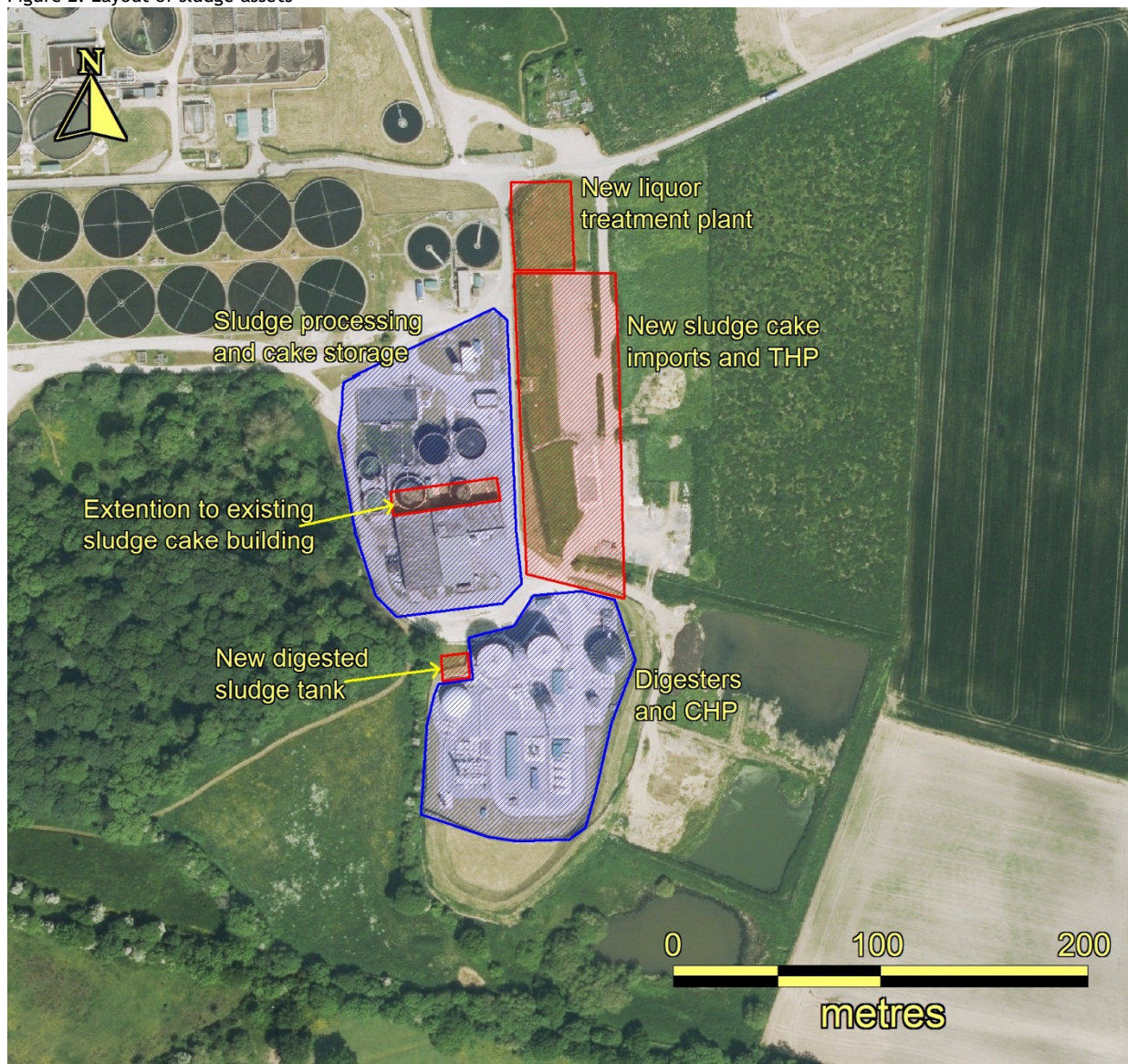
Figure 1: Location of Five Fords WwTW



3.2 Treatment process

Five Fords WwTW is a relatively large works which serves a population equivalent of approximately 132,000. The layout of the current and planned sludge treatment assets at Five Fords WwTW is shown in Figure 2. The blue areas represent existing assets and the red areas the planned upgrade assets.

Figure 2: Layout of sludge assets



3.2.1 Existing sludge treatment operations

Liquid sludge is imported into Five Fords WwTW. This flows through 1 of 2 No. screens which discharge rags into 1 of 2 No. open skips. The screened sludge is then pumped to the strain presses, where it is joined by sludge from the Five Fords primary settlement tanks (PSTs). This sludge then passes through 1 of 4 No. strain presses and into the mixed screened sludge tank. The strained material is deposited to 1 of 2 No. open skips. The raw sludge is then thickened in 1 of 2 No. gravity belt thickeners (GBT) before entering the thickened sludge tank. Surplus activated sludge (SAS) from the covered SAS buffer tank is pumped to 1 No. GBT before also entering the thickened sludge tank. There is also a standby GBT which is not used as part of normal operations.

From the thickened sludge tank the sludge is pumped via 1 of 2 No. heat exchangers, into 1 of 2 No. digesters. After digestion the sludge is pumped into 1 No. open post digestion tank.

Gas from the digesters is collected and stored in a gas storage bag before being used to fuel boilers and 2 No. combined heat and power (CHP) plant. Water heated via the boilers is used in the heat

exchangers. A waste biogas burner (flare) is also present on site that can be used to burn excess gas when required.

From the post digestion tank the digested sludge is pumped to 1 of 2 No. open lime consolidation tanks. Lime is added to the sludge within the pipe to these tanks. From the consolidation tanks the limed digested sludge is fed into 1 of 2 No. open sludge holding tanks.

From the sludge holding tanks the sludge is pumped to 1 of 3 No. centrifuges which operate on the first floor of the sludge cake building. Cake from the centrifuges is then stored in the sludge cake building prior to transport off-site.

Liquors from the centrifuges and belt presses are pumped to re-enter the wastewater treatment works prior to the PSTs.

The current site operations are served by 1 No. OCU which extracts and treats air from the following:

- Raw sludge reception pumping station
- Liquor returns pumping station
- Screened sludge tank
- Gravity belt thickeners
- Thickened sludge buffer tank

3.3 Changes - Proposed upgrade

The proposed sequence of sludge treatment will remain as is upstream of the 1 No. thickened sludge tank.

From the thickened sludge tank instead of going straight to the digesters, the sludge will be dewatered in 1 of 2 No. pre-THP centrifuges. Excess sludge for the centrifuges can also be stored in a pre-THP centrifuge buffer tank when required. From the centrifuges the sludge will be pumped into 1 of 2 No. THP feed silos.

Imported raw sludge cake will be tipped into 1 of 2 No. hoppers. Once the material has been tipped the doors of the hopper will close. The imported sludge cake will then be pumped into the THP feed silos. In the pipework to the silos the cake will be diluted with final effluent from the wastewater treatment works.

The combined sludge from the THP feed silos will then enter the THP system, which is a sealed system. In this system the sludge will first go to the pulper tank, where it will be brought up to temperature (approximately 70°C), then into 2 No. reactor tanks, where pressurised steam will be used to increase the pressure and temperature (to approximately 180°C). From here the sludge will enter a flash tank where a rapid drop in pressure and temperature will cause the breakdown of cell walls within the sludge. The steam from the flash tank will be re-used and therefore there should be no odorous escapes to atmosphere.

The sludge will then enter 1 of 2 No. digesters via a 2 stage cooling system. The gas from the digesters will be extracted and held in the existing gas bag. The waste biogas flare will also remain on site to burn any excess gas. The digester gas will then be sent to join the national grid. It is understood there are no odour releases from these processes. The existing CHPs will remain on site, but will not be used in the course of normal operations.

The sludge from the digesters will be pumped to a new post digestion tank. From here it will be pumped to the cake building, which will be extended, where it will go through 1 of 3 No. post digestion centrifuges. The cake from these will be deposited in the sludge cake building and periodically

transported off site. Liquors from the centrifuges will be pumped to a new liquor treatment plant. This will consist of 1 No. balance tank followed by 2 No. sequential batch reactor (SBR) tanks.

2 No. OCUs will serve the operations, in addition to the current sludge OCU. The cake preparation OCU will serve the:

- Imported sludge hoppers
- THP feed silos
- Pre-THP centrifuges
- Pre-THP centrifuge buffer tank

The cake building OCU will extract air from the cake handling building, releasing the air from a stack on the North-West corner of the building.

3.4 Changes - Alternative upgrade

The changes for the alternative upgrade are as those listed above for the proposed upgrade, with the exception that the emissions from the sludge cake building will not be extracted and treated through an OCU. Instead the post digestion centrifuges and cake handling and storage will be located in a building with open sides and no extraction.

4 Review of odour sources

4.1 Overview of the mechanisms for odour generation from wastewater treatment operations

The generation of odour from the processing of sewage is primarily associated with the release of odorous Volatile Organic Compounds (VOCs) that are generated as a result of the anaerobic breakdown of organic matter by micro-organisms. Anaerobic breakdown starts within the human bowel and may continue within the sewerage network and treatment works if conditions (i.e. a lack of oxygen) allow.

The key objectives of the sewage treatment process are to remove solid organic matter which is responsible for generation of the majority of sewage odours and to provide treatment to remove any residual contaminants from the wastewater so that it can be returned back into the environment.

Since the main source of odour and VOCs is the solid organic matter, the most intense and offensive odours tend to be generated from the operations involving the handling of sludge i.e. the processes applied to dewater, treat and store raw sludge. These processes are generally considered to present the greatest risk of odour impact offsite, unless adequate controls are put in place. Depending upon the quality of the sewage presented to the works, the aspects of the treatment process involved in the handling of raw sewage (e.g. preliminary and primary treatment stages) may also generate significant levels of offensive odours.

Odours generated from the sewage treatment processes downstream of the primary sludge removal stage (e.g. the activated sludge processes and final settlement) present a significantly reduced risk of odour impact. This is due to the fact that the majority of odorous biogenic material has been removed from the flow at this point, and the treatment processes applied to remove any remaining contaminants in the sewage are aerobic which inhibits the formation of the majority of the reduced sulphur compounds which are responsible for offensive sewage odours.

The rate of odour release from sewage and sludge sources is primarily dependent upon the temperature of the material, and the surface area exposed to the atmosphere. As a result, odorous emissions from sewage treatment operations tend to be highest during the summer months. Furthermore, activities that lead to increases in the surface area of odorous material exposed to the atmosphere (e.g. due to turbulence generated by sewage handling processes and agitation of sludge) will inevitably lead to an increase in the magnitude of odour released.

4.2 Identification of odour sources

The sources of odour identified for the baseline and upgrade conditions are summarised in the table below. A tick mark indicates an active odour source and a cross indicates a none active odour source (e.g. sources that will be decommissioned as a result of the upgrade).

Table 3: Operational sludge odour sources under each scenario

Odour Source	Frequency of emission	Baseline	Proposed upgrade	Alternative upgrade
Imported sludge screens, strain presses and skips	Intermittent	✓	✓	✓
Sludge OCU	Continuous	✓	✓	✓
Fugitive emissions from covered SAS buffer tank	Continuous	✓	✓	✓
1 No. open rectangular post digestion tank	Continuous	✓	✗	✗
2 No. open lime consolidation tanks	Continuous	✓	✗	✗
2 No. open sludge holding tanks	Continuous	✓	✗	✗
3 No. centrifuges for limed sludge in a building	Continuous	✓	✗	✗
Storage of limed sludge cake in a building	Continuous	✓	✗	✗
Collection of limed sludge cake in a building	3 trailers/day	✓	✗	✗
2 No. imported sludge hoppers	8 lorries/day	✗	✓	✓
Cake preparation OCU	Continuous	✗	✓	✓
1 No. circular post digestion tank	Continuous	✗	✓	✓
Cake building OCU	12 hrs/day	✗	✓	✗
3 No. centrifuges of THP sludge cake in an open sided building	12 hrs/day	✗	✗	✓
Agitation of THP sludge cake in an open sided building	7 hrs/day	✗	✗	✓
Storage of THP sludge cake in an open sided building	Continuous	✗	✗	✓
1 No. open liquor treatment balance tank	Continuous	✗	✓	✓
2 No. open liquor treatment SBR tanks	Continuous	✗	✓	✓

*Cake preparation OCU serves the imported sludge hoppers, pre-THP centrifuges, pre-THP centrifuge buffer tanks and THP feed silos.

**Cake building OCU extracts air from within the cake building which contains the post digestion centrifuges, cake storage and agitation.

5 Estimation of odour emissions

5.1 Assumptions applied to estimate odour emissions

5.1.1 General assumptions

A summary of the key assumptions applied to derive emission estimates are presented below. Full details of the emission values used in the model can be found in Annex A.

- The odour emission rates for the majority of odour sources were calculated with reference to odour emission rates measured during the 2014 Afan and 2013 and 2012 Treborth odour sampling programs and from emissions obtained from a broader range of studies conducted on sewage treatment processes by the Odournet group.
- For turbulent sources, a multiplier was applied to reflect the increase in emissions associated with the increased surface area of liquid exposed to the atmosphere at such locations. The following factors were applied to account for varying levels of turbulence:

Table 4: Turbulence factors

Level of turbulence	Factor
Quiescent	1
Low	3
Moderate	6
High	12
Extreme	20

5.1.2 Baseline emission assumptions

A summary of the key assumptions applied to derive emission estimates are presented below.

- The sludge OCU has been assumed to be operating at its design specification of 2 No. fans operating at duty assist together extracting 4000m³/hr of air and treating it to 1000 ou_E/m³. The following assumptions have been applied to estimate emissions from the sludge OCU:

Table 5: Emission estimates for OCU

Odour source	Outlet odour concentration [ou _E /m ³]	Flow rate [m ³ /s]	Emission rate [ou _E /s]	Efflux velocity [m/s]	Stack height [m]
Sludge OCU	1000	1.1	1100	12	3

- The emission rate from the SAS buffer tank has been assumed based on data measured by Odournet UK at other operational WwTWs in the UK. The area emission rate has been reduced by 50% to account for the containment provided by the covering of the tank.
- Emissions from the sludge skips have been estimated on the basis of measurements undertaken by Odournet UK at other operational WwTW in the UK. It has been assumed that 2 No. sludge press skips and 2 No. sludge screen skips will be present on site.
- The post digestion tank emission rate has been derived from the emission rate measured at Afan WwTW. An area of turbulence has been applied to the post digestion tank to account for the tank filling, which is assumed to occur for 50% of the time.
- The lime consolidation and limed sludge holding tank emission rates have been derived from the full limed sludge tank emission rate measured at Treborth WwTW. An area of turbulence has been applied to each tank to account for the tank filling, which is assumed to occur for 25% of the time for each tank.

- The digested limed sludge centrifuges are assumed to operate for 24 hours/day. Emissions from the centrifuges and associated movement of sludge have been estimated based on Odournet's experience at operational WWTWs across the UK.
- The sludge cake has been assumed to remain on site for an average of 7 No. days. It is assumed that on average approximately one third of the building area is covered with cake. A 50% reduction in odour emissions has been applied due to the containment provided by the building. This is assumed to be a precautionary estimate due to the open doors and gaps in the building fabric.
- It is assumed that 22 No. 15 tonne trailers collect sludge cake each week over a period of 30 minutes each. The emission rate for this has been derived from Odournet's experience from measurements undertaken at WwTW across the UK.

5.1.3 Proposed upgrade emission assumptions

A summary of the assumptions applied to derive emission estimates for the upgrade aspects of the works for the proposed upgrade are presented below.

- It is assumed that emissions from the pre-THP centrifuge, pre-THP centrifuge buffer tank and THP feed silos are fully captured by the cake preparation OCU and that there are no fugitive emissions. Emissions from within the sludge hoppers are assumed to be fully captured by the OCU, however a fugitive release is also applied for the tipping of the sludge cake into the hopper. The emission rate for this is based on the agitation of raw sludge measured at Afan, and it is assumed that 9 No. 29 tonne trucks deposit each day over a 20 minute period each.
- It is assumed that emissions from the post digestion centrifuges, associated movement of material, cake bays and collection of cake are fully captured by the cake handling OCU, and that there are no fugitive emissions.
- The sludge OCU has been assumed to be operating at its design specification of 2 No. fans operating at duty assist, together extracting 4000 m³/hr of air and treating it to 1000 ou_E/m³.
- The following criteria have been applied for the OCUs from discussion with MMB. The outlet odour concentration for the cake handling OCU has been reduced from the specified 2000 ou_E/m³ to 500 ou_E/m³ due to Odournet's experience of the likely odour loading to this type of OCU.

Table 6: Emission estimates for OCU

Odour source	Outlet odour concentration [ou _E /m ³]	Flow rate [m ³ /s]	Emission rate [ou _E /s]	Efflux velocity [m/s]	Stack height [m]	Temp. [°C]
Sludge OCU	1000	1.1	1100	12	3	0
Cake preparation OCU	2000	3.5	7000	12	3	0
Cake building OCU	500	12.0	6000	12	11.8 ⁶	0

- Emissions for the post digestion tank were calculated based on the measured result at Afan multiplied by the surface area of the tank. It is assumed that the tank is filling for 50% of the time and that there is an area of turbulence associated with this. This area has been based on that observed in the current sludge tanks at Five Fords.
- Emissions from the liquor balance tank and SBR tanks were estimated using data measured by Odournet UK at other operational WwTW in the UK.

⁶ Assumed to be released vertically 1m above building height.

5.1.4 Alternative upgrade emission assumptions

The emission rates and assumptions for the proposed upgrade are also assumed for the alternative upgrade, with the exceptions of those details below.

- It is assumed that the post digestion centrifuges and associated movement of material, cake bays and collection of cake is undertaken in an open sided building, with no forced extraction and therefore no cake building OCU.
- The sludge cake has been assumed to remain on site for an average of 7 No. days. It is assumed that an area of approximately one third of the building area is covered with cake. The emission rate measured at Afan WwTW has been applied for this source.
- It is assumed that 50 No. 15 tonne trailers collect sludge cake each week over a period of 30 minutes each. The emission rate measured at Afan WwTW has been applied for this source.
- The digested limed sludge centrifuges are assumed to operate for 12 hours/day. The emission rate applied per centrifuge has been estimated on the basis of measurements undertaken by Odournet at other WwTW around the UK.

5.2 Breakdown of estimated emissions

A breakdown of the odour emissions generated from the sludge assets for the baseline and the proposed upgrade scenarios is presented in the table below. The emission rates presented have been adjusted to reflect the frequency of occurrence of each odour source, and are thus time weighted.

Table 7: Breakdown of time weighted odour emissions for the baseline and upgrade scenarios

Odour Source	Baseline scenario		Proposed upgrade		Alternative upgrade	
	Emission rate [ouE/s]	% of total	Emission rate [ouE/s]	% of total	Emission rate [ouE/s]	% of total
Sludge screens and strain presses	750	3.9	750	3.8	750	3.9
Sludge OCU	1100	5.7	1100	5.6	1100	5.8
SAS buffer tank	49	0.3	49	0.3	49	0.3
Rectangular Post digestion tank	2151	11.1	-	-	-	-
2 No. open lime consolidation tanks	5938	30.7	-	-	-	-
2 No. open sludge holding tanks	4367	22.6	-	-	-	-
Centrifuge of limed sludge	3000	15.4	-	-	-	-
Storage of limed sludge cake	1925	9.9	-	-	-	-
Agitation of limed sludge cake	71	0.4	-	-	-	-
2 No. imported sludge hoppers	-	-	1483	7.6	1483	7.8
Cake preparation OCU	-	-	7000	35.7	7000	36.7
Circular post digestion tank	-	-	481	2.5	481	2.5
Cake building OCU	-	-	6000	30.6	-	-
Centrifuges of THP sludge cake	-	-	-	-	1500	7.9
Agitation of THP sludge cake	-	-	-	-	50	0.3
Storage of THP sludge cake	-	-	-	-	3941	20.7
Open liquor treatment balance tank	-	-	950	4.9	950	5.0
Open liquor treatment SBR tanks	-	-	1767	9.0	1767	9.3
Total	19351	100	19581	100	19071	100

Review of the table above indicates only small changes in the total time weighted odour emission rates occur for the upgrade scenarios in comparison to the baseline. From the baseline to the proposed upgrade there is an increase in time-weighted emissions by approximately 1.2%. From the baseline to the alternative upgrade there is a decrease in the time-weighted emissions by approximately 1.5%.

The largest contributor to the baseline emissions comes from the lime consolidation and limed sludge holding tanks which contribute approximately 53% of the total time weighted emissions. The emissions from the digested sludge tank, the centrifuges and associated agitation, and the cake storage and handling account for 11%, 15% and 10% of total time weighted emissions respectively. The remaining emissions from the sludge screens and strain press skips, sludge OCU and SAS buffer tank together contribute only 10% to the site emissions.

It should be noted that due to the time weighting the agitation of sludge cake appears as a small contributor to emissions, however at its time of occurrence it will give a larger emission rate.

The greatest contributor to time weighted emissions for the upgrade scenarios are the cake preparation OCU at 36% and 37% for the proposed and alternative upgrades respectively. The cake centrifuges, handling and treatment (cake handling OCU or cake storage and handling and centrifuges) are the next largest contributors to site emissions at approximately 31% and 29% for the proposed and alternative upgrades respectively. This is where the difference in emission rates between the 2 upgrade scenarios occurs, with the assumed outlet concentration of an OCU against the calculated emission rates of the sources.

If the initial stated outlet odour concentration of the cake building OCU was utilised, then the emissions from this source would be 4 times higher than the emissions from the open sided cake building processes. As such the 500 ou_E/m³ outlet concentration was applied as it is unlikely that the inlet to the OCU will reach 2000 ou_E/m³. Due to the similarity of the assumed cake building OCU and the open sided building cake process emission estimates it is probable that extraction without odour treatment would achieve the 500 ou_E/m³ outlet concentration.

The baseline cake storage and handling and centrifuge emissions are lower than those for the upgrade scenarios due to the covering provided by the building and the smaller surface area of sludge cake out-weighing the reduced usage time of the upgrade centrifuges and the less odorous nature of the sludge cake.

The time weighted emissions from sludge cake import are relatively low at approximately 8% in both the proposed and alternative upgrades. Like with the sludge agitation however, at the time of these occurring these emissions are much greater.

The liquor balance tanks contribute approximately 14% of time weighted emissions for the proposed and alternative upgrades, and the unchanged sources (i.e. sludge strain presses, screens and skips, sludge OCU and SAS buffer tank) account for approximately 10% of time weighted emissions.

Although the emissions released from the baseline and upgrade scenarios are broadly comparable, the way in which they are released varies considerably with the use of OCUs, the release time periods and the location of the sources. As such the effect of the upgrades in terms of changes in off-site odour exposure and hence potential impact risk, will be evaluated by the dispersion modelling.

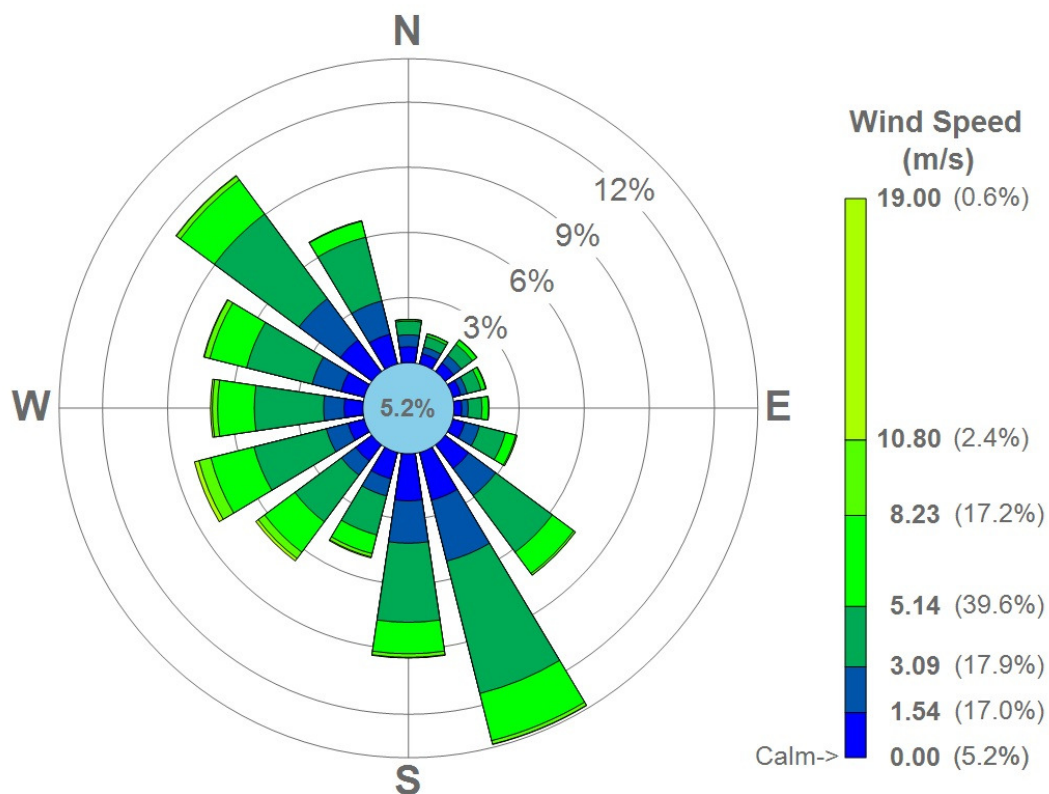
6 Review of changes to odour exposure levels

6.1 Modelling assumptions

The key assumptions which were applied within the model to represent site operations and define the dispersion characteristics for the site were as follows:

- Meteorological data utilised within the study was derived from 5 years of recent sequential hourly average data obtained from Hawarden meteorological station for the years 2009 to 2013. This meteorological recording station is located approximately 17 km to the North of the site. The meteorological data was adjusted to reflect the surface characteristics of the meteorological site in accordance with the guidelines issued in the AERMOD Implementation Guide⁷ issued by the US EPA. The wind rose for the meteorological data utilised in the study is presented below.

Figure 3: Wind rose for Hawarden meteorological station for 2009 - 2013



- The study area was defined as rural, in line with land use classification techniques described in the AERMOD User Guide issued by the US EPA.
- A 2 km by 2 km uniform Cartesian receptor grid was defined for the study area with a spacing of 50 m.
- Data describing the topography of the area surrounding the works was obtained from Ordnance Survey in Landform Panorama™ format.
- The following buildings have been assumed to be present on site for the baseline scenario:

⁷ AERMOD Implementation Guide, Published by the US EPA, Last Revised: March 19, 2009

Table 8: Assumed building dimensions for baseline Scenario

Building	Height [m]	Dimensions
Existing sludge cake building	13.4	26 m x 18.5 m and 48.5 m x 33 m
Disused tank to the North of proposed cake building OCU	8	5.5 m radius
Disused tank to the North of proposed cake building OCU	8	5.5 m radius
Lime storage building	4	11 m x 5.5 m
2 No. digesters	22.5	8.5 m radius
Mixed screened sludge tank	11.9	8.5 m radius
SAS buffer tank	5.9	2.5 m radius
Kiosk to West of Sludge OCU	3	21.5 m x 6 m
Kiosk to south of sludge OCU	3	10 m x 3 m
Kiosk to East of Sludge OCU	3	6 m x 4.5 m and 8.5 m x 2 m
Thickened sludge tank	11.8	4 m radius
Kiosk to North West of thickened sludge tank	3	11 m x 5.5 m
Gas balloon	12.8	7 m radius
GBTs	2	15 m x 4 m
2 No. lime consolidation tanks	10.5	7.5 m radius

- The following buildings have been assumed to be present on site for the proposed and alternative upgrades:

Table 9: Assumed building dimensions for upgrade Scenarios

Building	Height [m]	Dimensions
Extension of sludge cake building	10.8	51 m x 11 m
Existing sludge cake building	13.4	26 m x 18.5 m and 48.5 m x 33 m
Pre-THP centrifuge buffer tank	17	5.5 m radius
Pre-THP centrifuge building	7.7	15 m x 12 m
2 No. THP feed silos	17	6 m radius
2 No. Cake reception hoppers	10.4	12 m x 8 m
Disused tank to the North of proposed cake building OCU	8	5.5 m radius
Disused tank to the North of proposed cake building OCU	8	5.5 m radius
Liquor treatment SBR tank	9	5.5 m radius
Liquor treatment SBR tank	9	7.5 m radius
Liquor treatment balance tank	9	7.5 m radius
Lime storage building	4	11 m x 5.5 m
2 No. digesters	22.5	8.5 m radius
Mixed screened sludge tank	11.9	8.5 m radius
SAS buffer tank	5.9	2.5 m radius
Kiosk to West of Sludge OCU	3	21.5 m x 6 m
Kiosk to south of sludge OCU	3	10 m x 3 m
Kiosk to East of Sludge OCU	3	6 m x 4.5 m and 8.5 m x 2 m
Thickened sludge tank	11.8	4 m radius
Kiosk to North West of thickened sludge tank	3	11 m x 5.5 m
Gas balloon	12.8	7 m radius
GBTs	2	15 m x 4 m

- The model only considers normal operational occurrences. Short term events such as plant breakdown, maintenance and repair may impact considerably on the odorous emissions from time to time. Such short term variations have not been considered within the model.

6.2 Results of odour dispersion modelling

6.2.1 Output of dispersion model

The output of the dispersion model for the baseline and upgrade scenarios are presented in Figures 4, 5 and 6 below for 2010, the worst case meteorological year of the 5 year period. For the upgrade scenarios the baseline is also presented as a blue dashed line for comparison purposes. Isopleth maps for the remaining years are shown in Annex B. Table 10 shows the areas covered by each impact contour for each scenario.

Figure 4: Odour contours for the baseline scenario. Results presented are for 2010, the worst case year of the 5 year period.

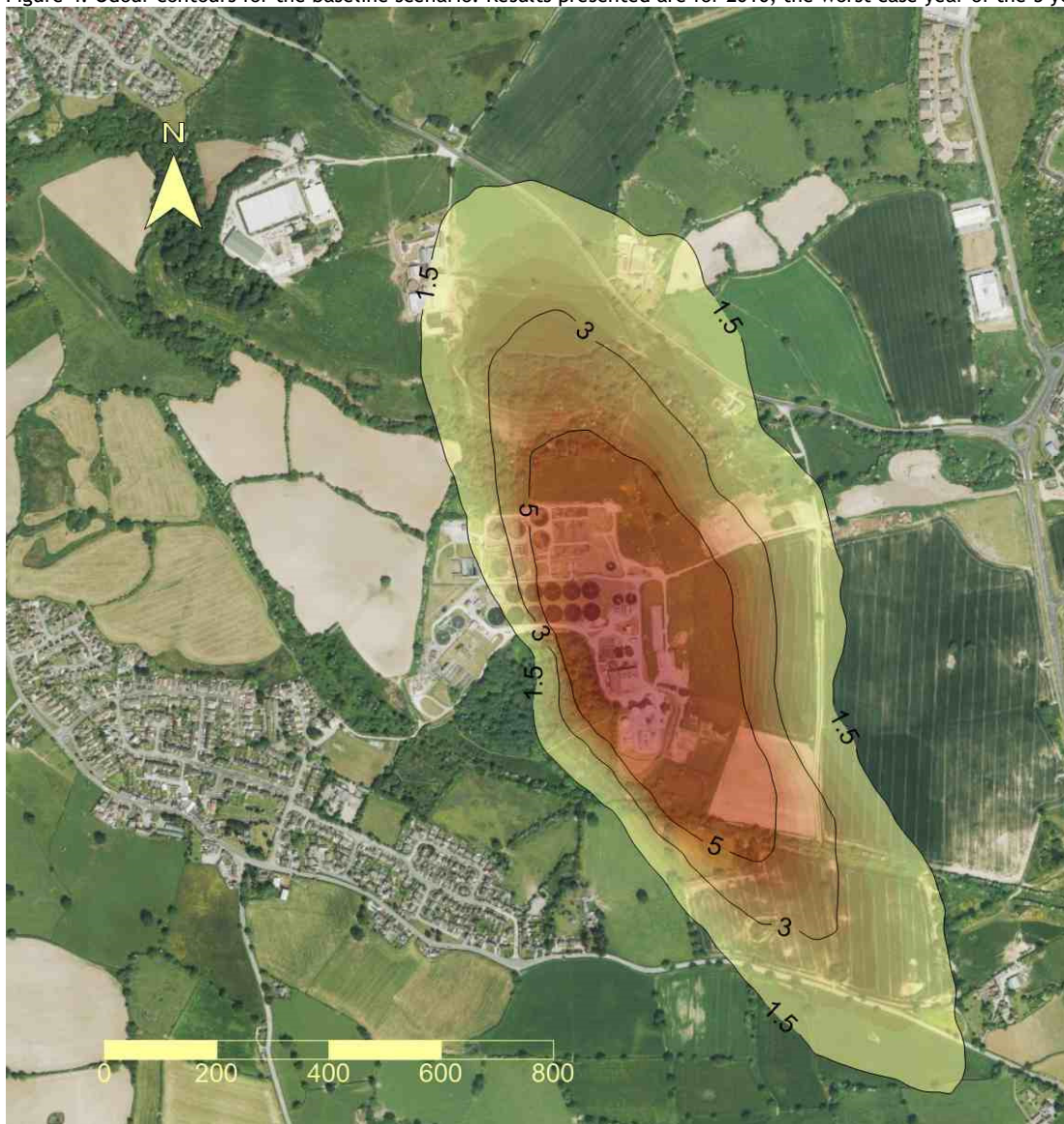


Figure 5: Odour contours for the proposed upgrade for 2010. The baseline scenario is also presented as blue dashed lines.

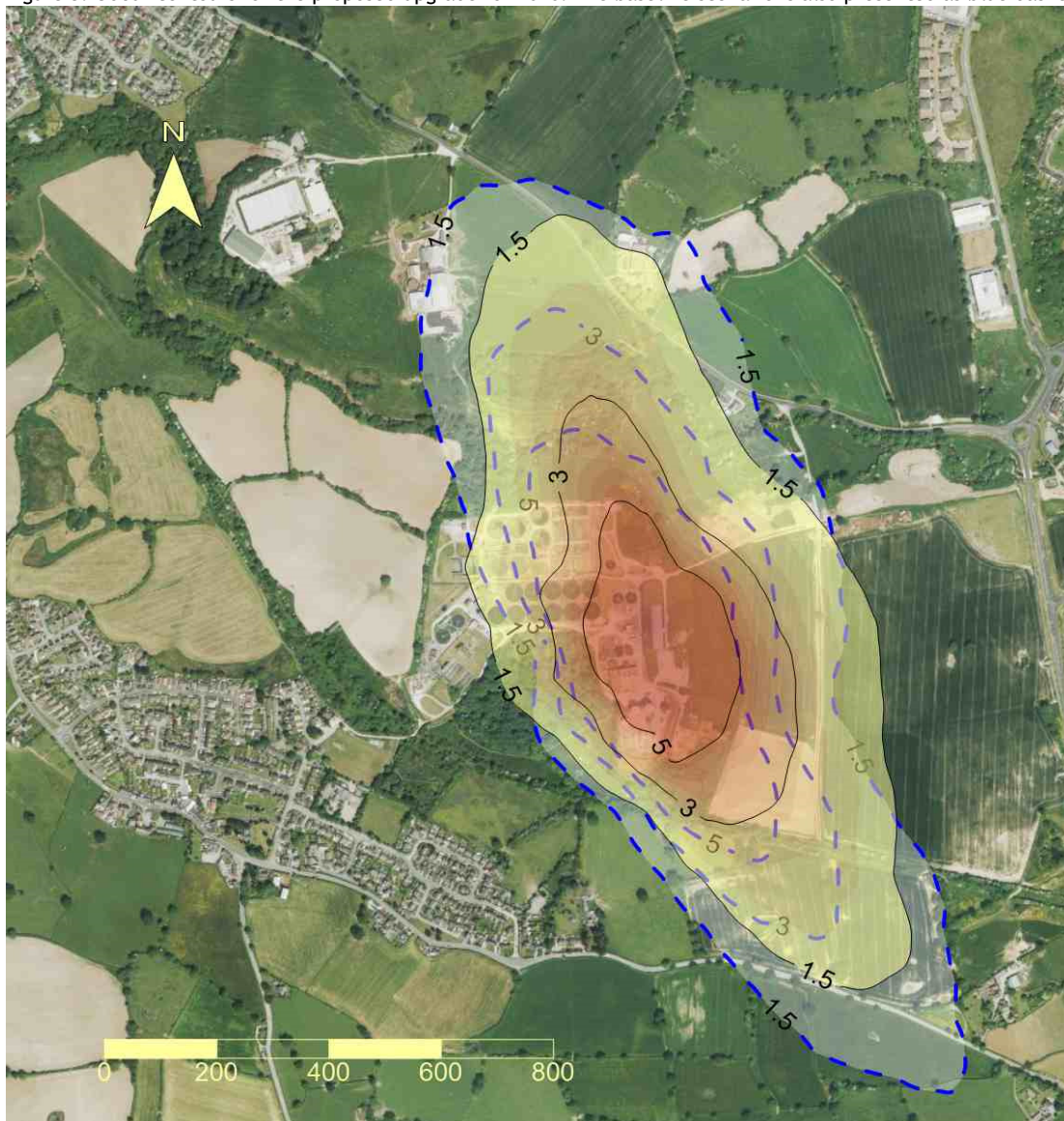


Figure 6: Odour contours for the alternative upgrade for 2010. The baseline scenario is also presented as blue dashed lines.

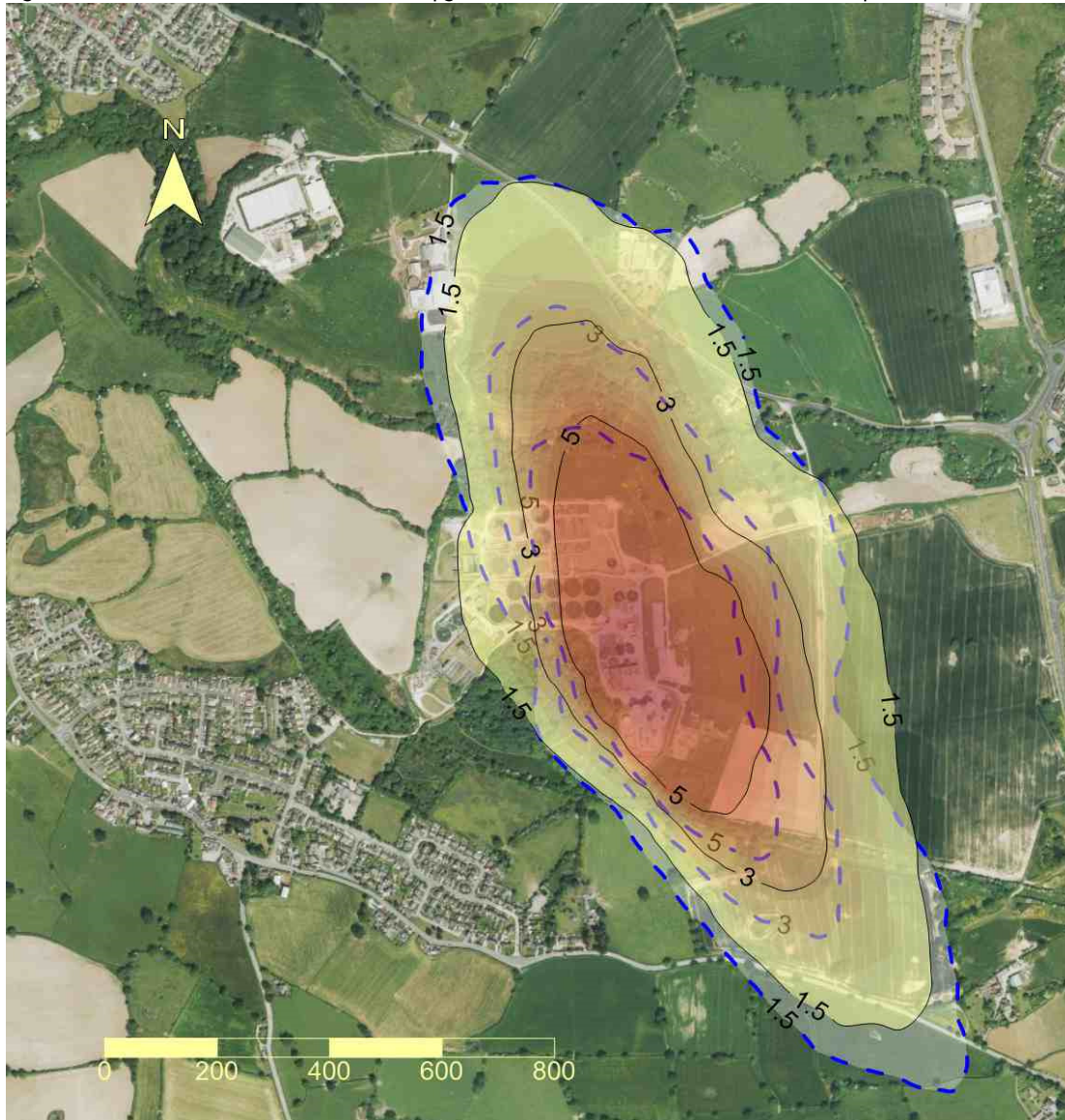


Table 10: Areas covered by each odour impact isopleth for 2010, the worst case year

Odour criteria	Baseline scenario (km ²)	Proposed upgrade (km ²)	Alternative upgrade (km ²)
C ₉₈ 1 hour ≥ 1.5 ou _E /m ³	0.80	0.64	0.76
C ₉₈ 1 hour ≥ 3.0 ou _E /m ³	0.37	0.21	0.34
C ₉₈ 1 hour ≥ 5.0 ou _E /m ³	0.20	0.08	0.17

6.2.2 Discussion of results

It is clear from Figures 4, 5 and 6 and Table 7 that the areas covered by each odour impact criteria decrease for each upgrade scenario in comparison to the baseline for 2010, the worst-case meteorological year. The reduction seen is greater for the proposed upgrade than for the alternative upgrade, which is likely due to the increased height at which the emissions from the cake building are released. This increased height allows for greater dilution and dispersion of emissions.

7 Summary of findings

The key findings of the study are as follows:

1. The predicted change in odour emissions from the sludge sources at Five Fords WwTW as a result of the proposed upgrade is an increase of approximately 1%.
2. Despite this slight increase in odour emissions the predicted offsite odour exposure levels for the proposed upgrade, as indicated by dispersion modelling, are predicted to reduce. The area exposed to commonly used UK odour impact criteria under the baseline and proposed upgrade scenarios are summarised in the table below:

Table 11: Areas covered by each odour impact isopleth for 2010, the worst case year

Odour criteria	Baseline scenario (km ²)	Proposed upgrade (km ²)
C ₉₈ 1 hour ≥ 1.5 ou _E /m ³	0.80	0.64
C ₉₈ 1 hour ≥ 3.0 ou _E /m ³	0.37	0.21
C ₉₈ 1 hour ≥ 5.0 ou _E /m ³	0.20	0.08

3. This reduction in predicted offsite odour exposure is due to the change in the way in which the odour emissions are released, especially in relation to the post-digestion centrifuges and cake storage and handling, where the emissions are released at height allowing for greater dilution and dispersion in the atmosphere.
4. The implementation of the proposed upgrade to the sludge operations at the works is therefore not anticipated to increase the offsite impact risk or to result in an increase in adverse impact on the amenity of the area around the site.

Annex A Emission rates

Specific emission rates for baseline operational conditions

The specific emission rates applied to each source under baseline operational conditions are presented below:

Table 12: Emission assumptions for open sources

Stage of treatment	Odour Source	Odour emission rate (excluding turbulence) [ou _E /m ² /s]	Turbulence multiplier
Sludge handling and treatment	Post digestion tank	5	1 - 6
	Lime consolidation tanks	16	1 - 6
	Sludge holding tanks	16	1 - 6
	Sludge cake bays	10*	1
	SAS buffer tank	5*	1
	Sludge press skips	50	1
	Sludge screens skips	50	1

*This does not include the 50% reduction in emission rate for containment provided.

Table 13: Emission assumptions for agitation sources

Stage of treatment	Source	Operation	Emission rate [ou _E /kg]
Thickened sludge handling	Collection of sludge cake by trailers	Agitation during collection of cake from bays.	260*

* This does not include the 50% reduction in emission rate for containment provided by the building.

Table 14: Emission assumptions for volume sources

Stage of treatment	Source	Emission rate [ou _E /s]
Sludge handling and treatment	Centrifuge of digested limed sludge [each]	1000

Table 15: Emission estimates for OCU

Odour source	Outlet odour concentration [ou _E /m ³]	Flow rate [m ³ /s]	Emission rate [ou _E /s]	Efflux velocity [m/s]	Stack height [m]
Sludge OCU	1000	1.1	1,100	12	3

Specific emission rates applied for the proposed upgrade

The specific emission rates applied for the proposed upgrade are presented below:

Table 16: Emission assumptions for open sources

Stage of treatment	Odour Source	Odour emission rate (excluding turbulence) [ou _E /m ² /s]	Turbulence multiplier
Sludge handling and treatment	Post digestion tank	5	1 - 6
	Liquor treatment balance tank	10	1
	2 No. liquor treatment SBR tanks	5	1
	SAS buffer tank	5*	1
	Sludge press skips	50	1
	Sludge screens skips	50	1

*This does not include the 50% reduction in emission rate for containment provided.

Table 17: Emission assumptions for agitation sources

Stage of treatment	Source	Operation	Emission rate [ou _E /kg]
Sludge handling and treatment	Raw sludge deposit to hopper	Agitation during depositing of raw sludge	491

Table 18: Emission estimates for OCU

Odour source	Outlet odour concentration [ou _E /m ³]	Flow rate	Emission rate [ou _E /s]	Efflux velocity [m/s]	Stack height [m]
Cake preparation OCU	2000	3.5	7000	12	3
Cake building OCU	500*	12.0	6000	12	11.8
Sludge OCU	1000	1.1	1100	12	3

*The design criteria for the outlet odour concentration for this source was to achieve 2000 ou_E/m³. From examination of the potential incoming load an outlet concentration of 500 ou_E/m³ has been applied.

Specific emission rates applied for the alternative upgrade

The specific emission rates applied to each source for the alternative upgrade are presented below:

Table 19: Emission assumptions for open sources

Stage of treatment	Odour Source	Odour emission rate (excluding turbulence) [ou _E /m ² /s]	Turbulence multiplier
Sludge handling and treatment	Post digestion tank	5	1 - 6
	Liquor treatment balance tank	10	1
	2 No. liquor treatment SBR tanks	5	1
	Sludge cake bays	7	1
	SAS buffer tank	5*	1
	Sludge press skips	50	1
	Sludge screens skips	50	1

*This does not include the 50% reduction in emission rate for containment provided.

Table 20: Emission assumptions for agitation sources

Stage of treatment	Source	Operation	Emission rate [ou _E /kg]
Sludge handling and treatment	Raw sludge deposit to hopper	Agitation during depositing of raw sludge	491
	Collection of sludge cake by trailers	Agitation during collection of cake from bays.	40

Table 21: Emission estimates for OCU

Odour source	Outlet odour concentration [ou _E /m ³]	Flow rate [m ³ /s]	Emission rate [ou _E /s]	Efflux velocity [m/s]	Stack height [m]
Cake preparation OCU	2000	3.5	7000	12	3
Sludge OCU	1000	1.1	1100	12	3

Table 22: Emission assumptions for volume sources

Stage of treatment	Source	Emission rate [ou _E /s]
Sludge handling and treatment	Centrifuge of digested limed sludge [each]	1000

Annex B Dispersion model outputs for the remaining years

Proposed Upgrade

The dispersion model outputs for years 2009, 2011, 2012 and 2013 are presented in the figures below. In each case the proposed upgrade is presented as solid black lines and the baseline for the corresponding year is presented as blue dashed lines.

Figure 7 Predicted odour exposure levels for the proposed upgrade for 2009.

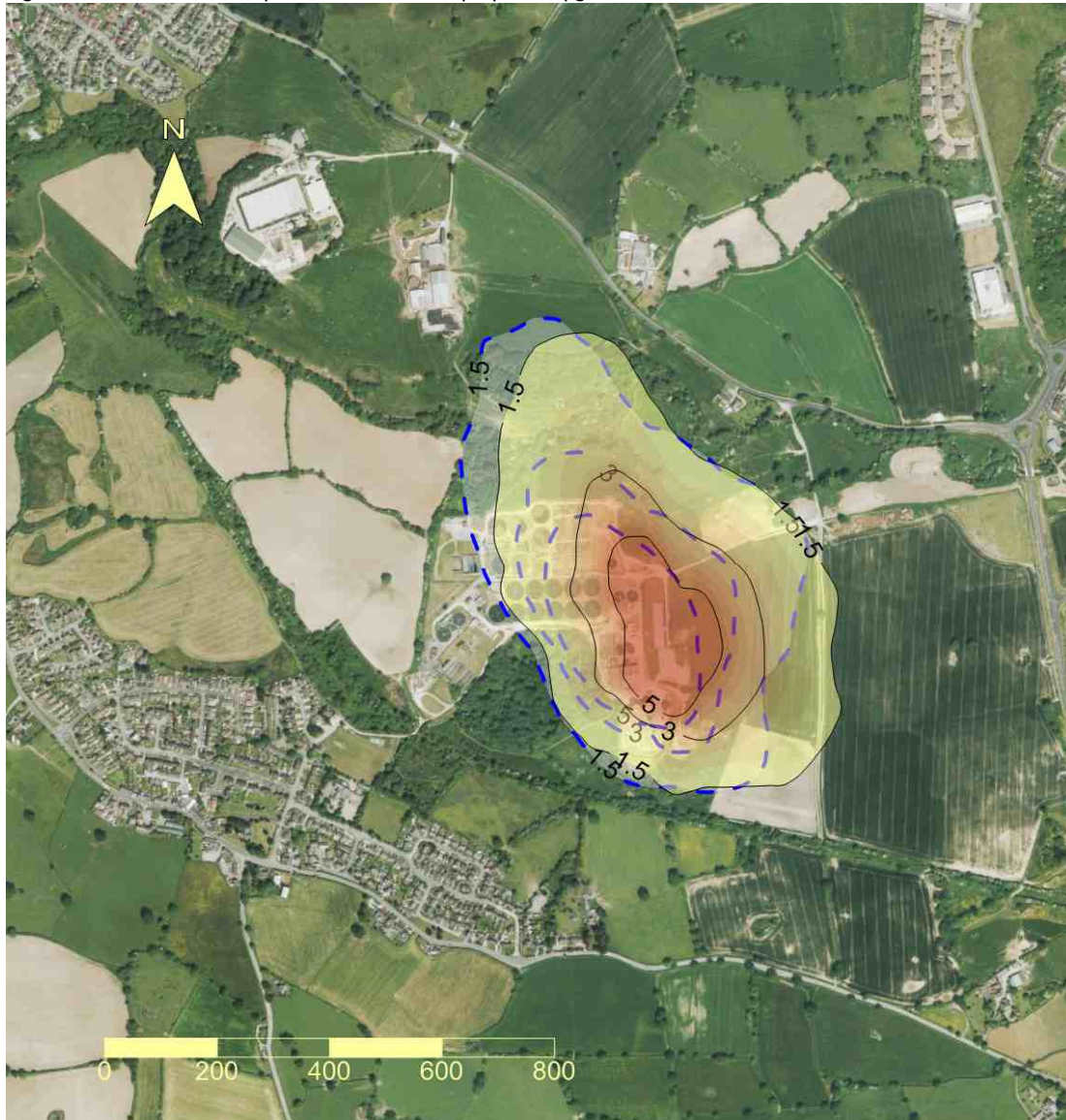


Figure 8: Predicted odour exposure levels for the proposed upgrade for 2011.

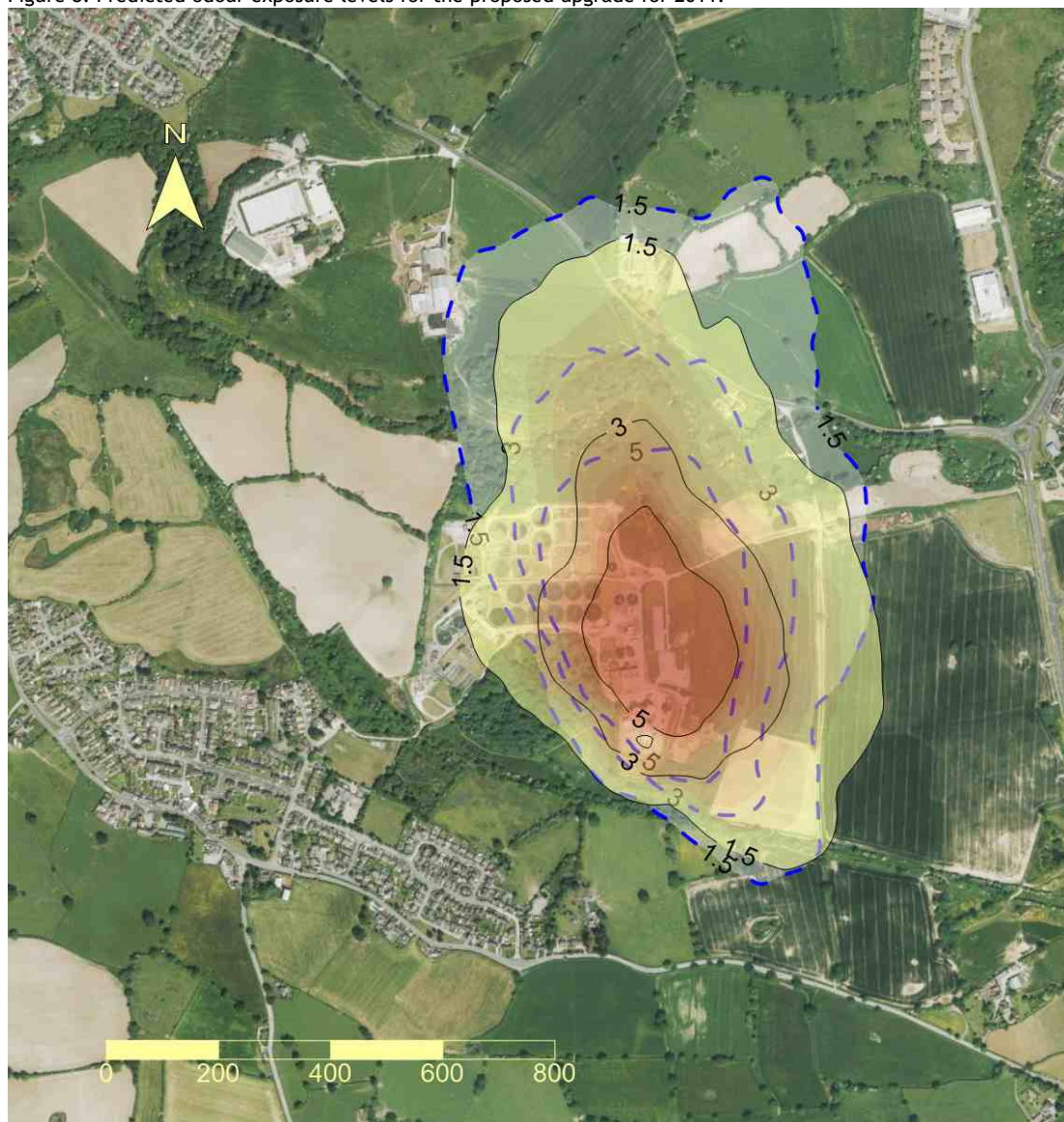


Figure 9 Predicted odour exposure levels for the proposed upgrade for 2012.

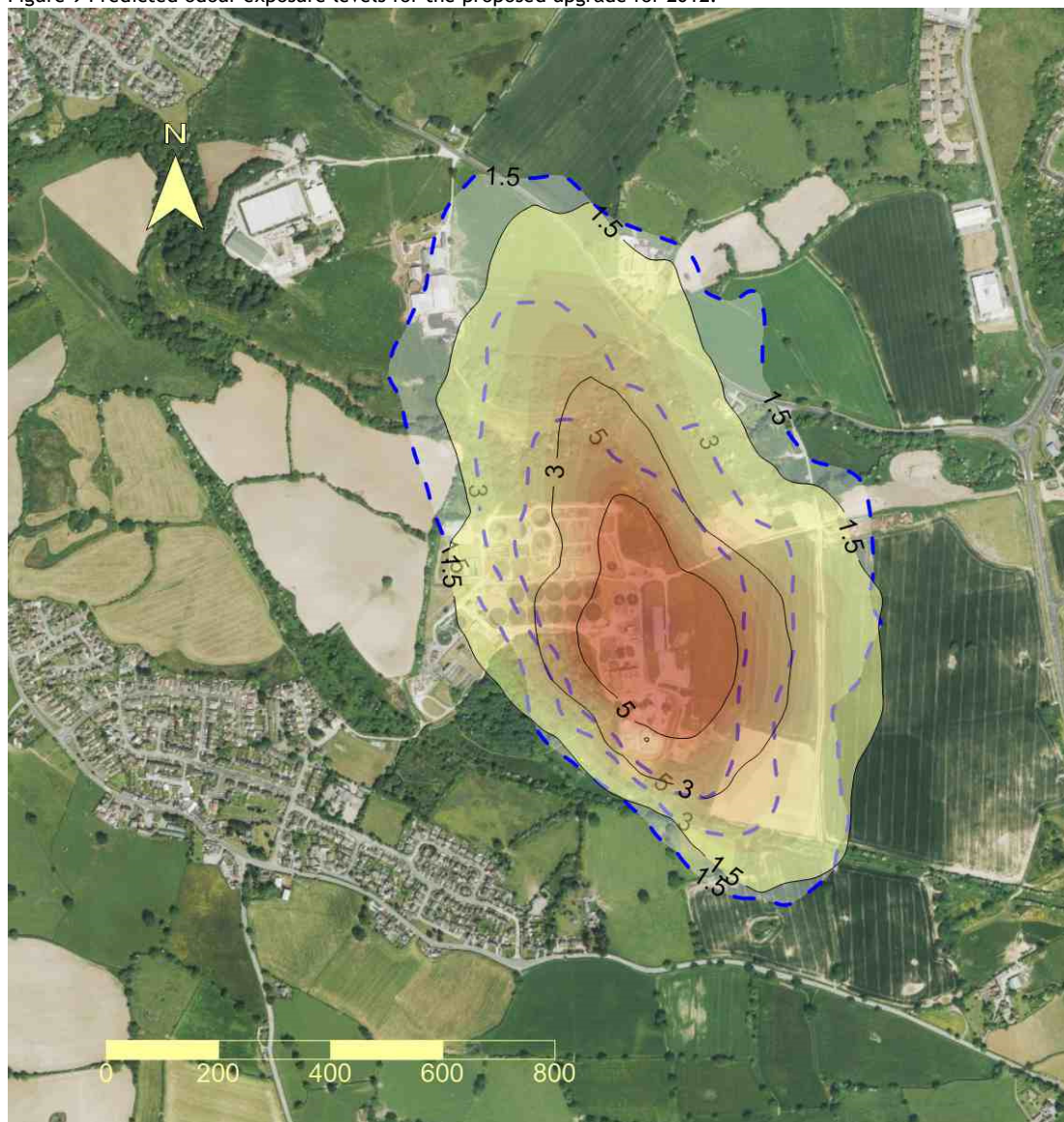
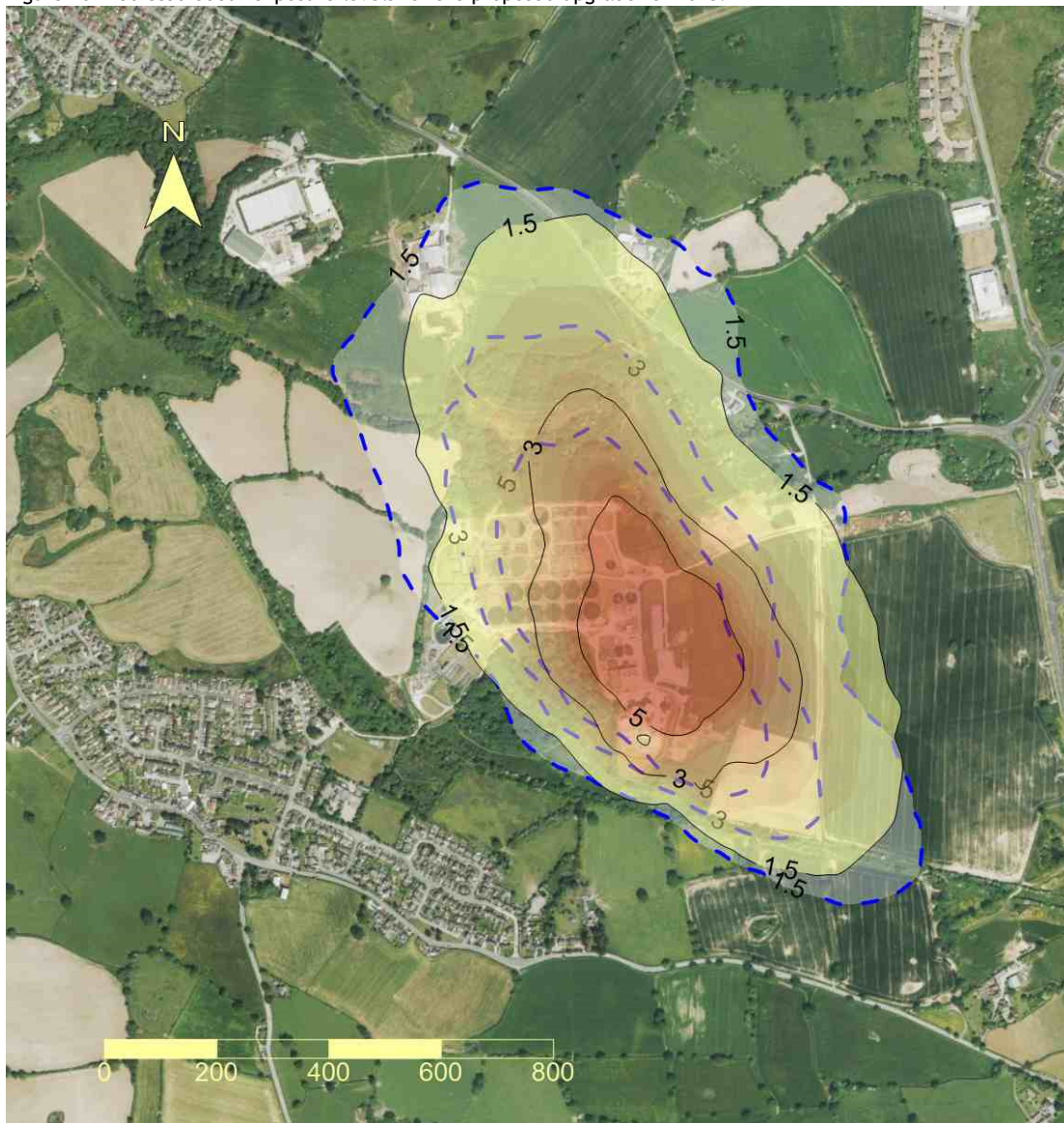


Figure 10 Predicted odour exposure levels for the proposed upgrade for 2013.



Alternative upgrade

The dispersion model outputs for years 2009, 2011, 2012 and 2013 are presented in the figures below. In each case upgrade scenario 2 is presented as solid black lines and the current baseline for the corresponding year is presented as blue dashed lines.

Figure 11 Predicted odour exposure levels for the alternative upgrade for 2009.

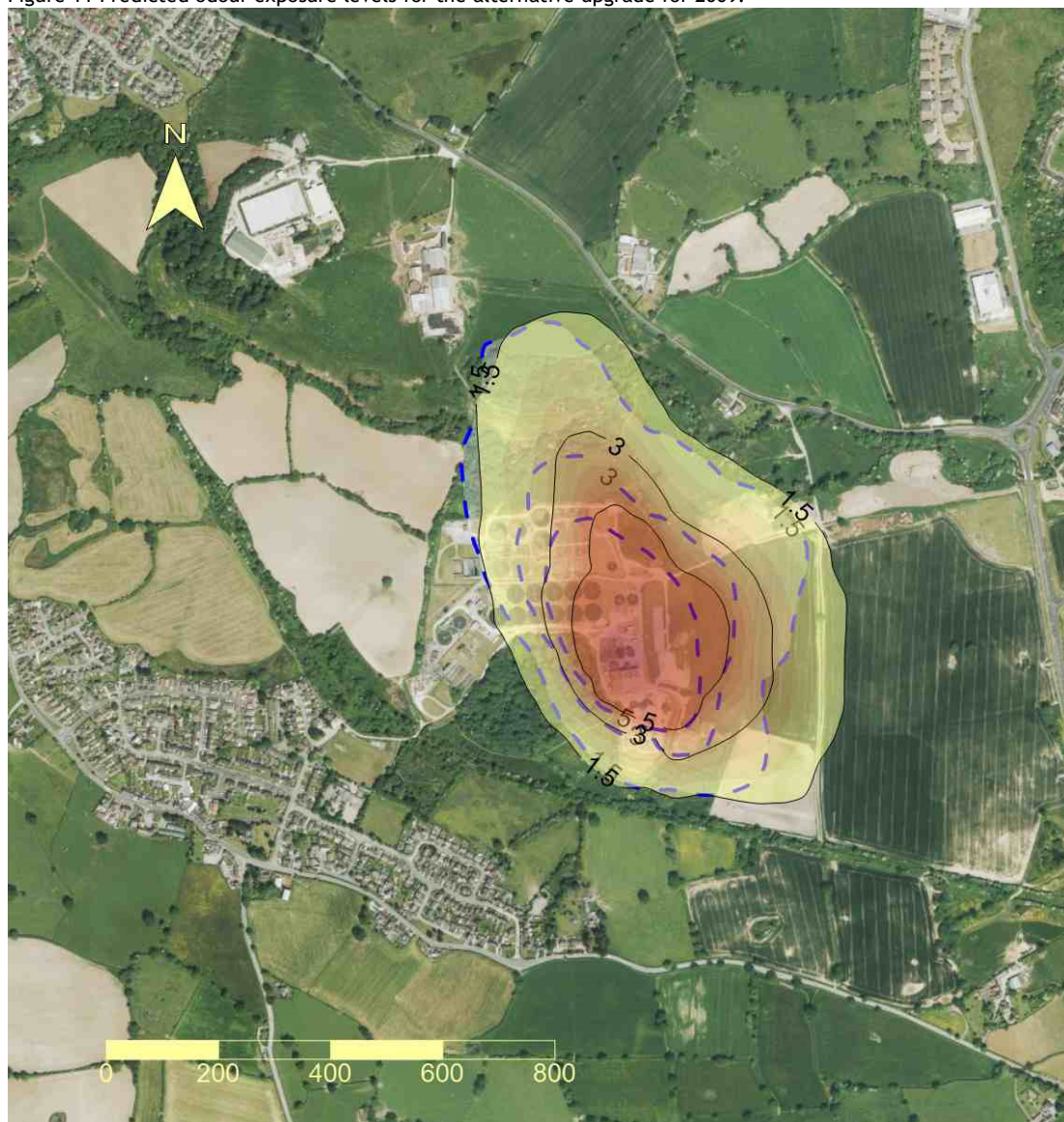


Figure 12 Predicted odour exposure levels for the alternative upgrade for 2011.

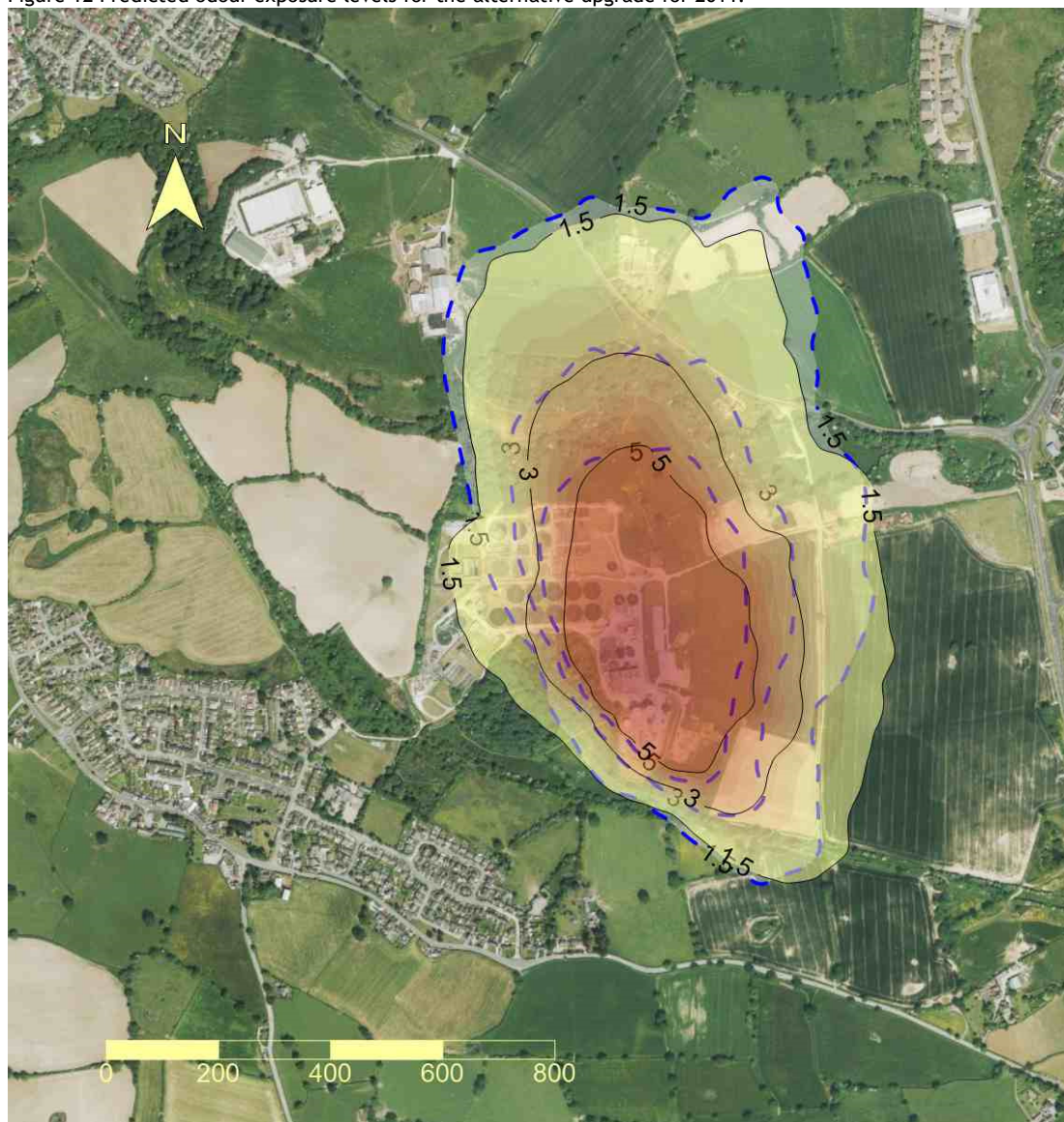


Figure 13 Predicted odour exposure levels for the alternative upgrade for 2012.

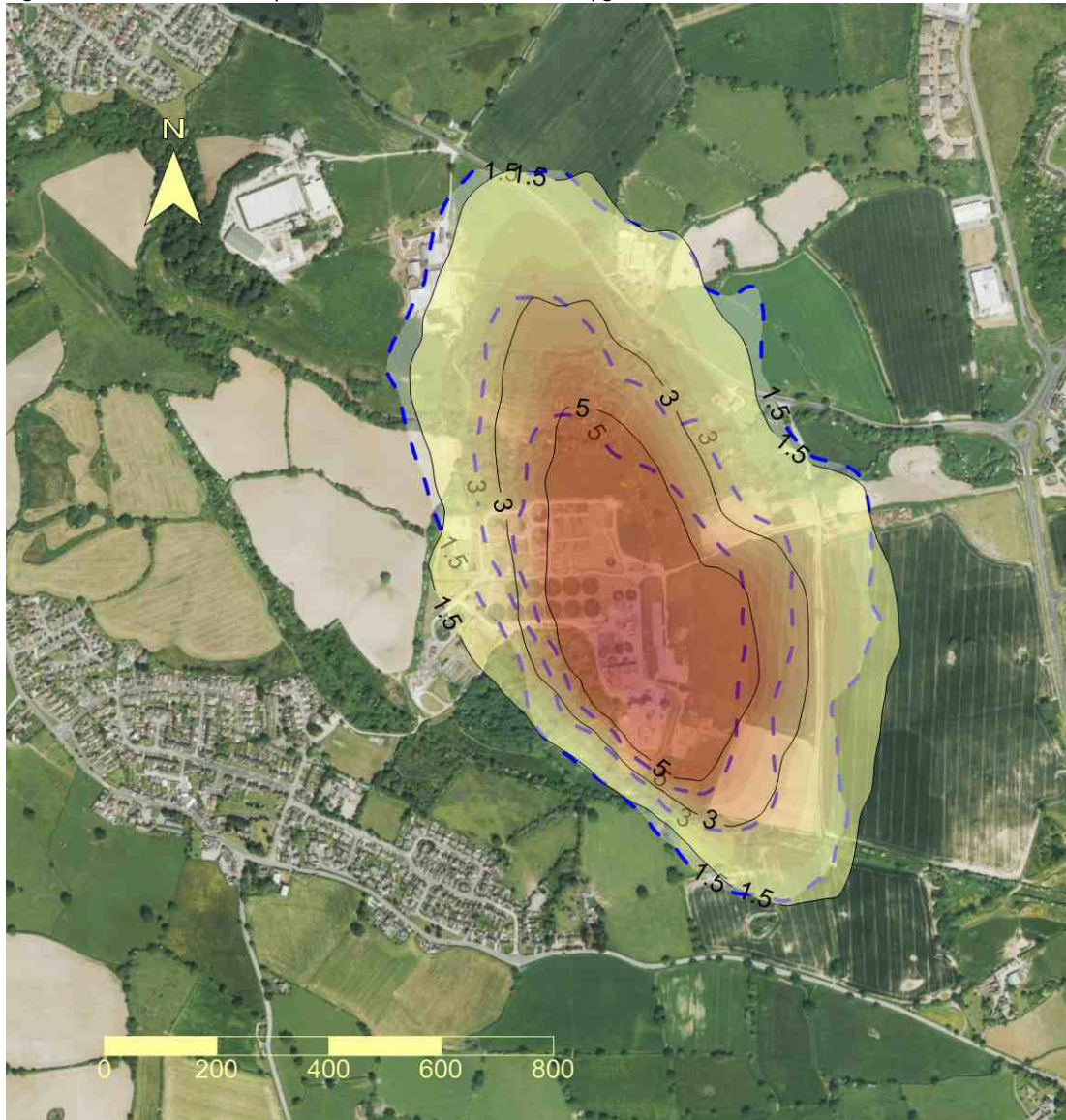


Figure 14 Predicted odour exposure levels for the alternative upgrade for 2013.

