As can be observed from *Table 2.1*, and using the Dutch based ranking system, Wastewater treatment plants (WWTP) have a mean raking of 12.90 in terms of dislike. Other odours with similar mean dislike ranking include Oil Refinery, Livestock Feed Factory, Livestock odour (i.e. intensive pig/poultry production). Generic odours such as Sauerkraut and Cleaning agents have also similar dislike abilities to WWTP odours. Dravnieks *et al.*, 1994 performed hedonic tone ranking of generic odours including Sauerkraut, Cleaning agents and Sewer odour and obtained a mean hedonic score of –0.60, –1.69 and –3.68, respectively. There is a clear trend in these studies whereby both mean ranking of dislike ability and hedonic scoring provide subjective ranking of odours and their respective ability to cause offensive/complaint. It would appear that when the hedonic tone of the odour reached a specific level, the odour hedonic tone decreases rapidly to small increases in odour threshold concentration (i.e. small increases in odour threshold concentrations will cause a large change in the perceived odour offensiveness). Such trends have been observed by Odour Monitoring Ireland in a laboratory-based environment. It has been suggested that when an odour reached an odour intensity level of 3 (distinct) and a mean hedonic score of –2 (unpleasant), an odour will become offensive and cause odour complaint. This scoring level can be assessed through the use of olfactometric techniques in a laboratory based environment whereby the odour concentration level corresponding to an odour intensity level of 3 and a hedonic tone of –2 can be determined. This methodology of analysis is very important in spot-checking odour abatement systems. By implementing hedonic tone assessment techniques on source odour samples, the odour threshold concentration responsible for causing on odour complaint following dynamic dilution can be determined. VDI Guidelines 3882 Part 2 – Determination of odour Hedonic tone specifies a methodology for such an assessment.

3.3.4. Commonly used odour annoyance criteria utilised in dispersion models

An odour impact criterion defines the odour threshold concentration limit value above baseline in ambient air, which will result in an odour stimulus capable of causing an odour complaint. There are a number of interlinked factor, which causes a nearby receptor (i.e. resident) to complain. These include:

- Odour threshold concentration, odour intensity and hedonic tone-defined measurable parameters at odour source,
- Frequency of odour-how frequently the odour is present at the receptor location,
- Duration of odour-how long the odour persists at the receptor location,
- Physiological-previous experiences encountered by receptor, etc.

By assessing these combined interlinked factors, the ability for a facility to cause odour complaint can be determined. As odour is not measurable in ambient air due to issues in sampling techniques, limit of detections for olfactometers and the inability to monitor continuously, therefore dispersion models become useful tools in odour impact assessments and odour risk analysis. Dispersion modelling also allows for the assessment of proposed changes in processes within the WWTP without actually having to wait for the processes to be changed (i.e. predictive analysis).

When utilising dispersion models for impact assessment, specific impact criterion (odour concentrations) need to be established at receptors. For odour assessment in general terms, this is called an odour impact criterion, which defines the maximum allowable ground level concentration (GLC) of odour at a receptor location for a particular exposure period (i.e. ≤ 1.50 Ou_E m^{-3} at the 98^{th} percentile of hourly averages). Commonly used odour annoyance criteria in Ireland, UK, Netherlands and other world wide countries are illustrated in *Table 2.2*. The odour concentration, % odour exposure at this odour concentration, the dislike ability, the dispersion model and industry it applies are presented (*see Table 2.2*).

Table 2.2. Odour annoyance criterion used for environmental odours.

Country	Odour conc. limit (Ou_E m^3)	Percentile value (%)	Average time (minutes)	Industry type	Dispersion model	Type area it applies	Dislike ability (see *Table 1.2*)	Application of criterion
Ireland	≤6.0[1]	98th	60	Intensive pig production	Complex 1	Limit value for existing pig production units	12.80	For all pig production units in Ireland
Ireland	≤3.0[1]	98th	60	Intensive pig production	Complex 1	Limit value for existing pig production units	12.80	For all pig production units in Ireland
Ireland	≤1.50[2]	98th	60	Slaughter house	Complex 1/ISC ST3	Limit value for new slaughter house facilities	17.0	Limit value for new slaughter house facilities
Ireland	≤1.50[3]	98th	60	Balbriggan WWTP	ISC Prime/ISC ST3	Limit value at sensitive receptor locations	12.90	Limit value for existing facility at sensitive receptor locations.
UK	≤1.50[4]	98th	60	WWTP	ADMS/ AERMOD	Indicative odour exposure criterion for licensing	12.90	IPPC H4 Guidance Notes Part 1-Regulation and Permitting, Environment Agency
Ireland	≤3.0[3]	98th	60	Enniscorthy WWTP	ISC Prime/ISC ST3	Limit value at sensitive receptor locations	12.90	Limit value for existing facility at sensitive receptor locations.
UK	≤5.0[4]	98th	60	WWTP-Newbiggin by the Sea Planning	ADMS	Used as a limit value prevent odour impact associated with WWTP	12.90	Planning application-Newbiggin by the Sea
UK	≤1.50[4]	98th	60	Livestock feed factory	ADMS/ AERMOD	Indicative odour exposure criterion for licensing	13.20	IPPC H4 Guidance Notes Part 1-Regulation and Permitting, Environment Agency
UK	≤1.50[4]	98th	60	Oil refinery	ADMS/ AERMOD	Indicative odour exposure criterion for licensing	13.20	IPPC H4 Guidance Notes Part 1-Regulation and Permitting, Environment Agency
UK	≤3.0[5]	98th	60	Landfill activities	Complex 1	Odour exposure criterion developed through laboratory based odour intensity studies and complaint correlation	14.10	Longhurst et al 1998 for Landfill planning application
NL	≤3.50[6]	98th	60	WWTP	Complex 1	Limit value to prevent odour nuisance existing plant	12.90	Industry sector specific air quality criterion for odours in Netherlands
NL	≤1.50[6]	98th	60	WWTP	Complex 1	Limit value to prevent odour nuisance new plant	12.90	Industry sector specific air quality criterion for odours in Netherlands

Notes: [1] denotes reference BAT Note development for intensive agriculture sector & EPA, 2001. Odour Impacts and Odour emissions control for Intensive Agriculture. R&D Report Series no. 14. EPA, Johnston Castle, Wexford.

[2] denotes EPA, (2004). BAT Notes for the Slaughterhouse sector, EPA, Johnston Castle, Wexford.

[3] denotes Odour limit values used during EIA application for WWTP's.

[4] denotes Environment Agency, (2002). Technical Guidance Notes IPPC H4-IPPC, Horizontal Guidance for Odour, Part 1-Regulation and Permitting. Environment Agency, Bristol, UK.

[5] denotes Magette, W., Curran, T., Provolo, G., Dodd, V., Grace, P., and Sheridan, B., (2002). BAT Note for the Pig and Poultry Sector. EPA, Johnston Castle, Wexford.

[6] denotes EPA, 2001. Odour Impacts and Odour emissions control for Intensive Agriculture. R&D Report Series no. 14. EPA, Johnston Castle, Wexford

Table 2.2. illustrates the range of odour impact criterion used in Ireland, UK, Netherlands, and other worldwide communities. The impact criterion accepted in Ireland and UK are based on research performed in Netherlands over the mid 80's and early 90's. In the late 90's the UK Environment Agency performed some research on validating those standards developed in Netherlands through studies performed in the UK. The main aims of these studies were for the developing of guidance notes on odour for licensing procedures under the EPA Act 1992. Over the last decade, these impact criterions have been providing protection to the community at large in the vicinity of such facilities. There is a general trend in odour impact criterion and dislike ability presented in *Table 2.1*. As can be observed in *Table 2.1 and 2.2*, the more offensive the odour is perceived, the lower the acceptable ambient odour concentration above baseline. Odours such as bakery odours are considered less offensive than pig production facilities and this is observed through the relative dislike ability and also the odour impact criterion established to limit nuisance. Wastewater treatment plants have similar dislike ability to intensive pig production facilities and therefore it would be rational to suggest a similar odour impact criterion to intensive pig production facilities. Other factors that require consideration include, the location of the WWTP / pumping station, the surrounding sensitive receptors, and amount of odour mitigation to be implemented into the overall design. For example in Ireland, pig production facilities are generally located in rural environments, whereby sensitive receptors in the vicinity of the facility are working in similar livestock operations and therefore do not consider the perceived odour as offensive as say a person not familiar with the odour. WWTP's / Pumping stations on the other hand in recent times are located close to the source of effluent and in the vicinity of sensitive receptors (population encroachment of residences and industrial estates). In addition, in recent times WWTP's and pumping stations have installed odour control technologies to limit the risk of odour complaint (e.g. Sutton Pumping station, Limerick Main Drain Pumping station, Ringsend Pumping station, etc.). By abating the sources of offensive odours within the WWTP and Pumping station, the odour limit value becomes less conservative as the odour emitted from the odour abatement technology is considered less offensive and therefore has a markedly lower potential risk of causing complaint. Taking into account these factors for the WWTP's and Pumping stations, it is proposed that:

- All sensitive locations and areas of amenity should be located outside the 1.50 Ou_E m^{-3} at the 98th percentile of hourly averages over a meteorological year.
- All sensitive locations and areas of amenity should be located outside the 3.0 Ou_E m^{-3} at the 99.5th percentile of hourly averages over a meteorological year.

These proposed odour impact criterion is sufficiently conservative to provide protection to the community at large taking into account latest suggested odour impact criterion by environmental agencies in Ireland, UK and Netherlands. In the case of the proposed Cork Harbour Main Drainage Scheme WWTP, all significant odour sources (wastewater handling and sludge handling operations) capable of generating offensive odours will be enclosed, sealed and negatively ventilated to an odour control system. Only the Aeration tankage, secondary settlement tankage and storm water tankage within the proposed WWTP will be open to atmosphere. All other odour sources will be enclosed, sealed and abated using odour treatment system (two stages of treatment for biological treatment unit as first stage).

For all pumping stations, an odour management system will be implemented to ensure that no uncontrolled release of fugitive odours occur.

For the WWTP odour impact assessment, the 99.5th percentile of hourly averages is used to complement the 98th percentile of hourly averages to take account of predicted downwind odour concentrations during short time worst-case meteorological conditions thereby providing added protection to the public at large. This was not performed upon the pumping station odour impact assessment as the predicted plume spread as assessed using the 98th percentile assessment criterion concluded negligible odour impact due to the overall low odour emissions due to odour source characteristics (i.e. odour emission rate from pumping stations is predicted to be low).

3.4. Meteorological data.

Cork airport meteorological station Year 1993 to 1997 inclusive was used for the operation of Aermod Prime. This allowed for the determination of the worst-case meteorological year for the determination of overall odour impact from the proposed Cork Harbour Main Drainage Scheme WWTP and each of the five Pumping stations on the surrounding population.

3.5. Terrain data.

Topography affects in the vicinity of the WWTP site were accounted for within the dispersion modelling assessment using a topography file. All significant deviations in terrain are examined in modelling computations through terrain incorporation using AerMap software.

All building wake effects within the propose WWTP and Pumping stations were accounted for in the modelling scenarios (i.e. building effects on point sources) as this can have a major effect on the odour plume dispersion at short distances.

4. Results

This section will present the results obtained from the study.

4.1. Odour emission data

Two data sets for odour emission rates were calculated to determine the potential odour impact of the proposed WWTP operation and design utilising site specific and library individual source odour emission data gathered onsite. These scenarios included:

Ref Scenario 1: Predicted overall odour emission rate from proposed Cork Harbour Main Drainage Scheme WWTP specimen design with the incorporation of odour mitigation protocols (*see Table 4.1*).

Ref Scenario 2: Predicted overall odour emission rate from major pumping stations with the incorporation of odour management systems (i.e. tight fitting covers, etc.) (*see Table 4.2*).

A worst-case odour-modelling scenario was chosen to estimate worst-case odour impact from the proposed Cork Harbour Main Drainage Scheme WWTP and five pumping stations following the incorporation of odour management systems (i.e. five years of met data, predicted odour emission rate, etc.).

4.2. Odour emission rates from Cork Harbour Main Drainage Scheme specimen design WWTP and Pumping stations operations for atmospheric dispersion modelling Scenario 1 and 2

Table 4.1 and *Table 4.2* illustrate the overall odour emission rate from the proposed Cork Harbour Main Drainage Scheme WWTP and five pumping stations (i.e. with installed odour management systems implemented).

As can be observed in *Table 4.1*, the overall odour emission rate from the proposed Cork Harbour Main Drainage Scheme WWTP specimen design will be at or less than 6,611 Ou_E/s. This overall source odour emission rate is based on worst case estimated of maximum emissions that could occur from the site with odour mitigation strategies implemented.

Table 4.2 illustrates the overall odour emission rate from the five pumping stations to be located in Raffeen, West Beach, Monkstown, Church Road (existing) and Carrigaloe Pumping Stations following implementation of odour management systems.

Odour emission rates are based on a number of mitigation assumptions that will require to be implemented into the Cork Harbour Main Drainage Scheme WWTP while odour emissions rates for the five pumping stations design are based on the implementation of good design and implementation of standard odour management systems (i.e. tight fitting covers).

Table 4.1. Predicted overall odour emission rate from proposed Cork Harbour Main Drainage Scheme WWTP specimen design with the incorporation of odour mitigation protocols (ref Scenario 1).

Source identity	Area (m^2)	Odour emission flux ($Ou_E/m^2/s$)	Volumetric airflow rate (m^3/s)	Odour threshold conc (Ou_E/m^3)	Odour emission rate (Ou/s)	% Contribution
Inlet works-Primary treatment building[1]	0	See OCU emission rate		-	0	0
Primary settlement tank 1[2]	0	See OCU emission rate	-	-	0	0
Primary settlement tank 2[2]	0	See OCU emission rate	-	-	0	0
Primary settlement tank 3[2]	0	See OCU emission rate	-	-	0	0
Storm water tank 1[3]	952.47	0.50		-	476	7.20
Storm water tank 2[3]	952.47	0.50		-	476	7.20
Aeration tank[4]	1200	1.20		-	1440	21.78
Secondary settlement tank 1[5]	952.47	0.50		-	476	7.20
Secondary settlement tank 2[5]	952.47	0.50		-	476	7.20
Secondary settlement tank 3[5]	952.47	0.50		-	476	7.20
Secondary settlement tank 4[5]	952.47	0.50		-	476	7.20
OCU 1 - Inlet works building OCU[6]	-	-	1.0	300	300	4.54
OCU 2 - Primary settlement tanks/Flow splitting chambers OCU[7]	-	-	0.93	300	279	4.22
OCU 3 - Sludge holding tanks/Digesters/Sludge drier OCU[8]	-	-	2.27	500	1135	17.17
OCU 4 - Primary sludge storage OCU[9]	-	-	1	300	300	4.54
OCU 5 - Secondary sludge treatment OCU[10]	-	-	1	300	300	4.54
Total odour emission rate[11, 12, 13]	**-**	**-**	**-**	**-**	**6,611**	**100**

Notes:

[1, 6] denotes all inlet works processes (screening and grit removal) will be double contained (to achieve legislative requirements of odourants in work space environment) and up to 6 to 10 AC/hr applied within enclosed process. All odourous air will be treated in an odour control unit. The double containment principle will apply here to ensure no emissions of odours escape to the headspace of the building. At all times the legislative concentrations of odourant will be required to be below their respective occupational exposure concentration level in all buildings.

[2] denotes the Primary settlement tanks will be covered with tight fitting covers and negatively ventilated to an odour control system.

[3] denotes the storm water tanks will be fitted with automated washing facilities to ensure each tank is free of organic debris following emptying. This will minimise any odour emissions associated with such process.

[4] denotes the odour emission rate from aeration process is based on library data assuming efficient oxygen transfer through the wastewater liquor (absence of anaerobicity). Advancements in the oxygen transfer equipment market have facilitated faster aerobic digestion of wastewater and efficient transfer of oxygen into the wastewater therefore reducing odour emission rates in comparison to older based techniques (OMI database on WWTP's in Ireland)

[5] denotes that secondary settlement tanks will be operated in accordance with standard practices and the build-up of scum will be prevented.

[7] denotes all sludge drying operations will be performed indoors. The sludge drying operation will be effectively sealed and negatively ventilated to prevent odour release to the headspace of the building. All odours generated as a result of drying and storage of undried/drier sludge cake will be negatively extracted to an odour control unit.

[8] denotes all sludge thickening process including Gravity belt thickeners and centrifuges will be double contained within their respective building and negatively ventilated to an odour control unit. All associated sumps and tankage will be sealed with tight fitting covers and negatively ventilated to an odour control unit.

[9] denotes all tankage associated with the handling and processing of primary sludge will be sealed with tight fitting covers and negatively ventilated to an odour control unit. All primary sludge treatment processes will be enclosed and negatively ventilated to an odour control unit.

[10] denotes all tankage associated with the handling and processing of secondary sludge will be sealed with tight fitting covers and negatively ventilated to an odour control unit. All secondary sludge treatment processes will be enclosed and negatively ventilated to an odour control unit.

[11] denotes the overall odour emission rate of 6,611 Ou/s is based on the facts of effective containment and extraction of odours from odour generating processes. The odour emission rate associated with odour treatment is assumed to be residual odour from the odour treatment process itself and aeration, secondary settlement and storm water tank processes.

[12] denotes it is anticipated that 5 odour control system will be installed providing an estimated treatment volume of 6.20 m^3/s to an exhaust odour concentration of less than or equal to 300 Ou_E/m^3 for OCU's 1, 2, 4, 5 and less than of equal to 500 Ou_E/m^3 for OCU 3 . This equated to an overall odour emission rate of 2,314 Ou_E/s from the treatment technologies. This treatment volume airflow rate should be sufficient to capture and maintain each process under slight negative pressure if effective enclosure, double containment and sealing of tankage/processes occur. In accordance with good engineering practice, the overall stack height will be at least 12 metres high. The overall effective efflux velocity will be 15 m/s at stack tip. This will aid in the dispersion of residual odours. The hedonic tone of this odour exhaust from the odour control units should not be considered unpleasant (Scale greater than –2) as assessed in accordance with VDI 3882:1997, part 2; ('Determination of Hedonic). The specimen design suggests the use of three OCU's. The following should be achieved at minimum: total odour emission rate of 6,611 Ou/s is achieved for the entire WWTP; the total minimum odour treatment volume of 6.20 m^3/s is treated within the OCU's, and a total odour emission rate of less than or equal to 2,314 Ou_E/s is achieved for the OCU's, then the number of OCU's utilised onsite is not important from an odour treatment viewpoint.

[13] denotes the overall odour treatment extraction rate is assumed and may need revision depending on process layout and final engineering design. This can only be changed if the DBO contractor can provide evidence that the selected design is sufficient to contain minimise and prevent fugitive odour emission to atmosphere. The overall containment process will be process proved independently using traditional smoke generation techniques so as to demonstrate containment of odours.

Table *4.2.* Predicted overall odour emission rate from five Pumping stations specimen design with the implementation of good design and odour management system operation (i.e. tight fitting covers, etc.) (ref Scenario 2).

Source identity	Odour emission rate (Ou_E/s)
Raffeen PS OCU[1]	90
West beach PS OCU[1]	360
Monkstown PS OCU[1]	120
Church Rd PS OCU[1]	81
Carrigaloe PS OCU[1]	51

Notes:

[1] denotes the overall odour emission rate will be dependent on the implementation of good design and odour management systems (e.g. good design in term of odour, tight fitting covers, etc.).

4.3. Results of odour dispersion modelling for the proposed Cork Harbour Main Drainage Scheme WWTP and Pumping stations operation and design

Aermod Prime was used to determine the overall odour impact of the proposed Cork Harbour Main Drainage Scheme WWTP and Pumping stations operation at as set out in odour impact criteria *Table 2.1* and *2.2*. The output data was analysed to calculate:

Ref Scenario 1:

- Predicted odour emission contribution of overall proposed Cork Harbour Main Drainage Scheme WWTP operation to surrounding population (*see Table 4.1*), to odour plume dispersal at the 98th percentile for an odour concentration of less than or equal to 1.50 Ou_E m^{-3} (*see Figure 8.1*).
- Predicted odour emission contribution of overall proposed Cork Harbour Main Drainage Scheme WWTP operation to surrounding population (*see Table 4.1*), to odour plume dispersal at the 99.5th percentile for an odour concentration of less than or equal to 3.0 Ou_E m^{-3} (*see Figure 8.2*).
- Predicted odour emissions contribution of individual grouped Odour control units 1 to 5 to surrounding population (*see Table 4.1*), to odour plume dispersal at the 98th percentile for an odour concentration of less than or equal to 0.30 Ou_E/m^3 (*see Figure 8.3*).
- Predicted odour emissions contribution of individual grouped Aeration, Secondary settlement and Storm water tankage sources to surrounding population (*see Table 4.1*), to odour plume dispersal at the 98th percentile for an odour concentration of less than or equal to 1.50 Ou_E/m^3 (*see Figure 8.4*).

These odour impact criterions were chosen for the WWTP in order to ascertain the level of proposed impact to the surrounding residential and industrial population in the vicinity of the proposed WWTP.

Ref Scenario 2: These contours are selected in order to allow for representation of the results obtained from the dispersion modelling. The limit value in terms of odour impact criterion is less than 1.50 Ou_E/m^3 at the 98th percentile and less than 3.0 Ou_E/m^3 at the 99.5th percentile of hourly averages. Since the overall predicted odour emission rate from the five major pumping stations is low (due to the small nature and characteristics of the odour source), these odour contours were selected for illustrative purposes only to demonstrate the absence of odour impact and in addition, the contours for the 99.5th percentile are not presented.

- Predicted odour emission contribution of overall proposed Raffeen Pumping Station operation to surrounding population (*see Table 4.2*), to odour plume dispersal at the 98th percentile for an odour concentration of less than or equal to 0.10 Ou_E m^{-3} (*see Figure 8.5*).
- Predicted odour emission contribution of overall proposed West beach Pumping Station operation to surrounding population (*see Table 4.2*), to odour plume dispersal at the 98th percentile for an odour concentration of less than or equal to 0.30 Ou_E m^{-3} (*see Figure 8.6*).
- Predicted odour emission contribution of overall proposed Monkstown Pumping Station operation to surrounding population (*see Table 4.2*), to odour plume dispersal at the 98th percentile for an odour concentration of less than or equal to 0.20 Ou_E m^{-3} (*see Figure 8.7*).
- Predicted odour emission contribution of overall proposed Church Road Pumping Station operation to surrounding population (*see Table 4.2*), to odour plume dispersal at the 98th percentile for an odour concentration of less than or equal to 0.14 Ou_E m^{-3} (*see Figure 8.8*).
- Predicted odour emission contribution of overall proposed Carrigaloe Pumping Station operation to surrounding population (*see Table 4.2*), to odour plume dispersal at the 98th percentile for an odour concentration of less than or equal to 0.10 Ou_E m^{-3} (*see Figure 8.9*).

Since the predicted odour emission rate from the pumping stations is low following the implementation of odour management systems (e.g. good design in terms of odour management, tight fitting covers, etc.), odour isopleths suitable for reporting clarity were chosen (i.e. actual impact criterion is less than or equal to 1.50 Ou_E/m^3 at the 98th percentile of hourly averages over 5 years of meteorological data). All odour impact criterions chosen were in accordance with best international practice (*see Section 3.3.4*). Taking this low impact into account, there is no requirement to perform risk analysis using the 99.5th percentile assessment criterion, as the predicted odour impact criterion will always be below this level.

These computations give the odour concentration at each Cartesian grid receptor location that is predicted to be exceeded for 0.50% (44 hours) and 2% (175 hours) of a standard meteorological year.

This will allow for the predictive analysis of any potential impact on the neighbouring sensitive locations while the WWTP and Pumping stations are in operation. It will also allow the operators of the WWTP and Pumping station site to assess the effectiveness of their suggested odour abatement/minimisation strategies. The intensity of the odour from two or more sources of the WWTP operation will depend on the strength of the initial odour threshold concentration from the sources and the distance downwind at which the prediction and/or measurement is being made. Where the odour emission plumes from a number of sources combine downwind, then the predicted odour concentrations may be higher than that resulting from an individual emission source. It is important to note that various odour sources have different odour characters. This is important when assessing those odour sources to minimise and/or abate. Although an odour source may have a high odour emission rate, the corresponding odour intensity (strength) may be low and therefore it is easily diluted. Those sources that express the same odour characters as an odour impact should be investigated first for abatement/minimisation before other sources are examined as these sources are the driving force behind the character of the perceived odour.

5. Discussion of results

This section will discuss the results obtained during the desktop study.

5.1. Odour plume dispersal for proposed Cork Harbour Main Drainage Scheme WWTP specimen design with the incorporation of odour mitigation protocols

The plotted odour concentrations of $\leq$ 1.50 Ou_E m^{-3} for the 98th percentile and $\leq$ 3.0 Ou_E m^{-3} for the 99.5th percentile for the proposed Cork Harbour Main Drainage Scheme WWTP specimen design operation are illustrated in *Figure 8.1 and Figure 8.2*, respectively. As can be observed for the 98th percentile contour, it is predicted that odour plume spread is small with a radial spread of 80 metres from the boundary of the facility in a northerly direction. In accordance with odour impact criterion in *Section 3.6.4*, and in keeping with currently recommended odour impact criterion in this country, no long-term odour impacts will be generated by receptors in the vicinity of the future proposed WWTP.

In terms of the 99.5th percentile of hourly averages over five years of meteorological data, the overall odour plume spread is similar with a radial spread of 75 metres in a northerly and easterly direction. In accordance with odour impact criterion in *Section 3.6.4*, and in keeping with currently recommended odour impact criterion in this country, no short-term odour impacts will be generated by receptors in the vicinity of the future proposed WWTP.

Figures 8.4 and 8.5 illustrates the odour plume spread for individual grouped odour sources to include odour control units (OCU's) 1 to 5 and tankage odour sources Aeration, Secondary settlement and Storm water tankage. As can be observed, the main contributor of odour to the actual plume spread is the aeration, secondary settlement and storm water tankage. All other offensive odour sources will be covered, sealed and negatively ventilated and odourous air directed to two stages of odour control if biological treatment is chosen as first stage. The maximum predicted ground level concentration for odour control units 1 to 5 will be less than 0.41 Ou_E/m^3 at the 98 percentile of hourly averages over 5 years of meteorological data. This is a result of a guaranteed odour threshold concentration of less than 300 Ou_E/m^3 for OCU's 1, 2, 4, and 5 and less than 500 Ou_E/m^3 for OCU 3. The overall stack heights of each OCU is 12 m high from ground level with an efflux velocity greater than 15 m/s.

5.2. Odour plume dispersal for five Pumping stations with the incorporation of good design and odour management systems

The plotted odour concentrations of ≤ 0.10 Ou_E m^{-3} for the 98^{th} of hourly averages for five years of meteorological data for the proposed Raffeen Pumping station is illustrated in *Figure 8.5*. The maximum ground level concentration of odour in the vicinity of the facility will be 0.19 Ou_E/m^3 for the 98^{th} percentile following the implementation of standard design elements for odour management (e.g. tight fitting covers, etc.). In accordance with odour impact criterion presented in *Section 3.3.4*, no long-term odour impacts will be perceived in the vicinity of the Pumping station. This is up to 87% lower than the odour impact criterion presented in *Section 3.3.4*.

The plotted odour concentrations of ≤ 0.30 Ou_E m^{-3} for the 98^{th} of hourly averages for five years of meteorological data for the proposed West beach Pumping station is illustrated in *Figure 8.6*. The maximum ground level concentration of odour in the vicinity of the facility will be 0.34 Ou_E/m^3 for the 98^{th} percentile following the implementation of standard design elements for odour management (e.g. tight fitting covers, etc.). In accordance with odour impact criterion presented in *Section 3.3.4*, no long-term odour impacts will be perceived in the vicinity of the Pumping station. This is up to 77% lower than the odour impact criterion presented in *Section 3.3.4*.

The plotted odour concentrations of ≤ 0.20 Ou_E m^{-3} for the 98^{th} of hourly averages for five years of meteorological data for the proposed Monkstown Pumping station is illustrated in *Figure 8.7*. The maximum ground level concentration of odour in the vicinity of the facility will be 0.23 Ou_E/m^3 for the 98^{th} percentile following the implementation of standard design elements for odour management (e.g. tight fitting covers, etc.). In accordance with odour impact criterion presented in *Section 3.3.4*, no long-term odour impacts will be perceived in the vicinity of the Pumping station. This is up to 84% lower than the odour impact criterion presented in *Section 3.3.4*.

The plotted odour concentrations of ≤ 0.14 Ou_E m^{-3} for the 98^{th} of hourly averages for five years of meteorological data for the existing Church Road Pumping station is illustrated in *Figure 8.8*. The maximum ground level concentration of odour in the vicinity of the facility will be 0.18 Ou_E/m^3 for the 98^{th} percentile following the implementation of standard design elements for odour management (e.g. tight fitting covers, etc.). In accordance with odour impact criterion presented in *Section 3.3.4*, no long-term odour impacts will be perceived in the vicinity of the Pumping station. This is up to 88% lower than the odour impact criterion presented in *Section 3.3.4*.

The plotted odour concentrations of ≤ 0.10 Ou_E m^{-3} for the 98^{th} of hourly averages for five years of meteorological data for the proposed Carrigaloe Pumping station is illustrated in *Figure 8.9*. The maximum ground level concentration of odour in the vicinity of the facility will be 0.15 Ou_E/m^3 for the 98^{th} percentile following the implementation of standard design elements for odour management (e.g. tight fitting covers, etc.). In accordance with odour impact criterion presented in *Section 3.3.4*, no long-term odour impacts will be perceived in the vicinity of the Pumping station. This is up to 90% lower than the odour impact criterion presented in *Section 3.3.4*.

The implementation of good design and odour management systems (e.g. standard design for odour minimisation, tight fitting covers, etc.) within each pumping station (both minor and major) will minimise the uncontrolled release of fugitive odour emissions and prevent complaints from the public at large.

6. Conclusions

A worst-case odour emission scenario was modelled using the atmospheric dispersion model Aermod Prime with meteorology data representative of the study area. A worst-case odour emission data set was used to predict any potential odour impact in the vicinity of the proposed Cork Harbour Main Drainage Scheme WWTP and five Pumping stations. Odour impact potential was discussed for proposed operations with the implementation of management and mitigation protocols. It was concluded that:

Cork Harbour Main Drainage Scheme WWTP

- In accordance with odour impact criterion in *Table 2.2*, and in keeping with current recommended odour impact criterion in this country, no odour impact will be perceived by sensitive receptors in the vicinity of the proposed Cork Harbour Main Drainage Scheme WWTP following the installation of proposed odour management, minimisation and mitigation protocols assuming specimen design. As can be observed, the overall odour emission rate from the new proposed Cork Harbour Main Drainage Scheme WWTP will be no greater than 6,611 Ou_E/s based on the specimen design.
- All residents/industrial neighbours in the vicinity of the proposed Cork Harbour Main Drainage Scheme WWTP will perceive an odour concentration at or less than 1.50 Ou_E m^{-3} for the 98th percentile and less than 3.0 Ou_E/m^3 for the 99.5th percentile for five years of meteorological data (*see Figures 8.1 and 8.2*). Those odour sources considered most offensive (inlet works, primary treatment and holding tanks, centrate, filtrate, sludge, RAS/WAS pump sumps, flow splitting chambers and all sludge handling processes including tankage will be effectively contained and ventilated to an odour control system and therefore the overall risk of any resident/industrial neighbours detecting odour will be negligible since the major odour sources contributing to the remaining odour plume are considered low risk in term of odour. These sources include the aeration tankage, secondary settlement tankage and storm water tankage (*see Figures 8.3 and 8.4*).
- Those management and mitigation strategies discussed through this document should be considered and implemented in the design of the proposed Cork Harbour Main Drainage Scheme WWTP. Any deviations from the proposed mitigation strategies will require reassessment in order to ensure no odour impact in the vicinity of the proposed facility.

Pumping Stations

- In accordance with odour impact criterion in *Section 3.3.4*, and in keeping with current recommended odour impact criterion in this country, no odour impact will be perceived by sensitive receptors in the vicinity of the major Pumping stations Raffeen, West Beach, Monkstown, Church Road and Carrigaloe Pumping Stations following the implementation of good design in terms of odour management (e.g. tight fitting covers, etc.).
- All residents/industrial neighbours in the vicinity of the proposed pumping stations will perceive an odour concentration at or less than 1.50 Ou_E m^{-3} for the 98th percentile for five years of meteorological data (*see Figures 8.5 to 8.9*). All pumping station (both minor and major) will incorporate the use of an odour management system (e.g. good design in terms of odour minimisation, tight fitting covers etc.) to ensure no fugitive release of odours from each pumping station. In addition, each pumping station will be regularly visited so as to ensure efficient operation of the odour management system.
- It is acknowledged that many of the pumping stations are located in populous areas. For this reason the design of the collection system will include best practice and adequate odour management systems to prevent odour complaint and impact.
- The pumping stations will be covered/sealed to allow for containment of odours. The implementation of odour management systems within each pumping station (both minor and major) will minimise the uncontrolled release of fugitive odour emissions.

- Pumping stations will be subject to Part 8 Planning at detailed design. It will be the responsibility of the designer and contractor to review the PS location and the odour management systems proposed to prevent odour complaints and impact.

7. Recommendations

The following recommendations were developed during the study:

1. Odour management, minimisation and mitigation procedures as discussed within this document in general will be implemented at the proposed Cork Harbour Main Drainage Scheme wastewater treatment plant and each Pumping Station in order to prevent any odour impact in the surrounding vicinity.
2. The maximum allowable odour emission rate from the overall proposed WWTP should not be greater than 6,611Ou_E s^{-1} (*see Table 4.1*) inclusive of the odour emission contribution from the abatement systems installed on the primary treatment, pumping and sludge handling processes. The maximum overall odour emission rate from the odour control units shall be no greater than 2,314 Ou_E s^{-1} (exhaust stack concentration of less than 300 Ou_E/m^3 for OCU 1, 2, 4 and 5 and less than 500 Ou_E/m^3 for OCU 3, respectively). The hedonic tone of this odour should not be considered unpleasant (Scale greater than –2) as assessed in accordance with VDI 3882:1997, part 2; ('Determination of Hedonic) for all emission points. The specimen design suggests the use of three OCU's. As long as the total odour emission rate for the WWTP (i.e. 6,611Ou_E s^{-1}) is achieved along with the total minimum odour treatment volume (i.e. 6.20 m^3/s) and a total odour emission rate from the OCU's of less than or equal to 2,314 Ou_E s^{-1} is similar, then the number of OCU's utilised onsite is not important.
3. The odour management systems to be installed upon Raffeen, Carrigaloe, West Beach, Monkstown and Church road should be sufficient to prevent any uncontrolled fugitive odours escaping from the system. In addition any odour management system incorporated into the design and upgrade of the pumping station should be capable of achieving less than 1.50 Ou_E/m^3 at the 98th percentile and less than 3.0 Ou_E/m^3 at the 99.5th percentile of hourly averages.
4. Maintain good housekeeping practices (i.e. keep yard area clean, etc.), closed-door management strategy (i.e. to eliminate puff odour emissions from sludge dewatering building), maintain sludge storage within sealed airtight containers and to implement an odour management plan for the operators of the WWTP and all Pumping station. All odourous processes such as inlet works, primary treatment, and thickening will be carried out indoors/enclosed tankage.
5. Avoid accumulation of floating debris and persistent sediments in channels and holding tanks by design (i.e. flow splitters and secondary sedimentation tanks, etc.). Techniques to eliminate such circumstances shall be employed.
6. Enclose and seal all primary treatment, wet wells and sludge handling processes.
7. Operate the proposed WWTP within specifications to eliminate overloading and under loading, which may increase septic conditions within the processes.
8. Odour scrubbing technologies employing will be implemented within the proposed Cork Harbour Main Drainage Scheme WWTP. An odour management system will be implemented upon each pumping station (both minor and major). All other odour management, minimisation and mitigation strategies contained within this document where necessary will be implemented within the overall design.
9. When operational, it is recommended that the contractor should provide evidence through the use of dispersion modelling (Aermod Prime) and olfactometry measurement (in accordance with EN13725:2003), that the as built WWTP and Pumping stations are achieving the overall mass emission rate of odour and emission limit values for the installed odour management systems.

8. Appendix I-Odour dispersion modelling contour results for Cork Harbour Main Drainage Scheme

8.1 Predicted odour emission contribution of proposed overall Cork Harbour Main Drainage Scheme WWTP operation with odour abatement protocols implemented (ref Scenario 1) (see Table 4.1), to odour plume dispersal at the 98th percentile for an odour concentration of ≤ 1.50 Ou_E m^3 for five years of meteorological data.

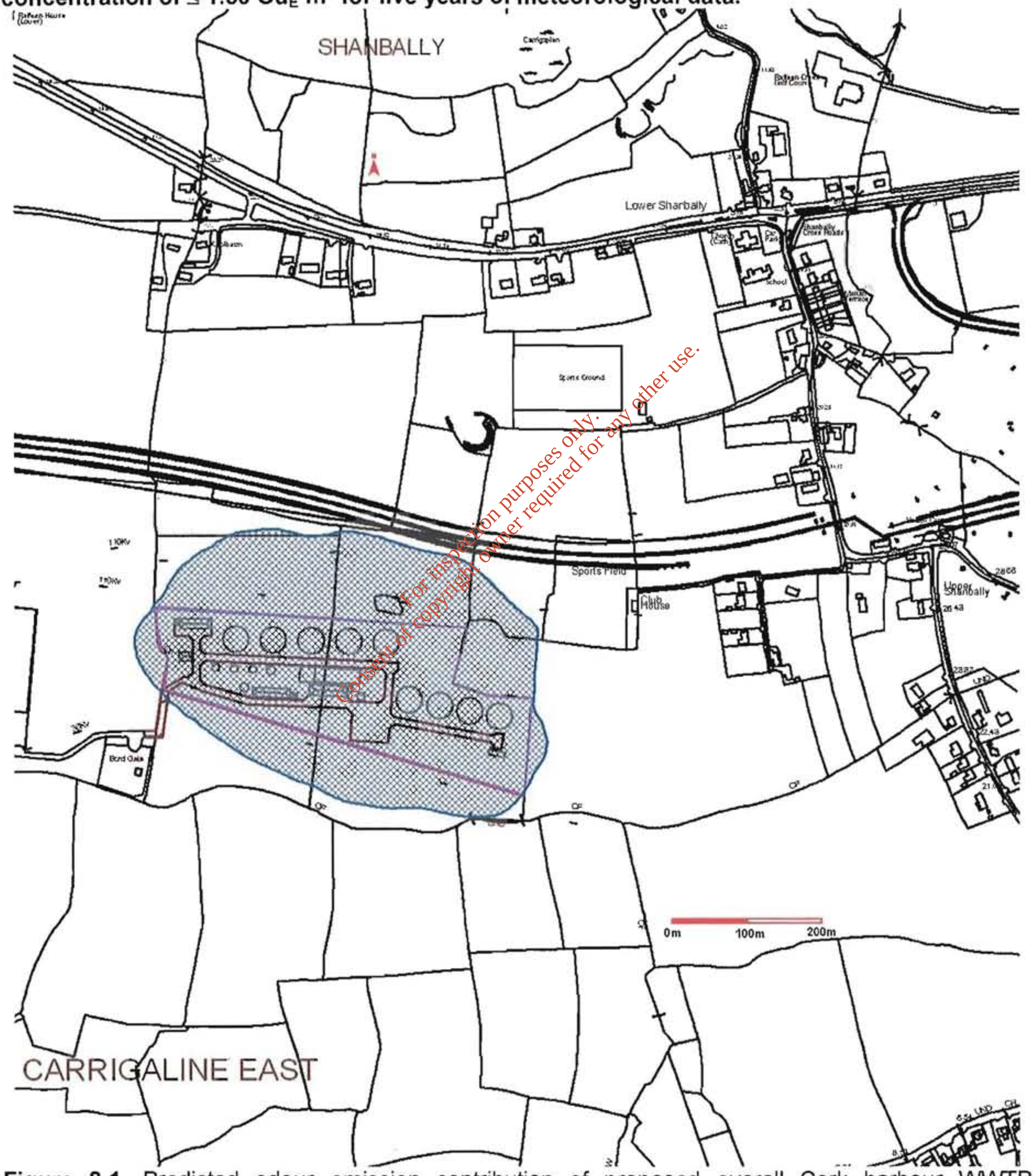

Figure 8.1. Predicted odour emission contribution of proposed overall Cork harbour WWTP operation with odour abatement protocols implemented to odour plume dispersal for Scenario 1 at the 98th percentile for odour concentrations ≤ 1.5 Ou_E m^{-3} (▬▬) for five years of meteorological data.

8.2 Predicted odour emission contribution of proposed overall Cork Harbour Main Drainage Scheme WWTP operation with odour abatement protocols implemented (ref Scenario 1) (see Table 4.1), to odour plume dispersal at the 99.5th percentile for an odour concentration of ≤ 3.0 Ou_E m^3 for 5 years of meteorological data.

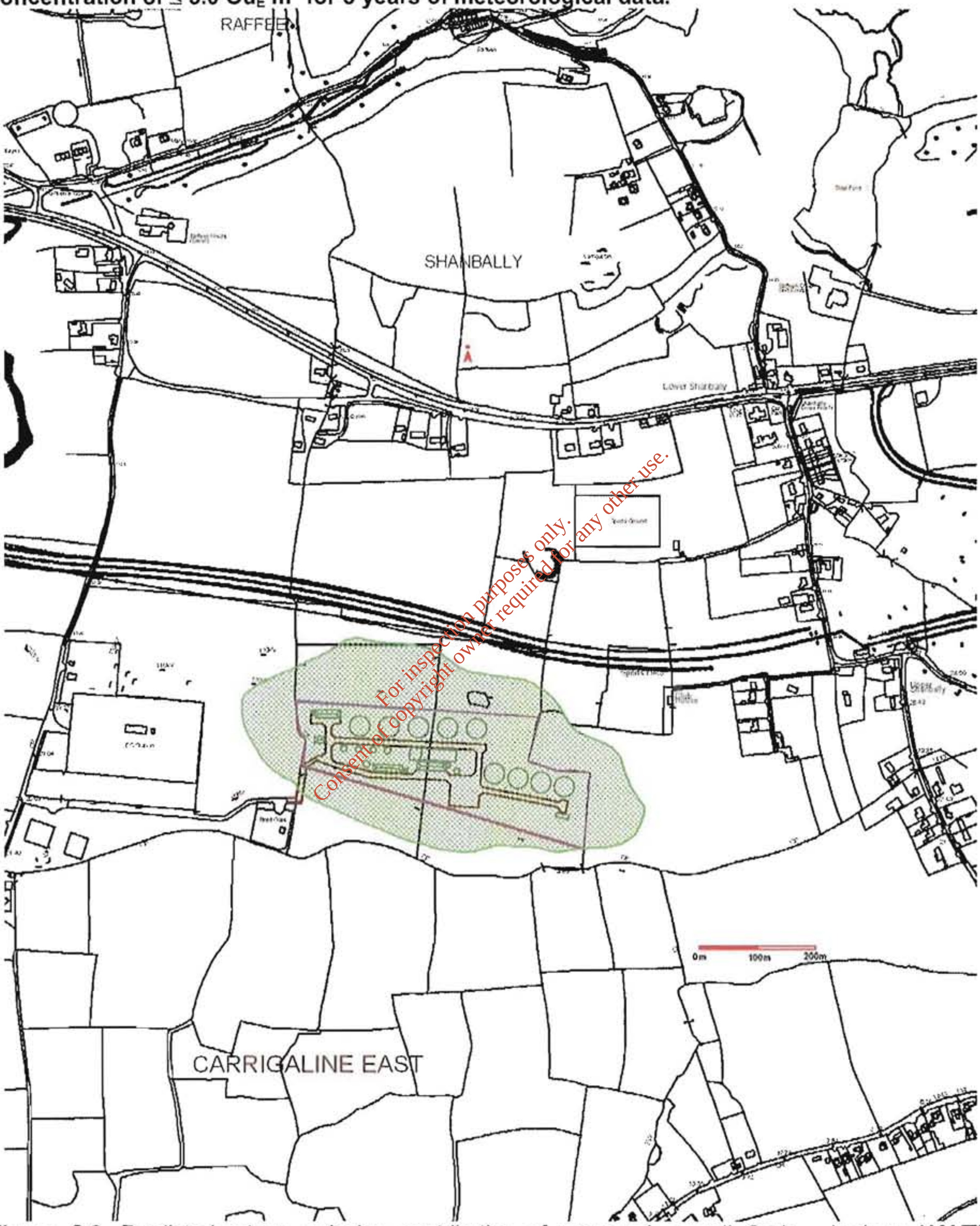

Figure 8.2. Predicted odour emission contribution of proposed overall Cork harbour WWTP operation with odour abatement protocols implemented to odour plume dispersal for Scenario 1 at the 99.5th percentile for odour concentrations ≤ 3.0 Ou_E m^{-3} ( ) for 5 years of meteorological data.

8.3 Predicted odour emission contribution of individual grouped odour control unit sources for proposed overall Cork Harbour Main Drainage Scheme WWTP operation (ref Scenario 1) (see Table *4.1*), to odour plume dispersal at the 98th percentile for an odour concentration of ≤ 0.30 Ou_E m^3 for five years of meteorological data.

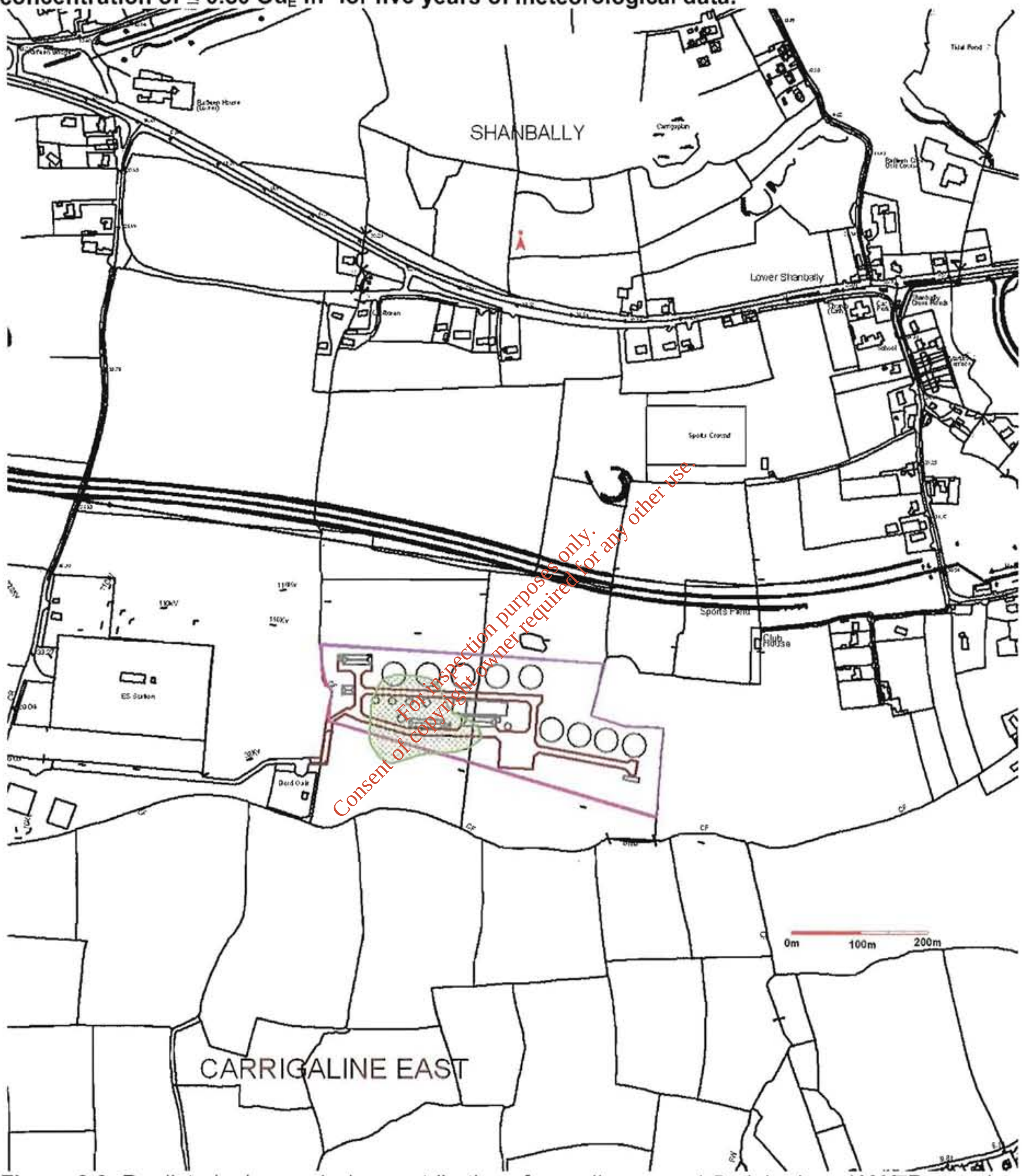

Figure 8.3. Predicted odour emission contribution of overall proposed Cork harbour WWTP to odour plume dispersal for grouped sources Odour control units 1, 2, 3, 4 and 5 for an odour concentration of less than or equal to 0.30 Ou_E m^{-3} ( )at the 98th percentile of hourly averages for 5 years of meteorological data.

8.4 Predicted odour emission contribution of individual grouped aeration tankage, secondary settlement tankage and storm water tankage sources for proposed overall Cork Harbour Main Drainage Scheme WWTP operation (ref Scenario 1) (see Table *4.1*), to odour plume dispersal at the 98th percentile for an odour concentration of ≤ 1.50 Ou_E m^3 for five years of meteorological data.

Figure 8.4. Predicted odour emission contribution of overall proposed WWTP to odour plume dispersal for grouped odour sources aeration tankage, Secondary settlement tankage and Storm water tankage for an odour concentration of less than or equal to 1.50 Ou_E m^{-3} (▬▬)at the 98th percentile of hourly averages for 5 years of meteorological data.

8.5 Predicted odour emission contribution of proposed Raffeen Pumping station operation with odour abatement protocols implemented (ref Scenario 2) (see Table 4.2), to odour plume dispersal at the 98th percentile for an odour concentration of ≤ 0.10 Ou_E m^3 for five years of meteorological data.

Figure 8.5. Predicted odour emission contribution of proposed Raffeen Pumping station operation with odour management protocols implemented to odour plume dispersal for Scenario 2 at the 98th percentile for odour concentrations ≤ 0.10 Ou_E m^{-3} (▬) for five years of meteorological data.

8.6 Predicted odour emission contribution of proposed West beach Pumping station operation with odour abatement protocols implemented (ref Scenario 2) (see Table 4.2), to odour plume dispersal at the 98th percentile for an odour concentration of ≤ 0.30 Ou_E m^3 for five years of meteorological data.

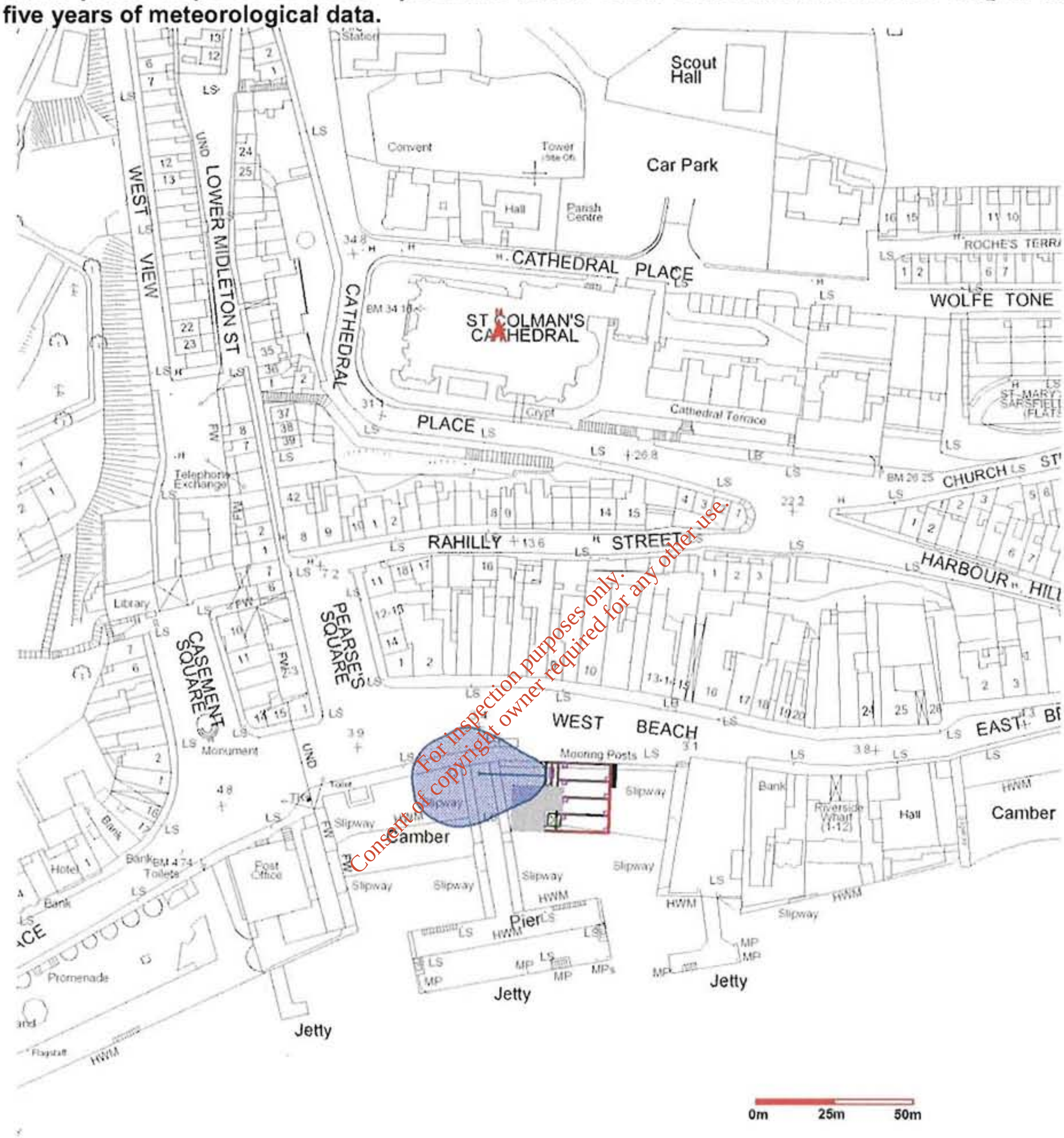

Figure 8.6. Predicted odour emission contribution of proposed West beach Pumping station operation with odour management protocols implemented to odour plume dispersal for Scenario 2 at the 98th percentile for odour concentrations ≤ 0.30 Ou_E m^{-3} (▬) for five years of meteorological data.

8.7 Predicted odour emission contribution of proposed Monkstown Pumping station operation with odour abatement protocols implemented (ref Scenario 2) (see Table 4.2), to odour plume dispersal at the 98th percentile for an odour concentration of ≤ 0.20 Ou_E m^3 for five years of meteorological data.

Figure 8.7. Predicted odour emission contribution of proposed Monkstown Pumping station operation with odour management protocols implemented to odour plume dispersal for Scenario 2 at the 98th percentile for odour concentrations ≤ 0.20 Ou_E m^{-3} (▬▬) for five years of meteorological data.

8.8 Predicted odour emission contribution of proposed Church Road Pumping station operation with odour abatement protocols implemented (ref Scenario 2) (see Table 4.2), to odour plume dispersal at the 98th percentile for an odour concentration of ≤ 0.14 Ou_E m^3 for five years of meteorological data.

Figure 8.8. Predicted odour emission contribution of proposed Church Road Pumping station operation with odour management protocols implemented to odour plume dispersal for Scenario 2 at the 98th percentile for odour concentrations ≤ 0.14 Ou_E m^{-3} (▬) for five years of meteorological data.

8.9 Predicted odour emission contribution of proposed Carraigaloe Pumping station operation with odour abatement protocols implemented (ref Scenario 2) (see Table 4.2), to odour plume dispersal at the 98th percentile for an odour concentration of ≤ 0.10 Ou_E m^3 for five years of meteorological data.

Figure 8.9. Predicted odour emission contribution of proposed Carraigaloe Pumping station operation with odour management protocols implemented to odour plume dispersal for Scenario 2 at the 98th percentile for odour concentrations ≤ 0.10 Ou_E m^{-3} (▬▬) for five years of meteorological data.

9. Appendix II - Background Information on odours pertaining to Cork Harbour Drainage scheme odour impact assessment.

9.1. Legislation pertaining to odours in Ireland

The Public Health Act of 1878 introduced legislation to control nuisance in Ireland, but its execution only became viable after the implementation of the Planning and Development Act (1963) (Scannell, 1995). Any industry producing a nuisance was controlled under these regulations and subsequent pressure from environmental lobby groups together with the development of scientific measurement techniques made it practical to quantify and control the release of gaseous environmental pollutants from these enterprises.

Odour impact from a WWTP on the surrounding vicinity may be considered a nuisance. Section 107 of the Public Health Act 1878 states that "sanitary authorities are bound to inspect their district for nuisances. Upon the receipt of any information respecting the existence of a statutory nuisance, the sanitary authority is obliged, if satisfied of the existence of the nuisance, to serve an abatement notice on the person by whose act or default the nuisance arises or continues or, if such a person cannot be found, on the owner or occupier of the premises on which the nuisance arises" (Scannell, 1995).

In order to control the possible pollution effects of large developments, relevant legislation was enacted under the Environmental Protection Agency (EPA) Act of 1992. Private and public sector developers of certain types and sizes of projects are required under section 72(4) of the EPA Act (1992) to submit a copy of an Environmental Impact Statement. If the project is of a class listed in Part II of the first schedule to the 1989 EIA regulations but does not exceed the threshold or criteria specified, the planning authority must require an Environmental Impact Statement (EIS) if it considers the project is likely to have a significant impact on the environment. One of those impacts relates to odour and is defined as environmental pollution in section 4(2) of the EPA Act (1992), as to cause a nuisance through noise or odour and/or adversely affect the countryside or place of special interest (Scannell, 1995).

Waste licensing and Integrated Pollution Control Licensing (IPC) (now IPPC) for specified facility types was implemented in 1996 by the EPA and the related guidance note was termed BATNEEC (Best Available Technology Not Entailing Excessive Cost) (i.e. now BAT which complement the BATNEEC Notes) (EPA, 1996). It set out specific conditions for these specific industries (i.e. Intensive Agricultural Production, Landfills, Waste transfer stations, etc) to be implemented in order to comply with the environmental requirements of the EPA. Minimisation of odour emissions and complaints is one of the requirements of the BATNEEC Guidance Note for industries likely to cause odour emissions. For example, a typical IPC license/Waste license condition states "that there shall be no emission to the atmosphere of environmental significance and that all operations on site shall be carried out in a manner such that air emissions and/or odours do not result in significant impairment and/or interference with amenities beyond the site boundary and at odour sensitive locations in the area" (EPA, 1996).

Local authorities and the EPA have responsibility for ensuring enterprises meet their planning and environmental requirements. Where these facilities are found to be causing odour nuisance, local government enforces Section 29 of the 1987 Air Pollution Act and serves the offenders with an abatement notice. If the facility is licensed as an IPC or Waste enterprise, the EPA can enforce the conditions of the license and either serves the facility with non-compliances for odour detected beyond the site boundary or prosecute the facility and seek a high court injunction to close the facility. Verification for the presence of odour nuisance usually encompasses the licensing officer visiting the facility and detecting the odour beyond the boundary.

In December 2005, the Department of Environment published Statutory Instrument (SI) 787 for the regulation of odours and noise from WWTP's. The main conclusions to be drawn from this SI 787 of 2005 include:

"A sanitary authority shall ensure that in formulating and approving plans for a waste water treatment plant to be provided by the authority or on its behalf the plant is so designed and constructed as to ensure that it avoids causing nuisance through odours or noise",

"A sanitary authority shall ensure that any waste water treatment plant under the sanitary authority's control is so operated and maintained as to ensure that it avoids causing nuisance through odours or noise".

It would also appear that SI 787 provides jurisdiction to the EPA to regulate WWTP for such nuisances and enforce the EPA Act 1992 *"For the purpose of Article 3(b) of these Regulations, the Agency shall be required to ensure compliance of waste water treatment plants with the requirements of the said Article 3(b), and the provisions of section 63 of the Environmental Protection Agency Act 1992 (No. 7 of 1992) shall apply accordingly".*

As part of SI 787 of 2005 *"the planning authority where granting permission for a development in accordance with section 34 of the Act of 2000 consisting of the provision of a waste water treatment plant attach such conditions to the permission as may be, in the opinion of the authority and having regard to the function of the Agency under Article 4 of these Regulations, necessary to ensure that the plant is so operated and maintained as to ensure that it avoids causing nuisance through odours or noise".*

Additionally, in considering a appeal to planning, Board Pleanala *"shall include such conditions as may be necessary in its opinion to ensure that the plant is so operated and maintained as to avoid causing nuisance through odours or noise".*

Although it is not unusual for statutory instruments not to include numerical values for the control of odour nuisance, it is apparent that there should not be odour nuisance from WWTP's in Ireland and so should be designed and operated to eliminate odour nuisance (Sheridan, 2002). In these times of regulation, guidance documents such as those for IPPC and Waste licensed facilities should be developed for WWTP design engineers and operators in order to allow them to implement Best Available Techniques (BAT). In the UK, such a guidance document was published to provide guidance for existing and new WWTP for odour assessment and control.

9.2. Characterisation of odour.

The sense of smell plays an important role in human comfort. The sensation of smell is individual and unique to each human and varies with the physical condition of the person, the odour emission conditions and the individual's odourous education or memory. The smell reaction is the result of a stimulus created by the olfactory bulb located in the upper nasal passage. When the nasal passage comes in contact with the odourous molecules, signals are sent via the nerve fibres where the odour impressions are created and compared with stored memories referring to individual perceptions and social values. Since the smell is individual some people will be hypersensitive and some will be less sensitive (ansomia). Therefore, the sense of smell is the most useful detection technique available as it specialises in synthesising complex gas mixtures rather than analysing the chemical compound (Sheridan, 2000).

9.3. Odour qualities

An odour sensation and complaint consists of a number of inter-linked factors. These include:

- Odour threshold/concentration,
- Odour intensity,
- Hedonic tone,
- Quality/Characteristics
- Component characteristics

The odour threshold concentration dictates the concentration of the odour in $Ou_E\ m^{-3}$. The odour intensity dictates the strength of the odour. The Hedonic quality allows for the determination of pleasantness/unpleasantness. Odour quality/characteristics allow for the comparison of the odour to a known smell (i.e. turnip, like dead fish, flowers). Individual chemical component identity determines the individual chemical components that constitute the odour (i.e. ammonia, hydrogen sulphide, methyl mercaptan, carbon disulphide, etc.). Once odour qualities are determined, the overall odour impact can be assessed. This odour impact assessment can then be used to determine if an odour minimisation strategy is to be implemented and if so, which technology. Additionally, by suitably characterising the odour through complaint logs, the most likely source of the odour can be determined. This allows for the implementation of immediate odour mitigation techniques to prevent such emission in the future.

9.4. Perception of emitted odours.

Complaints are the primary indicators that odours are a problem in the vicinity of any facility. Perceptions of odours vary from person to person, with several conditions governing a person's perception of odour:

- **Control:** A person is better able to cope with an odour if they feel it can be controlled.
- **Understanding:** A person can better tolerate an odour impact if they understand its source.
- **Context:** A person reacts to the context of an odour as they do to the odour itself (i.e. WWTP odour source due to sewage).
- **Exposure:** When a person is constantly exposed to an odour:
    - They may lose their ability to detect that odour. For example, a plant operator who works in the facility may grow immune to the odour *or*
    - There tolerance to the odour grows smaller and they complain more frequently.

From these criteria, we can predict that odour complaints are more likely to occur when:

- A new facility locates in areas where people are unfamiliar with facilities;
- When a new process establishes within the facility (i.e. anaerobic digestion processes);
- Or when an urban population encroaches on an existing facility.

The ability to characterise odours being emitted from the facility will help to develop a better understanding of the impact of the odour on the surrounding vicinity. It will also help to implement and develop better techniques to minimise/abate odours using existing technologies and engineering design. The correct recording of odour complaints data is very important to resolving any odour impact.

9.5. Characteristics of Waste water odours

Odours from wastewater treatment plants/pumping stations arise mainly from the uncontrolled anaerobic biodegradation of sewage to produce unstable intermediates. Other odours come directly from industrial waste water (solvents, volatile organic compounds, petroleum derivatives) or indirectly from warm, highly degradable sulphurous effluents (Burgess et al. 2001). Typically domestic sewage sludge contains 3-6 mg l^{-1} organic sulphur, mainly arising from proteinaceous material, approximately 4 mg l^{-1} from sulphonates contained in household detergents and 30-60 mg l^{-1} inorganic sulphur (as sulphonates) (Burgess et al. 2001). Odours are generated by a number of different waste water components, the most significant being the sulphur containing compounds (thiols, mercaptans, hydrogen sulphide), volatile fatty acids (butyric acid, valeric acid), amines (methylamine, Dimethylamine), phenols (4-methylphenol), chlorinated hydrocarbons (trichloroethylene, tetrachloride), etc. (Dawson et al. 1997). Most of these compounds have very low odour threshold concentrations as illustrated in *Table 9.2*. Different concentrations and mixtures of these compounds can intensify or reduce odour threshold concentration, determined as synergism and antagonism respectively. Hobbs et al., (2002) performed studies on various odours commonly found in pig odour. From his study he concluded that 4-methyl phenol had a negative effective on perceived odour concentration when mixed with other odourant.

Table 9.1. Odour detection thresholds of wastewater odour precursors.

Chemical component	Threshold Conc. (mg m^{-3})	Odour character
Ammonia	0.03-37.8	Pungent, sharp, irritating
Methylamine	0.0012-6.1	Fishy, Putrid Fishy
Trimethylamine	0.00026-2.1	Fishy, Pungent fishy
Dimethylamine	0.34 ppmv	Putrid fishy
Ethylamine	0.27 ppmv	Ammonia like
Triethylamine	0.48 ppmv	Fishy
Pyridine	0.66 ppmv	Sour, putrid fishy
Indole	0.0006-0.0071	Faecal, nauseating
Skatole	0.00035-0.00078	Faecal, nauseating
Hydrogen Sulphide	0.0005-0.002	Rotten eggs
Methyl mercaptan	0.0000003-0.038	Rotten cabbage
Ethyl mercaptan	0.000043-0.00033	Decaying cabbage/flesh
Propyl mercaptan	0.0001 ppmv	Intense rotten vegetables, Unpleasant
Allyl mercaptan	0.0001 ppmv	Garlic, coffee
Benzyl mercaptan	0.0003 ppmv	Skunk, unpleasant
Thiocresol	0.449 ppmv	Skunk
Dimethyl disulphide	0.000026 ppmv	Rotten vegetables
Carbon disulphide	0.0077-0.0096 ppmv	Rubber, intense sulphide
Acetic acid	0.024 to 0.120	Vinegar
Butyric acid	0.0004-42	Rancid
Valeric acid	0.0008-0.12	Sweaty, rancid
Propionic acid	0.028 ppmv	Rancid, pungent
Hexanoic acid	0.018 to 0.096	sharp, sour, rancid odour, goat-like odour
Formaldehyde	0.05 to 1.0 ppm	Pungent, medicinal
Acetone	0.067 ppmv	Pungent, fruity, sweet
Butanone	0.128	Sweet, solventy
Acetophenone	0.05 to 0.10 ppmv	Sweet pungent odour of orange blossom or jasmine
Limonene	0.063	Intense orange/lemons
Alpha Pinene	0.006 ppmv	Intense pine, fresh
THN Tetrahydronaphthalene	-	Meat

O'Neill & Phillips et al. (1992) and Suffet at al., 2004.

Although only indicators of odour emission from various processes within the WWTP, knowing which compound precursors that are responsible for odour is useful in designing control techniques for the minimisation and abatement of these gases. Technologies such as carbon filtration rely on the binding efficiency of the carbon (Van der Waals forces and molecular sieving) and knowing the gas constituents will help isolate the best carbon to perform the task. For example, Hydrogen sulphide because of its molecular size will not bind efficiently to activated carbon. By impregnating the carbon with potassium/sodium hydroxide chemisorption can be used to efficiently bind and hold on to the Hydrogen sulphide. Another reason for knowing Volatile Organic Compounds (VOC's) concentration present in air stream is to propose the best technology. Chemical scrubbers are good for low VOC's steady stream processes while high VOC concentration non-steady stream processes will not be as affectively treated with chemical scrubbers although many stages of treatment can be provided to buffer out the cyclic loading (but at greater operating expense).

9.6. Odourous compound formation in wastewater treatment plants/pumping stations

The formation of odourous components at WWTP's is usually limited to inlet works, primary settlement tanks and to the areas of sludge handling/pumping/processing, particularly during the handling of primary/anaerobic treated sludge. The formation of odours from pumping stations is usually limited to the displacement of odours from the inlet flow chamber, wet wells and any primary treatment that may occur at the pumping station (i.e. grit removal and screenings).

In WWTP's, under anaerobic conditions, the untreated primary sludge will readily decay, producing odourous components in the process. The possibility for anaerobic conversion of surplus activated sludge depends on the sludge-loading rate (k) in the activated sludge works. At a lower sludge-loading rate, the surplus activated sludge tends to be more stabilised, thus giving less cause for odour impact. In general the following values may be adhered to:

- $k < 0.05$; extreme sludge stabilisation, no anaerobic bacterial decay to be expected;
- $0.05 < k < 0.1$; moderate sludge stabilisation, some decay possible;
- $k > 0.1$ partial sludge stabilisation, anaerobic bacterial decay is most likely to occur.

The production of odourous components depends on the reduction-oxidation potential (redox-potential) and on the Biological Oxygen Demand (BOD) of the wastewater. The redox-potential is the condition under which decay can take place, while BOD is the parameter most commonly used to define the pollution strength of a wastewater.

Anaerobic bacterial decay will only take place if the redox-potential of the wastewater is low enough. Frequently this condition arises in rising mains, where anaerobic conditions occur. In gravitational sewers a slight draft provides enough oxygen to limit this, as oxygen is highly toxic to anaerobic bacteria. In certain cases, the dosing of bleach and Ferric will act as an oxidant and electron donator/acceptor and limit such conditions. It is important to use sophisticated monitoring equipment to measure dissolved oxygen and pH of the liquor to maintain ideal conditions for aerobic processes to dominate. The monitoring of sulphite levels in the inlet sewer can be used to estimate hydrogen sulphide generation levels within the WWTP.

Sludge handling processes can be more complicated depending on dewatering equipment design and processed sludge storage facilities. For example, it is reported that using high-speed centrifuges facilitate higher odour and H_2S emission than low speed centrifuge due to the shearing of proteins and carbohydrates within the sludge. This allows for the oxidation and reduction of methanthione and other proteins which readily breakdown to methyl mercaptan, dimethyl sulphide and H_2S (Sheridan, 2004). By dosing Ferric/Ferrous (2:1 blend) at the head of the plant odours associated with digestor gas and sludge handling can be reduced. The benefits of such dosing must be analysed since greater sludge volumes (i.e. especially primary sludge) will be produced.

9.7. Odour emissions formation at Wastewater treatment plants

The rate of release of odourous compounds into the atmosphere at WWTP's and pumping stations is influenced by:

- Liquid flow rate into the pumping station and WWTP,
- Trade effluent discharges containing high concentrations of sulphonates,
- Overloading of the WWTP;
- Long residence time of sewage in sewer;
- Temperature of mixed liquor (increased temperature causes increased anaerobic conditions and volatilisation);
- Positive displacement of odours through covers / from buildings especially in Pumping stations.
- The concentration of odourous compounds in the liquid phase exposed to air;
- Processes that generate surface turbulence (aeration basin, surface aerators, weirs overflows, return activate sludge channel feed, pumping of RAS/WAS/SAS, sludge thickening techniques etc.);
- Total air/surface waste water interface area;
- Maintenance of aerobic conditions within WWTP's (i.e. sludge handling, processing and storage).

Raw wastewater and sludge's have high concentrations of odourous compounds. Processes that create surface turbulence and high rates of interface renewal, such as open channel flow, weir overflows, biofilter flow distribution systems, surface aeration systems have much higher rates of volatilisation of odourous compounds than quiescent processes such as sedimentation as these processes allow for the change in the partial pressure at the surface interface and the mass transfer of the odourous compounds to the gaseous phase.

The main sources of odour emissions from WWTP's in Ireland are wastewater screening, grit separators, Grit and rag removal, inlet/outlet flow channels, (i.e. Inlet works), biotower flow distributions, primary treatment processes, flow splitter chambers (i.e. badly designed weirs that facilitate high volatilisation) and sludge handling processes (turbulent liquid removal at bottom of Gravity belt thickeners, high speed centrifuges, pumped streams, etc). With the exception of aerobically stabilised sludge's, sludge residues are the primary sources of odour emissions and should be considered high-risk sources. Other high-risk sources include, inlet works, primary settlement, pumped liquor streams and anaerobic digestion processes.

9.8. Odour management plan - Standard Practice

The Odour Management Plan (OMP) is a core document that is intended to detail operational and control measures appropriate to management and control of odour at the site. The format of the OMP should provide sufficient detail to allow operators and maintenance staff to clearly understand the operational procedures for both normal and abnormal conditions.

An Odour Management Plan (OMP) should be prepared for all processes. The OMP should also include sufficient feedback data to allow site management (and local authority inspectors) to audit site operations. An example of some of the issues to be considered is summarised as follows. More detailed guidance is provided with this document.

- A summary of the site and WWTP, odour sources and the location of receptors,
- Details of the site management responsibilities and procedures for reporting faults, Identifying maintenance needs, replenishing consumables, complaints procedure,

- Odour critical plant operation and management procedures (e.g. correct use of plant, process, materials; checks on plant performance, maintenance and inspection (*see Section 9.9 to 9.11*),
- Operative training,
- Housekeeping,
- Maintenance and inspection of plant (both routine and emergency response),
- Spillage management procedures,
- Record keeping – format, responsibility for completion and location of records,
- Emergency breakdown and incident response planning including responsibilities and mechanisms for liaison with the local authority.
- Public relations.

The Odour Management Plan is a living document and should be regularly reviewed and upgraded. It should form the basis of a document Environmental and Odour Management system for the operating site. The Odour Management System documentation should define the roles of the Plant Operator and staff and sets out templates in relation to the operating of the facility and reporting procedures to be employed. Requirements for the Odour management plan should be implemented thought out the site with a branched management system implemented in order to share responsibility around the site. The head manager should ensure all works are performed in accordance with the OMP. The OMP will be integrated in the overall Environmental Management System/Performance management system.

The contractor will develop and implement a detailed odour management plan for the actual as built plant and put into operation before commencement of treatment of waste water at Cork Harbour Main Drainage Scheme.

9.8.1. General rules for reduction of odour emissions for wastewater treatment plants operation by design – Standard Practice

The following minimum design features for the control of odours will be achieved throughout the design. These include:

- Avoid turbulence at the inlet works, weirs and when handling sludge's and return liquors.
- Sewage discharged from a rising main is more likely to be anaerobic (i.e. odourous), particularly during hot weather. Inlet covering will be performed and chemical dosing may be necessary.
- Minimise the retention of sewage under anaerobic conditions, especially in anoxic, balancing and storm tanks to prevent the formation of odourous compounds.
- Avoid accumulation of floating debris and persistent sediments in channels and holding tanks by design.
- Maintain minimal sludge delay in handling and treatment stages by design. Avoid exposure of untreated sludge to the atmosphere.
- Enclosed units should be sealed and vented to odour abatement systems. Provide storage provisions on site for odour prevention medium and chemicals.
- Ensure clear and concise odour management plans are produced for plant operation and abatement systems (i.e. complaints recording system operation and OCU maintenance procedures) (Sheridan, 2002).
- Prevent the displacement of highly odorous air through gaps or hatches in the covers over the sludge thickening and holding tanks and ensure that all air is vented through an odour abatement system. Badly sealed or broken hatches will act as significant points of odour emission. Even small openings, such as the openings around cable-duct and piping entry points, have been observed as significant sources of odour emission from raw-sludge storage tanks.
- In a covered storage tank, negative ventilation will be applied to all contained and covered processes.

- A minimum of two stages of treatment (if biological is first stage) will be provided on all odour control technologies.

9.8.2. Odour abatement management system/procedures – Standard Practice

Odour abatement/minimisation systems are installed with the aim of mitigating odours from the particular process(s). In some circumstances odour abatement system can become significant sources of odour especially if sufficient treatment is not being achieved. For example, insufficient treatment could be associated with system failure, poisoning of media, exhaustion of media, insufficient gas removal volume, broken covers, open hatches etc. There is a tendency in many facility environments that when an odour control system is installed it requires very little system checking especially if SCADA controlled. A simple management system incorporated into site operations can significantly reduce the risk of odour control plant failure and also provide a valuable picture for operations and maintenances schedules.

The overall odour control plant management system will vary for various technologies. For the proposed Cork Harbour Main Drainage Scheme WWTP, the following odour control/minimisation plant could be installed to control odours emanating from specific processes within the plant. These include:

- Chemical scrubbers,
- Activated carbon polishing,
- Dry chemical scrubbing (three stage),
- Biofilters
- Thermal oxidisers
- Fixed impermeable covers,
- Extraction ductwork located throughout WWTP,
- Chemical addition/dosing to waste water and sludge processing,
- Dissolved oxygen probes/pH probes located in aeration tanks and flow channels,

For each of the odour control technologies, an operational verification procedure should be performed from actually visiting each piece of equipment. For sensitive mechanical odour control plant, such as chemical scrubbers, biotrickling filters and biofilters, a daily check should be performed. Small changes in operational parameters could lead to significant emission of odours.

For odour control/minimisation plant such as pressure release values, odour control ductwork, fixed impermeable covers etc., which are less susceptible to breakdown (i.e. since there are little mechanical moving parts), a weekly check should be performed.

All system checks should be document controlled and available for viewing by odour complaints verification personnel, chief maintenance personnel and plant manager. Response/Action plans should be established for system repair where by a repair team trained in the operation and maintenances (O&M) of this specific plant are available to perform dedicated repair. O&M manuals should always be available and a spares inventory should be maintained for essential spares.

Any recording of system performance should be compared to design specification and performance as outlines within a P&ID flow diagrams developed for the built site.

Table 9.3 illustrates a typical odour control plant daily/weekly checking procedure for odour abatement plants such as chemical scrubber, dry chemical scrubbers and flares. Certain parameters such as subjective and objective assessment checks (airflow rate, static/differential pressures etc) should be performed daily while other parameters such as odour threshold concentration should be performed quarterly which is in keeping with EPA recommendations for similar facilities. *Table 9.4* illustrates a typical odour minimisation plant system checking procedure for impermeable covers, odour control ductwork, pressure release valves etc.

Table 9.3. Odour control unit (OCU) checking procedure and recording.

Odour Abatement Plant process data sheet			
OCU name		**Location (NE coordinate)**	
OCU P&ID ref. No.		**Time of check (24 hr)**	
Date of check:		**Commissioning date:**	
QA/QC by:		**Next service date:**	
Supplier and contact details:			
Emergency contact No.			
OCU description			
Notes:			

Process description **SENSOR CALIBRATION DATES**		
Chemical/BTF/Wet Cyclone	**Liquid flow sensor**	
Chemical/BTF/Flare/Cyclone/CHP	**Differential/static pressure**	
Chemical/BTF/Flare/Cyclone/CHP	**Temperature**	
Flare/Cyclone/CHP	**Particle concentration**	
Chemical/BTF/Flare/CHP	**H_2S sensor**	
Flare/CHP	**Oxygen sensor**	
Flare/CHP	**CO sensor**	
Flare/CHP	**NO_2 sensor**	
Flare/CHP	**SO_2**	
Notes:		

Subjective process verification	
Is the fan running and sounding OK (Y/N comments)?	
Is liquid recirculating within the recirculating line of the scrubber/cyclone (Y/N comments)?	
Is dump liquor flowing freely from overflow sump (Y/N comments)?	
Is liquid distributed equally over packing media (Y/N comments)?	
Is recirculating liquor clear or cloudy (Y/N comments)	
Are all liquid distribution nozzles/gate clear (Y/N comments)	
Notes:	

Table 9.3 continued. Odour control unit (OCU) checking procedure and recording.

Objective process verification					
Parameter	**Average**	**Min**	**Max**	**Design value as per P&ID**	**Action**
Air flow rate (m3/hr)					
Temperature (^0C)					
Inlet ductwork Static pressure (mm WG)					
Differential pressure across system components (mm WG)					
H_2S inlet conc. (ppm/v)					
Inlet dust load (mgN/m3)					
Gas consumption rate (m^3/hr, m^3/day)					
Odour character: (Descriptor)					
Notes:					
Treated airflow	**Average**	**Min**	**Max**	**Design value as per P&ID**	**Action**
Airflow rate (Nm^3/hr)					
Temperature (^0C)					
Outlet static pressure (mm WG)					
Outlet odour conc. (Ou_E/m^3)					
H_2S outlet conc. (ppm/v)					
Outlet odour emission rate (Ou_E/s)					
Outlet odour character: Descriptor					
Irrigation recirculation	**Average**	**Min**	**Max**	**Design value as per P&ID**	**Action**
Recirculation flow (m^3/hr)					
Temperature (^0C)					
Conductivity (μs)					
PH (0 to 14)					
Redox (mv)					
Stability on Redox/pH historically					
Irrigation drainage	**Average**	**Min**	**Max**	**Design value as per P&ID**	**Action**
Dump volume (m^3/hr)					
Conductivity (μs)					
Batch dumping frequency (weeks)					

Table 9.4 illustrates a typical odour minimisation plant system weekly checking procedure for odour control ductwork, etc.

Odour Abatement Plant process data sheet			
Equipment name		**Location (NE coordinate)**	
Equipment P&ID ref. No.		**Time of check (24 hr)**	
Date of check:		**Commissioning date:**	
QA/QC by:		**Next service date:**	
Supplier and contact details:			
Emergency contact No.			
Equipment description			
Notes:			

Process description		
Item description	**Parameter**	**Compliant/Actions**
Ductwork	**Static pressure P&ID location No 1**	
	Static pressure P&ID No location 2	
	Static pressure P&ID No location 3	
	Static pressure P&ID No location 4	
Volume control dampers (VCD)	**P&ID No. 1 Damper setting/head loss**	
	P&ID No. 2 Damper setting/ head loss	
	P&ID No. 3 Damper setting/ head loss	
	P&ID No. 4 Damper setting/ head loss	
Are all moisture drip points free flowing and unblocked?		
Notes:		

Table 9.5 illustrates a typical odour minimisation plant system weekly checking procedure for fixed/flexible impermeable covers, etc.

Odour Abatement Plant process data sheet			
Equipment name		Location (NE coordinate)	
Equipment P&ID ref. No.		Time of check (24 hr)	
Date of check:		Commissioning date:	
QA/QC by:		Next service date:	
Supplier and contact details:			
Emergency contact No.			
Equipment description			
Notes:			

Process description		
Item description	Parameter	Compliant/Actions
Static pressure under covers and volume flow on fresh air intake vents	Static pressure/volume flows P&ID location No 1	
	Static pressure/volume flows P&ID location No 2	
	Static pressure/volume flows P&ID location No 3	
	Static pressure/volume flows P&ID location No 4	
Hatches	P&ID No. 1 Hatch opened/closed	
	P&ID No. 2 Hatch opened/closed	
	P&ID No. 3 Hatch opened/closed	
	P&ID No. 4 Hatch opened/closed	
Are all flexible sealants in position?		
Notes:		

The implementation of such quality checking procedures will provide both system confidence and preventative maintenance thereby reducing any risk associated with odour control/minimisation equipment.

The frequency and planning of sampling depend on the type of process. When the parameters are expected to develop gradual trends like dry chemical scrubbers rather than sudden changes like chemical scrubbers, the frequency of checking can be low (monthly, biweekly). If the system is more susceptible to cyclic loads, weekly or even daily monitoring may be required, depending on the history and the consequences that may arise from not realising an issue. More importantly seasonal changes in odour loads on plant and equipment can affect the overall performance of the system and combined with the behaviour of people on the receptor side during changing weather conditions (i.e. warm summer days could result in higher odour loads due to higher metabolic activity of bacteria coupled with people enjoying outdoor activities, etc.) For some processes, continuous monitoring may be useful, especially when the consequences of failure are significant. Risk assessment of plant failure is important to define key operational and maintenance parameters for the odour control unit (OCU). On the basis of this risk assessment measures can be defined to reduce the probability of high consequence events or to mitigate their impact.

The public will remember unscheduled emission episodes with great tenacity. It is therefore important to not fully rely on the environmental performance of odour mitigation under normal operational conditions but also consider them under unscheduled emission events. It is therefore crucial to consider and manage risks of odour emissions during:

- Odour Control Unit (OCU) commissioning,
- Start-up and shutdown of odour abatement units with consideration for duty standby on particularly odour processes (i.e. this has been implemented into the design),
- Management of highly odorous materials
- OCU servicing, and unscheduled shutdown,

In assessing these risks, it must be taken into account that response to odours is almost immediate. In order to manage these odour detection and complaint risks, a number of actions may be considered:

- Plan high-risk activities in periods where receptor sensitivity to annoyance is low like during wet weather when they are indoors, or during colder winter months, or during early morning/late evenings during periods of low atmospheric turbulence, etc.
- Consider providing standby capacity, etc.

If all else fails, inform potentially affected residents of the probability of temporarily increased odours and explain potential benefits due to these increases (i.e. maintenance of OCU, etc.)

9.9. Olfactometry

Olfactometry using the human sense of smell is the most valid means of measuring odour (Dravniek et al, 1986) and at present is the most commonly used method to measure the concentration of odour in air (Hobbs et al, 1996). Olfactometry is carried out using an instrument called an olfactometer. Three different types of dynamic dilution olfactometers exist:

- Yes/No Olfactometer
- Forced Choice Olfactometer
- Triangular Forced Choice Olfactometer.

In the dynamic dilution olfactometer, the odour is first diluted and is then presented to a panel of screened panellists of no less than four (CEN, 2003). Panellists are previously screened to ensure that they have a normal sense of smell (Casey et al., 2003). According to the CEN standard this screening must be performed using a certified reference gas *n*-butanol. This screening is applied to eliminate anosmia (low sensitivity) and super-noses (high sensitivity). The odour analysis has to be undertaken in a low odour environment such as an air-conditioned odour free laboratory. Analysis should be performed preferably within 6 to 8 hours of sampling.