Odour impact criteria to avoid annoyance

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To determine separation distances between odour sources and residential areas to avoid odour nuisance and complaints by the residents, odour impact criteria OIC have to be adopted by the responsible authorities. There is a wide variety of OIC used for this purpose, which differ by the odour concentration threshold (between 0.12 ou_E m^{-3} and 10 ou_E m^{-3}), the averaging period (hourly or instantaneous) and by the tolerated exceedance probability of the adopted threshold (between 0.1% and about 35% of the time).

There are two groups of OIC used in various jurisdictions: the first one with a low odour concentration threshold and a high tolerated exceedance probability (e.g. Germany); and the second group with a high odour concentration threshold and a low tolerated exceedance probability (e.g. Ireland). The modelled direction-dependent separation distances (using OIC which are supposed to offer the same protection level) can vary significantly. The OIC of the second group, considering higher ambient odour concentrations, show a much lower sensitivity to site-specific meteorological data. Therefore, a higher tolerated exceedance probability seems more appropriate for the determination of OIC. Even if the similarity of separation distances by various OIC could be determined, the direction-dependent separation distances differ considerably for the same protection level for a certain receptor type, e.g. rural residential properties.

1. Direction dependent separation distance

The annoyance potential of odour sources can be assessed by separation distances. The direction dependent separation distance between odour sources and residential areas is used to divide the circumjacent area around a source in a zone which is protected from nuisance and a zone closer than the separation distance where nuisance can be expected and has to be accepted. The protection level depends also on the land use category; the higher the protection level, the farther the separation distance.

The direction-dependent separation distance between an odour source and the residential properties is the regulatory tool, which takes into account the entire chain starting from the odour emission rate (source strength), the dilution in the atmosphere (the dispersion model) and the evaluation of the predicted ambient concentration (the output of the dispersion model) against certain odour impact criteria OIC. In general, the OIC are set by the environmental agencies or other governmental institutions on a national basis.

The quantification of annoyance depends on various predictors which can be summarised by the FIDO factors (frequency, intensity, duration and offensiveness of the perceived odour) (Watts and Sweeten, 1995). In New Zealand (Ministry for the Environment New Zealand, 2003) and several countries in Europe, a fifth factor, the location, is additionally in use (FIDOL). This last factor describes the nuisance with regard to the sensitivity of the receiving environment which is taken into account by the zoning. The location factor can directly be compared to the factor reasonableness, suggested by Miner (1995). He defines reasonableness of odour sensation as odour

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causing fewer objections within a community where odour is traditionally part of the environment, e.g. for rural smells as part of the rural environment and for industrial smells in industrial areas. Problems also often arise when incompatible activities are located near each other. For example, complaints about existing intensive farming operations often occur when land use in the vicinity is changing. Personal knowledge of the operator of the livestock unit, long term residency, economic dependence on farming, familiarity with livestock farming and awareness of the agricultural-residential context are related to a reduced incidence of formal complaints. An assessment of this factor is often done by the land use (zoning) category of the neighbours, e.g. a pure residential area has a higher protection level as a rural site.

In most of the national jurisdictions which set up national odour impact criteria only the two dimensions “frequency” and “intensity” are used out of the FIDOL factors. The reasonableness and thereby the protection level for a certain zone, which is described by the dimension “location”, is considered by varying these two selected dimensions.

2. Odour impact criteria

For practical use separation distances are calculated to reduce or avoid odour annoyance depending on a certain protection level. At such a distance the frequency of odour sensation over a certain odour concentration threshold C_T does not exceed a pre-selected level, called the exceedance probability p_T. The exceedance probability can be defined as a conditional probability p_T = prob $[C|C > C_T]$. This concept is based on investigations of Miedema and Ham (1988) and Miedema et al. (2000) who found a strong relationship between the odour concentration threshold $C_{2\%}$ (respectively the 98 percentile) for an exceedance probability of p_T = 2% and the percentage of the highly annoyed neighbours HA, using an integration time of 1 hour (hourly mean values)

$$HA = K \log C_{2\%}$$

with a constant K = 9.25 (Miedema et al., 2000) or 10 < K <12 for pigs (Nicolas et al., 2008b).

2.1 National determination of OIC

Various national odour impact criteria NOIC which differ by the odour concentration threshold and exceedance probability are in use to protect inhabitants from the same level of nuisance.

Two examples of NOIC are given which differ considerably. In Germany the NOIC for pigs is defined by a low odour threshold of 0.25 ou m^{-3} (as an hourly mean value) and high exceedance probabilities of 20% for rural and 13.3% for urban areas. In Ireland an odour threshold of 6 ou m^{-3} for rural and 3 ou m^{-3} for urban areas with a low exceedance probability of 2% is in use.

This approach of OIC is used identically for all other odour sources (e.g. waste water treatment plants (Capelli et al., 2013), municipal solid waste landfills (Sironi et al., 2005).

The calculation of the separation distance is carried out using a dispersion model, which predicts the ambient odour concentration on an hourly basis. This time-series of concentration values allows a calculation of the percentage of time in the year during which the threshold odour concentration (OIC) would be exceeded. This can be compared to the tolerated exceedance probability.

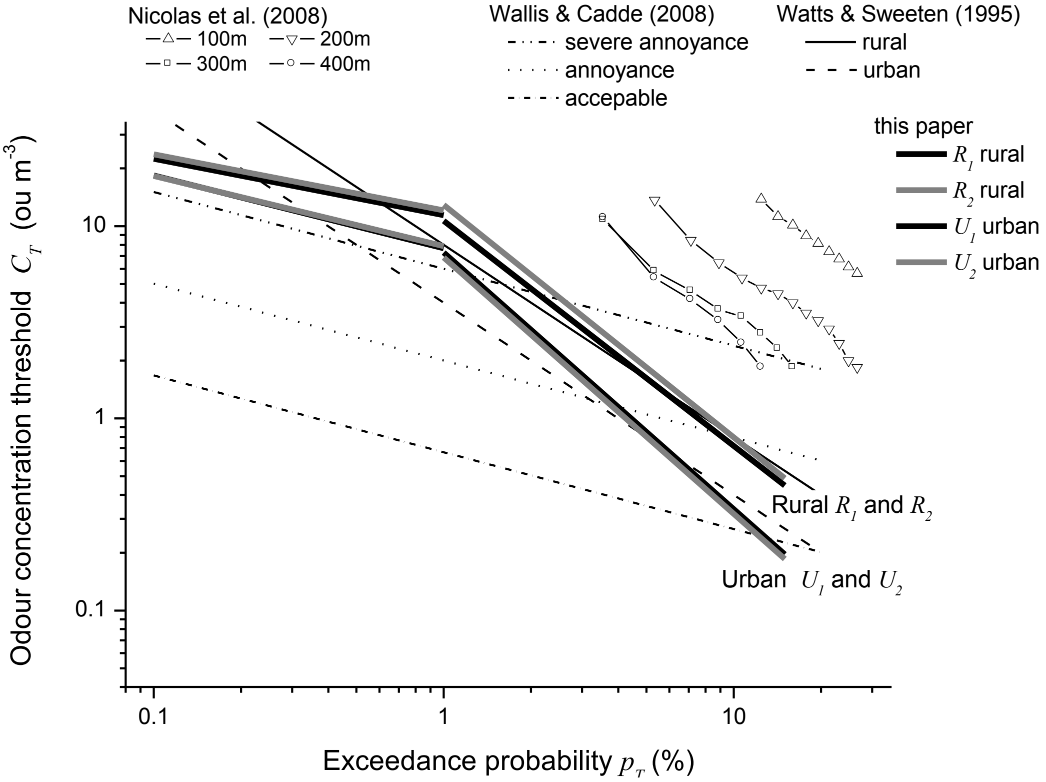

Figure 1: Relationship between exceedance probability p_T and odour concentration threshold C_T to define similar protection levels. The empirically derived functions are compared with the functions of Watts and Sweeten (1995) and Wallis and Cadee (2008). Additionally, empirical data are added for a pig farm (Nicolas et al., 2008a) (from Sommer-Quabach et al. (2014))

For a low exceedance probability of p_T = 2% or less only few distinct meteorological situations will contribute to the separation distance. For p_T = 0.1% (West Australia) only 9 hours are used to determine the separation distance. This means that for each wind direction at least nine hours per year of a certain meteorological situation with a very low dilution can be found which leads to a nearly circular separation distance. In contrast, for a high exceedance probability in the range of 10 to 20%, nearly all stability classes contribute to the separation distance as could be shown by Schauberger et al. (2006). Further on, the two isopleths of the protection levels of rural and urban residential areas show a higher discriminatory power for higher exceedance probabilities, because there the two isopleths have a greater distance (Figure 1). Even if the similarity of separation distances for various OIC can be determined, the direction dependant separation distances differ considerably for the same protection level.

2.2 Hedonic tone

The offensiveness of the odour perception, often measured in terms of “hedonic tone”, in the pleasantness–unpleasantness–dimension, is a powerful predictor of annoyance. It is shown that exposure-annoyance as well as exposure–symptom associations are strongly influenced by the hedonic tone. Whereas pleasant odours induced little to no annoyance, both neutral and unpleasant ones did (Sucker et al., 2008). In some countries (Germany, Ireland, and Belgium), the NOIC differ by the hedonic tone which means that for agricultural odour sources, the limit values depend on the kind of animals. This approach is suggested by the German odour guideline (GOAA, 2008) not only for odour emission caused by animal husbandry but also for all other odour sources. There a methodology is included into the guideline to judge if a perceived odour is closer to a pleasant smell or unpleasant malodour. According to the proximity to one of these two poles, the exceedance probability of the OIC can be adapted by using a weighting factor f. Then the nuisance relevant exceedance probability p_T* is calculated by $p_T* = p_T \ /f$. For an unpleasant odour (e.g. broilers with $f = 1.5$) the tolerated exceedance probability for pure residenatal areas is then reduced from 10% to $p_T* = 6.7\%$, for a more pleasant odour (e.g. dairy cattle with $f = 0.5$) the tolerated exceedance probability is increase to 20%.

2.3 Resonableness and protection level

Besides the hedonic tone also the reasonableness of odour sensation has a strong influence on the annoying potential. Taking the 10% value of annoyed people, the corresponding concentration threshold C_T for the exceedance probability of $p_T = 2\%$ (1-hour mean value) is $C_T = 1.3$ ou m^{-3} for the general public. In areas dominated by agricultural land use, the “acceptable” concentration reaches $C_T = 3.2$ ou m^{-3}. If pig odour is a historical feature of the environment, then $C_T = 6.3$ ou m^{-3}. For those inhabitants which are directly involved in livestock husbandry, the concentration is determined to $C_T = 13$ ou m^{-3} (EPA Ireland, 2001). These findings are good arguments that OIC can be adapted according to zoning and to the acceptance of a certain odour level by residents. For the German NOIC the protection level is adapted to a certain zoning by the variation of the exceedance probability (e.g. for residential areas $p_T = 10\%$, for rural areas $p_T = 15\%$), whereas in most of the other countries, this is done by the variation of the odour threshold concentration C_T.

3. Calculation of the separation distance

3.1 Empirical guidelines

Some countries have already developed guidelines to address odour from livestock. In all these guidelines, the separation distance is calculated as a function of the odour emission rate, sometimes parameterized by the number of animals. Recently new guidelines were published for Germany (Schauberger et al., 2012d; VDI 3894 Part 2E, 2011), for Belgium (Nicolas et al., 2008a), and for the US (Nimmermark et al., 2005). In Austria a new guideline is under development which will substitute the old version published in 1995 (Schauberger and Piringer, 1997), which will include the empirical approach by Schauberger et al. (2012a).

The structure of these guidelines is mostly very similar. On the basis of the odour emission rate E (in ou$_E$/s), the separation distance S is calculated by an empirical function. In many cases the selected relation is a power function $S = a\,E^b$ (Schauberger et al., 2012d) with a factor a and the exponent b which are derived empirically. The predictors for these two parameters are the meteorological situation (e.g. frequency of the wind direction and wind velocity) and the selected protection level for the separation distance.

3.2 Dispersion models

Two classes of dispersion models are currently used for topics of (regulatory) odour dispersion, namely Gauss and Lagrange models. Both model classes belong to the so-called non-CFD (computational fluid dynamics) models. Generally, different grades of approximations and simplifications to the primitive equations are used when calculating concentrations. For example, these models do not calculate the flow around a single building or obstacle when applied to an urban-like geometry, but the effect of a group of obstacles is taken into account through an increased surface roughness value or by a coarse resolution of the buildings. Non-CFD dispersion models are in general less complex and easier to run than typical CFD models and require much shorter calculation time. One main advantage is that non-CFD models may be run over a long series of input data to represent different meteorological conditions.

In Gauss models, flow-disturbing features like building influence or topography can only be treated via simple empirical relations and assumptions (e.g. flow around or across an isolated hill via the dividing streamline concept). In Lagrange models including a diagnostic wind field model, a more realistic simulation of the flow field due to topography or buildings is possible. A simple assessment of the ambient odour concentration in the near field of buildings can be found in Schauberger and Piringer (2004). For all types of models a meteorological station representative for the area of interest has to be chosen or erected to deliver the desired time series of meteorological parameters, at least over one whole year, in the form of hourly or half-hourly mean values. Additionally the atmospheric stability has to be derived from meteorological data or observations (e.g. cloud cover of a nearby airport) on an hourly basis.

The output of these dispersion models is the ambient concentration at a certain point with the same temporal resolution in the form of hourly or half-hourly mean values.

3.3 Assessment of the perceived odour concentration in the field

Contrary to most air borne pollutants odour is not a feature of a certain chemical species but a physiological reaction of humans. The sensation and perception of odorants depends on sniffing as an active stage of stimulus transport.

For the assessment of peak values, describing the biologically relevant exposure, often the so called peak-to-mean concept is used. This is a way to adopt dispersion models to short-term odour concentrations. The goal of the use of peak-to-mean factors is to mimic the perception of the human nose in a better way as it can be achieved by long term mean values.

The step from the one-hour mean value (as output of the dispersion model) to an instantaneous odour concentration is shown in Figure 2. For the one-hour mean value, the threshold for odour perception (here taken as 1 ou_E/m^3) is not exceeded. Taking mean values over 10 minutes, one concentration value exceeds the threshold. For the short term mean values of 12 s, concentrations in the range of 5 to 6 ou_E/m^3 can be expected, which means a distinct odour perception over several breaths. Figure 2 shows that the shorter the selected time interval, the higher the maximum concentration. For the shortest period of 12 s, a new feature of the time series can be seen. Besides 12 s intervals with odour concentrations above zero, a certain percentage of zero observations can be expected. The frequency of non-zero intervals is called intermittency (Chatwin and Sullivan, 1989).

Therefore, the maximum ambient odour concentration for a single breath C_p can be estimated using a peak-to-mean factor F which modifies the modelled odour concentration (one hour mean C_m) using $C_p = C_m F$. The shorter the integration time for the ambient odour concentration, the higher the peak-to-mean factor F. It is assumed that this peak concentration C_p is more appropriate to describe the odour sensation of the human nose than the one-hour mean value (Piringer and Schauberger, 2013; Schauberger et al., 2012b).

The following predictors are discussed, which influence the concentration fluctuation and thereby the peak-to-mean factor (Hanna and Insley, 1989; Olesen et al., 2005):

1. Stability of the atmosphere
2. Intermittency
3. Travel time or distance from the source
4. Lateral distance from the axis of the wake
5. Geometry of the source (emission height and source configuration)

The details for the parameterization of these five predictors can be found in Schauberger et al. (2012c).

A post-processing tool for dispersion calculations was developed by Schauberger et al. (2000) showing a decrease of the peak-to-mean factor with distance from the source. Further downwind the peak-to-mean factor is modified by an exponential attenuation function depending on the Lagrangian time scale (Piringer et al., 2007).

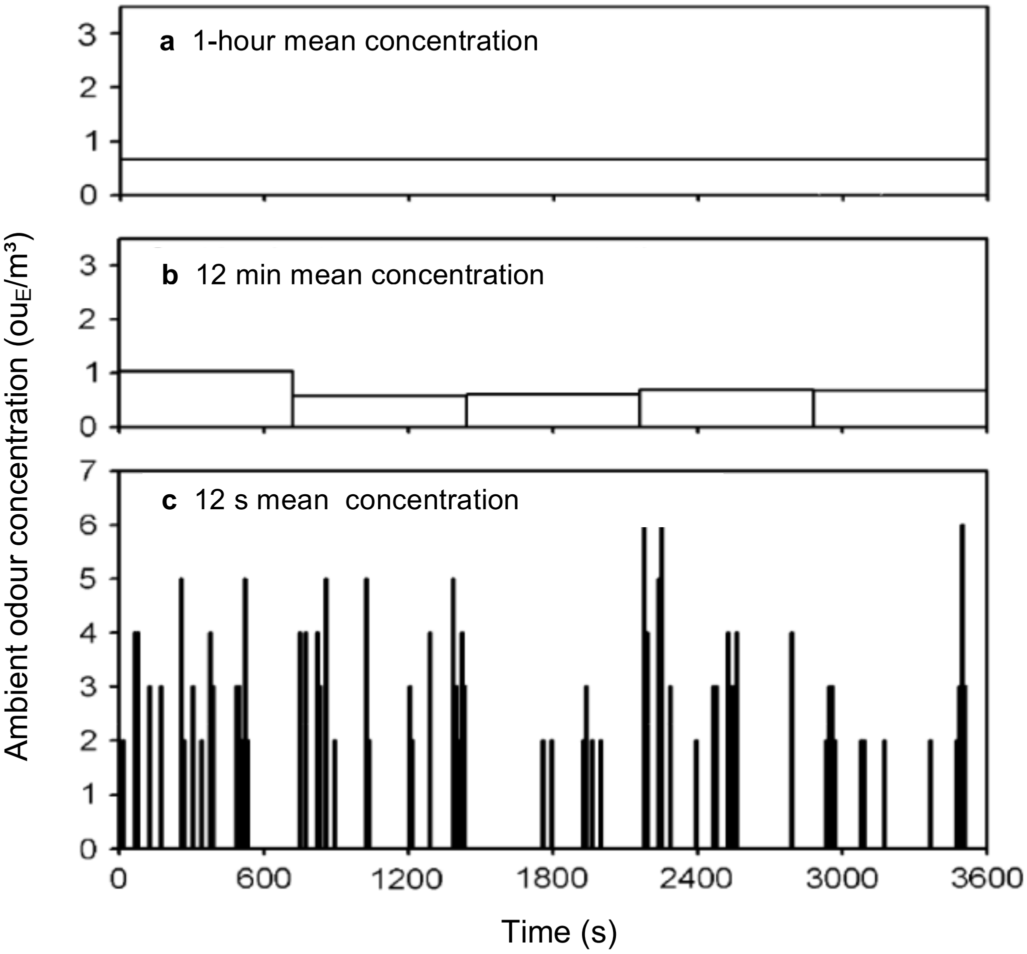

Figure 2: Time course of the odour concentration (ou$_E$ /m³) for three time intervals. (a) one-hour mean value (e.g. output of a dispersion model), (b) 12-min and (c) 12-s mean odour concentrations observed at a single receptor point during a field study. The 12-s mean values were recorded and subsequently used to calculate 12-min and one-hour mean concentrations (source: Schauberger et al. (2012c), modified from Nicell (2009)).

To apply the NOIC properly, the relevant integration interval for the odour concentration has to be known.

4. Conclusions

In many countries, odour impact criteria OIC are in use defined as the combination of odour concentration threshold (in ou m^{-3}) and exceedance probability (in %). A commitment of the environmental authorities for OIC, which guarantees a certain protection level depending on the zoning, is an important feature for a reliable planning process.

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