The effect of arduous odours on the community

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Environmental malodour remains a major source of complaints from communities. This factor is likely to increase, as the urban sprawl steadily encroaches into odour emitting industries. Within Australia, the efficacy of wastewater treatment and biosolids application are been undermined by community barriers due to malodour and its associated annoyance. This thesis is a study of the ways in which malodours and community satisfaction are understood within the context of wastewater treatment and biosolids. This involved a multiple-step research path which has incrementally provided information necessary to produce research and community interaction tools. This research path has centred on six wastewater treatment plants (WWTPs) that have provided a diverse set of industry-community interactions. The multiple-step research path has involved review of current literature, complaint management analysis, improving ecological validity of gas chromatography-mass spectrometry/olfactory (GC-MS/O), community and industry surveys, qualitative research for plant managers and land owners, before culminating in the application of online tool for dynamic community engagement. Foremost, a Literature Review assessing the effectiveness of odour and community assessment techniques within the context of community satisfaction guided the research plan. Complaint management procedures have been scrutinised with comparisons to odour report requirements as well as counterparts from other countries. We have also broadened methodologies for GC-MS/O in order to improve outcomes with community members who would not otherwise be represented. Community surveys at three community sites assessed the variation of response between WWTPs of high and low complaint levels, and have defined contributing factors of community satisfaction that have hitherto been disparate within research. We have also explored the under-researched area of industry culture through the use of surveys and plant manager interviews; this has revealed variations in industry attitudes and communicative relationships. These research landmarks have characterised gaps within industry-community engagement; namely establishing common language, appropriate inter-industry communication, appreciating community variance, as well as the adoption of techniques capable of defining malodour events. This thesis contributes both tools for community engagement as well as furthers research on the effect of malodours on communities.

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The Effect of Arduous Odours on the Community

James Emerson Hayes

A thesis in fulfilment of the requirements for the degree of Doctor of Philosophy

School of Civil and Environmental Engineering
Faculty of Engineering

The University of New South Wales
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This thesis is dedicated to my wife, Sarah.

Abstract

For the water industry, environmental malodour remains the predominant source of complaints from communities. This issue is likely to exacerbate, as the urban sprawl steadily encroaches into odour emitting water industry facilities as well as the increasing demand for such facilities. Within Australia, the efficacy of wastewater treatment and biosolids application are under researched and as a result undermined by community barriers due to malodour and its associated annoyance. As a topic of investigation, we have concentrated on six wastewater treatment plants (WWTPs) that have provided a varied set of industry-community interactions.

This Thesis is a study of the ways in which malodours and community satisfaction are understood within the context of wastewater treatment and biosolids. This involved a multiple-step direction which has incorporated a methodologically diverse set of implemented techniques. These techniques have provided a research path that have provided specific milestones as well as information that has contributed to further technique's implementation.

The multiple-step research path has involved review of current literature, complaint management analysis, improving ecological validity of gas chromatography-mass spectrometry/olfactory (GC-MS/O), community and industry surveys and qualitative

research for plant managers and land owners, before culminating in the application of an online tool for dynamic community engagement.

Foremost, a Literature Review assessing the effectiveness of odour and community assessment techniques within the context of community satisfaction guided the research plan. This Literature Review identified a need for a multi-faceted approach, given that current methodologies are separated between analytical, odour assessment, and social assessment techniques, and that prior combined approaches have produced effective outcomes. Complaint management procedures have been scrutinised with comparisons to odour report requirements as well as counterparts from other countries. A pertinent discovery to future complaint implementation is the current inadequacy of odour complaint logging as well as a detrimental focus on complaint reduction over complaint resolution.

We have also broadened methodologies for GC-MS/O in order to improve outcomes with community members who would not otherwise be represented. This part of the research also contributed towards the construction of a Community Odour Wheel for future techniques. Community surveys at three wastewater treatment plants (WWTP) assessed the variation of response between WWTPs of high and low complaint levels, and have defined contributing factors of community satisfaction that have hitherto been disparate within research. Of note, we found a series of questions relating to industry attitudes that predicted odour annoyance to a high degree of confidence, and that odour annoyance and frequency (previously unrecorded aspects of odour complaints) are significantly related to enacting community behaviour against industry. We have also explored the under-researched area of industry culture through the use of surveys and plant manager interviews; this has revealed variations in industry attitudes and communicative relationships. In particular, a distinct lack of integrated knowledge and inter-industry communication have meant best practice for community engagement has not been established despite expensive malodour amelioration efforts.

These research landmarks have characterised gaps within industry-community engagement; namely establishing common language, appropriate inter-industry communication, appreciating community variance, as well as the adoption of techniques capable of defining malodour events. As a response, we propose the use of the Online Dynamic Engagement for Communities (ODEC). This is an online and workshop-based platform that incorporates effective odour logging, common language between community and industry, as well as being a communicative and information structure that enhances community engagement to resolutions. ODEC was implemented to a test site, and its adoption has appeared to reduce community odour complaints, produced meaningful odour observation data, as well as provided a further method by which plant operations can be assessed.

In summary, this doctoral Thesis has produced a set of effective community engagement tools and techniques which will enhance the ability to reach community engagement goals, and provide novel avenues of research for future endeavours.

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List of Acronyms and Abbreviations

AS/NZS	Australian/New Zealand Standard
ASP	Average Sensitivity Panellist
AWA	Australian Water Association
BAF	Biosolids-Averse Farmer
BCF	Biosolids-Curious Interviewee
CD	Chemical Detector
CES-D	Center For Epidemiologic Studies (Depression Scale)
CL	Centrate Liquor
CRC	Cooperative Research Centre
df	Degrees Of Freedom
DMDS	Dimethyl Disulfide
DMTS	Dimethyl Trisulfide
DS	Digested Sludge
DWS	Dewatered Sludge
ECD	Electron Capture Detection
EPA	NSW Environment Protection Authority
FID	Flame Ionisation Detector
FIDO	Frequency, Intensity, Duration And Offensiveness (of an odour)
FIDOL	Frequency, Intensity, Duration, Offensiveness, And Location
fMRI	Functional Magnetic Resonance Imaging
FPD	Flame Photometric Detectors
GC	Gas Chromatography
GC-MS	Gas Chromatography-Mass Spectrometry
GC-MS/O	Gas Chromatography-Mass Spectrometry/Olfactometry
GOAA	Guideline On Odour In Ambient Air
H_2S	Hydrogen Sulfide
HSP	High Sensitive Panellist
MCS	Multiple Chemical Sensitivity Syndrome
MFC	Mass Flow Controllers
MS	Mass Spectrometry
NBA	A Farmer Who Was Ready To Adopt Biosolids Land Application
OAV	Odour Activity Value
OD	Olfactory Discrimination
ODEC	Online Dynamic Engagement For Communities
ODP	Olfactory Detection Port
OH	Olfactory Hedonic Appraisal
OI	Olfactory Identification
OPM	Olfactory Profile Method
OT	Odour Threshold

OU	Odour Units
PBF	Pro-Biosolids Farmer
PID	Photoionisation Detection
PM	Plant Managers
POMS	Profile Of Moods Questionnaire
PPB	Parts Per Billion
PPT	Parts Per Trillion
PS	Primary Sludge
PTSD	Post-Traumatic Stress Disorder
SCADA	Supervisory Control And Data Acquisition
SCD	Sulfur Chemiluminescence Detectors
SEIFA	Socio-Economic Indexes For Areas
SPME	Solid Phase Microextraction
SS	Suspended Solids
STP	Sewage Treatment Plant
TATA	Tick All That Apply
TS	Thickened Sludge
UNSW	University Of New South Wales
UPSIT	University Of Pennsylvania Smell Test
URL	Uniform Resource Locator
VDI	Association Of German Engineers
VOC	Volatile Organic Compounds
VSC	Volatile Sulfur Compounds
WWTP	Waste Water Treatment Plant

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List of Publications and Presentations

[1] **Hayes, J.E.**, Stevenson, R.J., & Stuetz, R.M. (2014). "The impact of malodour assessment on communities: a review of assessment techniques" Science of Total Environment 500: 395-407

[2] **Hayes, J.E.**, Stevenson, R.J., Fisher, R., & Stuetz, R.M. (2017) "Unrepresented community odour impact: improving engagement strategies" Journal of Environmental Management (submitted)

[3] **Hayes J.E.**, Stevenson, R.J., & Stuetz, R.M. (2017) "Survey of the effect of odour impact on communities" Science of Total Environment (submitted)

Conference Presentations

[1] **Hayes, J.E.**, & Stuetz, R.M. (2014) Odours: community engagement 4^{th} AWA Biosolids and Source Management Conference. Melbourne, Australia

[2] **Hayes, J.E.**, Fisher, R., & Stuetz, R.M. (2015) The variation of response between panellists of high and standard sensitivity when implementing Gas Chromatography- Mass Spectrometry/Olfactometry 6^{th} Iwa Conference on Odours & Air Emissions. Paris, France, IWA Publishing: 1-9

[3] Fisher, R., Alvarez-Gaitan, J.P., **Hayes, J.E.**, Vitanage, D., & Stuetz, R.M. (2017) Improving biosolids management through the use of odour wheel Ozwater2017. Sydney, Australia, AWA Publishing: 1-10

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[5] **Hayes, J.E.**, Mannebeck, C., Stevenson, R.J.,Aurisch, R., & Stuetz, R.M. (2017) Communicative structures for online odour management IWA Conference on Odours & Air Emissions. Warsaw: Poland, IWA Publishing: 1-10

Chapter 1

Introduction

Chapter 1. Thesis Introduction

Malodour remains the biggest source of complaints from communities in regards to environmental issues. Malodours are experienced as arduous for communities: they are not merely a bad smell, but have the ability to cause an enduring environmental impact for the communities experiencing them. This factor is likely to increase, as the urban sprawl steadily encroaches into malodourous emitting industries. Within Australia, the efficacy of wastewater treatment and biosolids application are undermined by severe community barriers due to malodour and its association with health effects. This thesis discusses the ways in which malodours and community satisfaction are understood within the context of wastewater treatment and biosolids. The multiple-step research path presented here has involved review of current literature, complaint management analysis, broadening strategies of gas chromatography-mass spectrometry/olfactometry (GC-MS/O), community and industry surveys, qualitative research for plant managers and land owners, before culminating in the development of a research tool, known as Online Dynamic Engagement for Communities (ODEC).

Current methodologies investigating environmental malodour are not contiguous; techniques vary from highly analytical identification of odorants to qualitative interviews, to community engagement practices. As a result, the thesis objectives have been accomplished through a multiple step approach that has attempted to incorporate both current methodologies as well as use these methodologies to improve impending research steps. Appropriately, this has meant that investigative techniques used in this thesis have a relationship with each other derived from using obtained information to determine future methodological approaches (**Figure 1**).

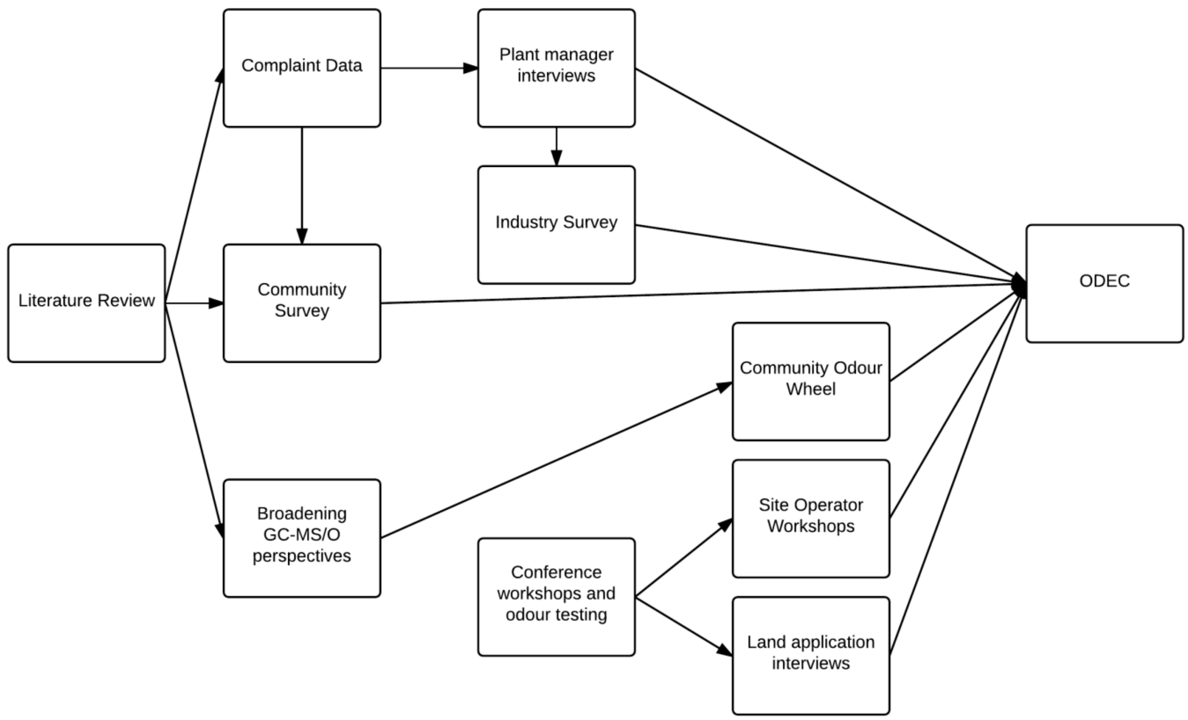

Figure 1. Relationship between thesis components. Each component has its own goals, but additionally contributed to other components.

As indicated in this Figure, components of the thesis have contributed to other components that have culminated in the design and implementation of ODEC. However, every component has also addressed the core thesis objectives and investigated specific goals indicative of the methodology researched. As a result, while separate components may implement varying methodologies, they contribute to each other's understanding and the overall investigation into community behaviour and engagement.

The first component is a Literature Review assessing prior research into the effects of environmental malodour, and how these varying methodologies can be applied to a community framework. We found that there are three broad perspectives on investigating environmental malodour: analytical, community assessment, and odour assessment methodologies. We found that not only are there divisive methodologies in play, but that there is very little dissemination between the avenues of research. In particular, olfactometers are a staple of several branches of scientific inquiry, yet the lack of cross pollination has meant that olfactometers have evolved separately and summarily without standardisation across disciplines. The overall rigidity of research avenues has affected the space in two ways. Firstly, there is a limitation on what is investigated; for instance, we found very little research into cultures of industrial companies and the effect that has on dealing with communities. Secondly, combined methodologies have revealed intriguing effects and interactions that are summarily under researched. As an example, GC-MS/O is a celebrated and very useful tool that has combined analytical and odour assessment to provide invaluable information. A second goal of the Literature Review was to investigate what are the effects of environmental malodour on communities. We found that malodour often caused health complaints, but that the explaining factor was not determined. Additionally, odour seems to behave as an “anchor” for communities in that it is often criticised as representative of an industry even when other factors (which are not as acceptable for complaints) are a larger concern. Perhaps most importantly, there is still no theory for why odour will cause a neighbour to complain and another will not. The

Literature Review provided a crucial starting block as to carry out analysis using complaint information, GC-MS/O, and surveys.

For the next research component, we investigated odour complaint data received from Sydney Water, SA Water, and Hunter Water. Within the context of malodour research, we found current complaint management standards able to produce only rudimentary information through complaint maps that did not provide variables necessary for further investigation or community engagement. We also found that there was a distinct pattern between “active” and “passive” communities. Active communities had a large number of complaints, but over half of these complaints were produced by a handful of community members. Standards of odour complaint management and community engagement from overseas were discussed and we established a series of recommendations that would be the most straightforward and meaningful for these Australian water companies to adopt. This component also provided a platform to introduce the six Waste Water Treatment Plants (WWTP) that we used as investigative markers throughout the Thesis. These WWTPs varied in size, number of complaints, and surrounding community engagement approaches. This component establishes the current situation of the WWTPs, community attitude, and expected odour qualities. This component sets the parameters for the next component, **Chapter 4**. **Chapter 4** continues by investigating how those odour qualities manifest, and this chapter bridges the understanding between odorant composition and the experience of the community.

The Literature Review also assisted in looking at the ways in which GC-MS/O could be used for different effects. GC-MS/O is currently most often used as a way to quantitate contributing odorants from a set of standardised panellists. This procedure is useful to establish odorants and their contributions, and has legislative components abroad. However, this approach is not particularly ecologically valid when considering communities whose members will include individuals of higher olfactory sensitivity. As a study, we duplicated samples from the unit processes of three WWTPs and measured the olfactory response of a participant with average olfactory sensitivity as well as a participant with high olfactory sensitivity. We found that the participant with high olfactory sensitivity was capable of detecting far more odorants, but also missing some that the average sensitivity participant was able to register. This research offers a new methodology for GC-MS/O, and also highlights the importance of considering community members of high olfactory sensitivity as current odour measurement practices may leave them unrepresented. These findings illustrate two important facets to community engagement. Drawing from our complaint records where a small number of community members produce a majority of complaints, it is important to consider individuals with high olfactory sensitivity may be detecting these odorants more readily than other residents or measurement policies. This component provides a model by which community odour experience can be assessed. This component, alongside **Chapter 3**'s assessment of odour complaints, provides the information necessary to undertake **Chapter 5**'s community survey. In this way, we establish the boundaries of the odour effects, as well as characterise them in a method that represents the community experience.

By using information derived from the Literature Review as well as the complaint data scrutinised in **Chapter 3**, we constructed a comprehensive Community Survey thatBy investigated facets of wellbeing, perceived control, odour impact, attitudes, and demographics. This Community Survey was distributed to three sites: a suburb surrounding a WWTP of high complaints, a suburb surrounding a WWTP of low complaints, and a suburb with no WWTP or notable industry. This Community Survey differed from most in prior literature in that we investigated a “non-active” response- WWTPs were not mentioned in the survey and residents were prompted to express what they perceived to be their nearest industry. Using binary logistic regression, we found several variables that predicated odour complaint likelihood. These included distance from WWTP, home ownership status, belief in odour legislation, and environmental worry. Interestingly, we did not find significant relationships between odour complaints and health, wellbeing, or perceived control. This Community Survey provides a measurement tool for industry, as well as elucidates what may be a “true” representation of odour complaints compared to what may be an aggravated response in other surveys. Within the context of the overall project, this Community Survey provided us with predictions for the uptake and design of the ODEC system, as well as insight into the best suited measurement techniques.

As a part of investigating the ways in which industry operates, we conducted a Water Industry survey as well as a series of plant manager interviews regarding the six WWTPs in focus for this project. The Water Industry survey provided us with the understanding that industry members recognise the threat of odour incursions, and that there were variations between Water Industry companies and the effectiveness of community engagement strategies. Plant Manager interviews provided further detail into cultural variations that exist between WWTPs. We found that inter-industry communication can be severely lacking, which has resulted in WWTPs pursuing similar goals by vastly different means and success. Similarly, land application interviews elucidated current interests and fears for farmers regarding biosolids which has been previously unexplored within literature. Biosolids within the context of land application is an element that elicits a variety of responses within an existing community dynamic and suggests that these responses should be investigated for appropriate market uptake.

Drawing from understanding of industry investigations, complaint standards, community beliefs, and prior literature we established several precepts necessary to produce a comprehensive odour observation and communication system: ODEC. ODEC was designed with several goals: the establishment of a common language between industry and community, the creation of a two-way communication platform between industry and community, as well as producing meaningful data for easy interpretation for site managers and upper management alike. ODEC consists of stakeholder workshops, community odour wheels, and an online application. The community odour wheel and stakeholder workshops were designed to be as simple and "casual" as possible in order for better adoption prospects and to produce a common language. The online application draws from these simple tools in order for stakeholders to make odour observations which can then be compared to weather reports, air dispersion models, as well as trends throughout the community. The ODEC platform also allows for two-way communication between industry and community, and also offers a platform for inter-industry discussion in order to establish best practice community engagement.

In conclusion, this Thesis presents an in-depth analysis to the efficacy of measurement techniques for community engagement, as well as a treatise on the current behaviour and actions of stakeholders within an environmental malodour paradigm. It has provided both novel research as well as tools for further investigation that will improve community-industry relationships. There are several key findings from this research. This includes a hitherto un-investigated lack of communication for inter-industry, which has additionally produced knowledge gaps regarding community engagement and odour measurement practices. Also, we have constructed a tool able to predict odour annoyances and provided recommendations for enhanced community engagement. Finally, ODEC provides a platform for common language and communication between all stakeholders which properly implemented will transform odour complaints into meaningful observations as well as reduce community dissatisfaction.

Chapter 2

Literature Review

Chapter 2. Literature Review

2.1 Introduction

Odours remain the major cause of complaints in regards to environmental issues for a wide variety of industries, including wastewater and waste management, intensive livestock, and biosolids, and continues to grow in both number and severity of complaints (Shusterman 1999, Gostelow *et al.* 2001, van Harreveld 2001, Harrison *et al.* 2002, Adams *et al.* 2003, Rappert *et al.* 2005, Brambilla *et al.* 2010, Intarakosit 2010). While odour abatement remains at the forefront of research into this area, it has been suggested that only with community approval can a project be considered successful; a fair estimation considering the time and cost sometimes necessary to alleviate community concerns (Perrin 1987, Elliott *et al.* 1997, Rosenfeld *et al.* 2000, Cervinka *et al.* 2004, Sucker *et al.* 2008a, Sucker *et al.* 2008b). These concerns seem to be multi-dimensional, in that it is not only the detected odour that determines the impact of a malodourous exposure on a community, but cognitive appraisal, community interests, as well as several other factors play a role in shaping the effects of arduous odour. These factors may elucidate why intolerance for malodour seems to be increasing (Sucker *et al.* 2008b). In addition, the understanding of these factors may also explain why, despite the enormous effort invested into the creation of odour parameters, governing bodies have had difficulty in establishing fair and effective regulations that address community needs (Rappert *et al.* 2005, Nicell 2009). As an example, Cervinka *et al.* found that canal air harbouring sewage odours caused a high degree of complaints even when those odours were drastically reduced in intensity (Cervinka *et al.* 2004). One of the many cited explanations for this increased complaint factor was the increased sensitivity to environmental stressors experienced by the community in the region; clearly, meeting community expectations requires a dynamic and multi-faceted understanding beyond that of an odour concentration-response paradigm (Cervinka *et al.* 2004).

Evaluations of malodour impact on communities are researched by a variety of methods: analytical, panellist, qualitative, and survey-based approaches. Each type of method assesses either the odour emitting industry, the odour itself, or the community that the odour affects (**Figure 2**). The difficulty that faces any particular proposed research to assess odour impact is that no single methodological approach can address both an accurate portrayal of actual odour exposure and physiological change, as well as identifying the human element and perceived effects of odour. While analytical methodologies may provide detailed information in regards to the actual qualities of malodours, appreciation of community impact remains an elusive and complicated objective. Conversely, qualitative research can establish some variables that modify the perception of specific odours, but cannot objectively establish the odour qualities themselves. There are some procedures, which do not offer definitive advantages in regards to establishing and describing odour impact, rather, they are implemented for other objectives of odour research. To that end, some methods, such as sensor arrays, confer no specific advantages for this particular field but may have some ancillary uses (Gardner *et al.* 1994, Stuetz *et al.* 2000, Francesco *et al.* 2001, Brattoli *et al.* 2011).

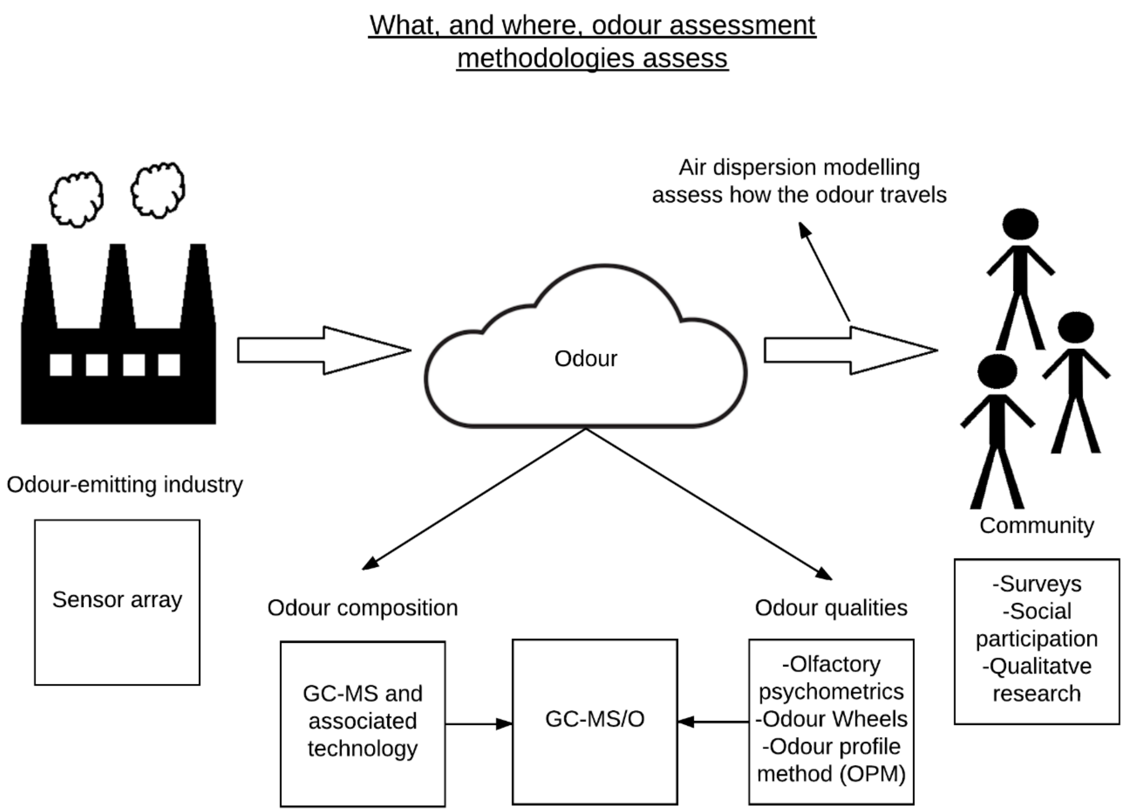

Figure 2. Odour assessment methodologies and what component they assess

The multi-faceted nature of this research area has created several objectives currently targeted in the assessment of malodour impact on communities. Firstly, there has been an attempt to establish a strong relationship between odour concentration and reaction to the odour, which has so far proven difficult (Cavalini *et al.* 1991, Sucker *et al.* 2001, Cervinka *et al.* 2004). Research has also focused on finding the factors that influence malodour impact, be it from an individual or community level (Sucker *et al.* 2001, Lebrero *et al.* 2011). Finally, there has been work put into operationalising findings in order to mitigate community concerns, which will improve community wellbeing as well as reduce opposition to industrial production. These objectives will most likely require an understanding of both odour qualities and community perception, and this has been seen in cross-paradigm approaches that have discovered intriguing characteristics of the inter-relationship between these two factors.

2.2 Analytical methodologies to assess odour

2.2.1 General advantages and disadvantages of analytical methodologies

Analytical methods of assessing environmental malodours encompass various procedures, ranging from inexpensive gas detection to highly sensitive Gas Chromatography-Mass Spectrometry (GC-MS) (**Table 1**). Specific gas detectors are comparatively cheap, and are often used in uncomplicated field testing, for example hydrogen sulfide detection (Firor *et al.* 2001, Muñoz *et al.* 2010). Specific gas detectors have clear cost and implementation advantages; however, their sensitivity is low, and can be affected by the environment, such as humidity or the presence of untargeted molecules (Gostelow *et al.* 2001, Muñoz *et al.* 2010). Furthermore, the odour impact may not be appropriately assessed because of non-detected odorous compounds significantly contributing to the overall smell (Gostelow *et al.* 2001, Muñoz *et al.* 2010). These analytical procedures are exceptionally powerful in regards to measuring precise concentrations and constitutions of odorants but tend to be laborious, expensive, and data intensive (Brambilla *et al.* 2010, Muñoz *et al.* 2010, Brattoli *et al.* 2011). In addition, specialised techniques are often required to analyse odorants at a "human" level, given the human nose's greater sensitivity compared to most GC-MS instruments (Rosenfeld *et al.* 2000). Another challenge with analytical assessment is that odour detection and concentration do not possess a linear relationship when detected by the human nose, especially when comparing varying odours to each other (Nagy 1991, Nicell 2003, Nicell 2009). As a result, while analytical methods may not detect particular odorants, very low concentrations of some odours, such as mercaptan, may produce the greatest effects (Acree *et al.* 1984, Nagy 1991, Muñoz *et al.* 2010). Most importantly in regards to understanding the impact of odours on communities, it cannot provide the perception of odours as experienced by individual receptors of the local area (Rosenfeld *et al.* 2000, Cervinka *et al.* 2004, Rappert *et al.* 2005, Muñoz *et al.* 2010). While analytical methods are useful legislatively, as well as providing definitive odorant levels, its arduous implementation and lack of human appreciation mean that it cannot be used to establish odour impact alone (Rappert *et al.* 2005).

Table 1. Analytical methods of assessing environmental malodours

Type of analysis	Methodology	Advantages	Disadvantages	Examples
Analytical methods (for example: GC-MS)	• Samples are taken from odour sources, then analysed using a various kinds of detectors (Hites 1997).	• Able to accurately assess the properties of the air within a given area more precisely than any other method (Muñoz *et al.* 2010). • The singular odorants within a combination can be detected (Muñoz *et al.* 2010). • Important from a legislative perspective (Agus *et al.* 2012). • Thanks to its analysis, can effectively separate different chemicals and as a result help in the evaluation of their origin in situations arising from multiple odour producing sources in close proximity to each other (Muñoz *et al.* 2010).	• Unable to assess the human elements of malodour perception (Nagy 1991). • Sample integrity dependent upon a range of factors, including time, container type, and time of sample (Le *et al.* 2013). • Most methods are unable to detect concentrations of some odorants otherwise detectable by the human nose(Rosenfeld *et al.* 2004) . • Expensive and laborious (Muñoz *et al.* 2010).	Agus *et al.* 2012 Bulliner *et al.* 2006 Rosenfeld *et al.* 2004
GC-MS/O	• Identical to GC-MS, except half of the flow after it is separated by GC flow to a sniffing port used by trained panellists(Zhang *et al.* 2010, Brattoli *et al.* 2011, Brattoli *et al.* 2013).	• Adds an important human factor to GC-MS analysis (Kleeberg *et al.* 2005, Cai *et al.* 2006, Cai *et al.* 2007, Zhang *et al.* 2010, Agus *et al.* 2012). • Cross tabulation of results between MS and Olfactometry can develop new insights into singular odorant contributions to overall smell (Kleeberg *et al.* 2005, Cai *et al.* 2006, Cai *et al.* 2007, Zhang *et al.* 2010, Agus *et al.* 2012).	• Due to GC separation, odorants cannot be analysed together, meaning that potential synergistic or antagonistic effects cannot be assessed (Laing *et al.* 1994, Lebrero *et al.* 2011). • Equally dependant on sample integrity as other analytical methods (Kleeberg *et al.* 2005).	Zhang *et al.* 2012 Kleeberg *et al.* 2005 Cai *et al.* 2006

Table 1. Analytical methods of assessing environmental malodours *(continued)*

Type of analysis	Methodology	Advantages	Disadvantages	Examples
Air dispersion	• A varied series of techniques that calculates the dispersion of odorised air that emanates from sources (Cesca *et al.* 2007, Sironi *et al.* 2010). • Used to assess the OU experienced by different areas of a local community (Blumberg *et al.* 2001, Hayes *et al.* 2006).	• A precise method of determining appropriate sampling populations, usually for surveys (Sironi *et al.* 2010).	• Some methods require years of recorded seasonal weather patterns to work effectively (McIntyre 2000). • There are several models of air dispersion, and do not necessarily produce similar results (Hobbs *et al.* 2000).	Cavalini *et al.* 1991 Cavalini 1994 Cesca *et al.* 2007
Sensory arrays	• Various devices (sometime referred to as "electronic noses") that have odorant-dependant sensors used to detect concentrations and qualities of odours (Gardner *et al.* 1994).	• Better at distinguishing odours that some other analytical methods, such as Photoionisation Detection (Hobbs *et al.* 1995). • Can be useful as a measure of odour where other methods are not applicable (Sohn *et al.* 2009, Capelli *et al.* 2013a).	• The technology is currently not as sensitive as olfactometry-based analysis, making their ability to assess community odour impact somewhat untenable (Stuetz *et al.* 2000, Francesco *et al.* 2001). • Sensor arrays are dedicated to only several different odorants, so will not detect non-targeted odours (Brattoli *et al.* 2011). • No true advantage in regards to assessing odour impact for communities beyond anything olfactometry can accomplish.	Stuetz *et al.* 2000 Sohn *et al.* 2009 Francesco *et al.* 2001

2.2.2 GC-MS and related technology

GC-MS is used to measure the type of chemicals and their abundances within an environmental odour sample (**Figure 1**). There are multiple variants of this standard model, each with a particular advantage fit for the specific research (**Table 2**). With regards to odour analysis, there are several steps involved with each method: sampling, sample preparation, separation, chemical analysis, and finally data interpretation.

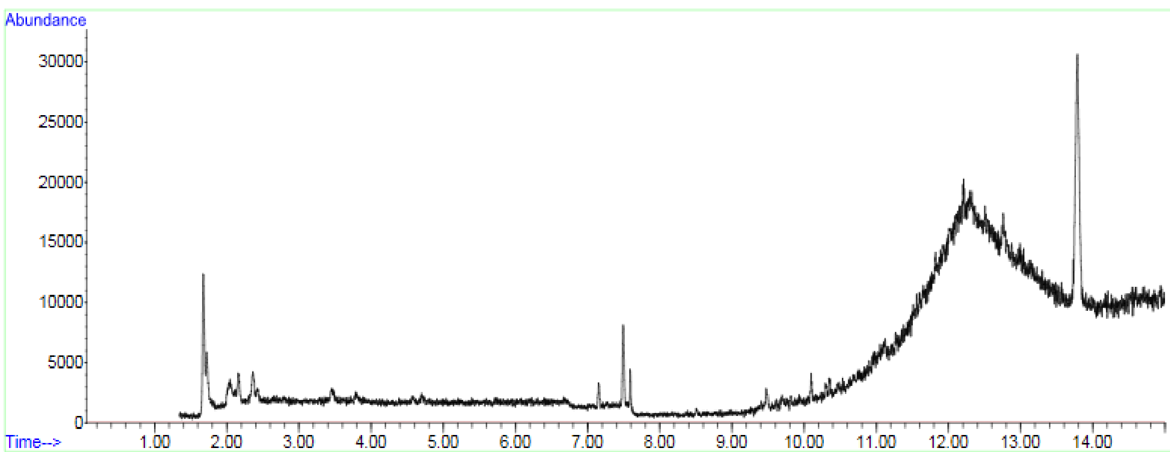

Figure 3. Example of typical GC-MS output. This spectra shows the abundance (*y*-axis) of chemicals dependent upon their retention time (*x*-axis).

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Table 2. Components of chemical analysis methodologies

Abbreviation	**Technique**	**Summary**	**Application**
GC (Delahunty *et al.* 2006)	Gas Chromatography	Gas Chromatography in odour research is used to separate samples.	• Almost all analytical investigations into odour begin with a GC aspect. • While GC can be used to identify compounds ,this is typically left to the following chemical detector due in part to the need for enhanced peaks (Muñoz *et al.* 2010).
MS (Kleeberg *et al.* 2005), MSD (Hobbs *et al.* 1995)	Mass Spectrometry	MS is a technique used to sort a sample's constituents through mass and charge via ionisation.	• The most common form of chemical detector that follows GC. • While very sensitive, it is not as acute as the human nose (Kleeberg *et al.* 2005, Muñoz *et al.* 2010).
O (Delahunty *et al.* 2006), SNIFF (Hochereau *et al.* 2004, Lehtinen *et al.* 2010), Olf (Agus *et al.* 2012), ODP (Ranau *et al.* 2004)	Olfactometry/ Odour Detection Port	Refers to the use of a human detector as a part of an analytical assessment.	• Required for sensorial analysis.
CD	Chemical Detector	Chemical Detector is a catch-all category for devices such as FID, MSD	
FID	Flame Ionisation Detector	An alternative to MS, FID detects ions through the combustion of compounds. They are unable to measure non-organic substances.	• Effective at measuring Volatile Organic Compounds (Muñoz *et al.* 2010). • While roughly as accurate as MS, FID is unsuitable for measuring Volatile Sulfur Compounds (Muñoz *et al.* 2010).

Table 2. Components of chemical analysis methodologies *(continued)*

Abbreviation	Technique	Summary	Application
MDGC	Multi-dimensional Gas Chromatograph	It uses the “heart-cut” of a sample; that is, the mid-stream of a sample.	-More effective separation than as standard GC (Bulliner *et al.* 2006)
TD	Thermal desorption	Using an increase in temperature to increase the volatility of a sample, thereby separating the sample into components.	-May degrade thermally unstable VOCs (Clausen *et al.* 2008) -May over better recovery for volatile and hydrophobic odorants.
GC×GC	Two-dimensional gas chromatography	One GC column periodically releases fractions of a sample to a second GC column. This produces a more detailed analysis that removes the requirements for heart-cut (Bulliner *et al.* 2006).	-highly accurate and very effective at chemical separation.
“-“		Hyphens are used to indicate one device being implemented after another. For example, GC-MS refers to a system that analyses a sample with a Gas Chromatograph followed by a Mass Spectrometer	
“/”		Slash marks are used to indicate devices being used simultaneously. For example, MS/O refers to a system that analyses a sample with a Mass Spectrometer and an Olfactometer at the same time.	
“×”		The times sign is used to indicate two-dimensional analyses. In most instances, this refers to GC×GC.	

2.2.2.1 Sampling

There are several methodologies by which odorants are taken from an environmental source. Most commonly implemented are bags, desorption tubes, and solid phase microextraction (SPME) (Lebrero *et al.* 2011). In order to conduct the analysis, samples are collected from industrial and field sites for processing, typically using either polymer bags or metal canisters; the accuracy of analysis is affected by the material of these containers, their storage conditions, as well as the sampling methods used (Bulliner *et al.* 2006, Hudson *et al.* 2008a, Hudson *et al.* 2008b, Muñoz *et al.* 2010, Brattoli *et al.* 2011, Lebrero *et al.* 2011, Le *et al.* 2013).

2.2.2.2 Sample preparation

Environmental odorous emissions usually are composed of a complex mixture of hundreds of chemical compounds at parts per billion (ppb) and parts per trillion (ppt) concentrations, which challenges the sensitivity and separation capacity of GC. These low concentrations present in odours are very often below the detection limits of most Chemical Detectors (CD), commonly in the nanogram range (Hudson *et al.* 2008a). Due to the minute concentration of the analytes, samples may have to be enriched prior to analysis to improve the pre-concentration of odorants (Sadowska-Rociek *et al.* 2009). This enrichment is accomplished either through cryogenic trapping, adsorption into either porous polymers or carbon-based adsorbents (Lebrero *et al.* 2011).

Multiple variants of sample preparation have been adopted, depending on the type of research intended. This includes homogenisation, centrifugation, acid traps, solvent extraction, liquid-liquid extraction, simultaneous distillation extraction, direct thermal desorption, closed loop stripping and cryofocusing (Le *et al.* 2013).

2.2.2.3 Separation

GC for odorant analyses is most often Flame Ionisation Detection (FID), Photoionisation Detection (PID), and Electron Capture Detection (ECD) (Rosenfeld *et al.* 2004, Muñoz *et al.* 2010). Additionally, more specific detectors include sulfur chemiluminescence detectors (SCD) and flame photometric detectors (FPD) when volatile sulfur compounds are the focus of analysis (Muñoz *et al.* 2010).

2.2.2.4 Chemical analysis

Samples are then processed; in the case of GC-MS, GC will separate the sample odour into base components, whereupon MS will measure the specific abundances of those components (Hites 1997).

2.3 Air dispersion

Another method of analysis, air dispersion of odorants, is both legislatively assessed, and used in combination with various measures of odour to produce accurate depictions of exposure to a community (Hobbs *et al.* 2000, Yang *et al.* 2000, Blumberg *et al.* 2001, Sarkar *et al.* 2003a, Department of Environment and Conservation 2005, Hayes *et al.* 2006, Cesca *et al.* 2007, Gallego *et al.* 2008, Sironi *et al.* 2010, Capelli *et al.* 2011). Typically, weather patterns for several years and odour sources are modelled and assessed to find how odours and associated concentrations are dispersed (McIntyre 2000). Alternatively, estimates of odour concentrations can be used as an inexpensive substitute if odours are considered negligible (Department of Environment and Conservation 2005). There are a number of variant programs for air dispersion modelling. Broadly, air dispersion models are divided into two types (with "hybrids"); Gaussian plume models, and the more sophisticated Lagrangian puff or particle models (Capelli *et al.* 2013b). While puff models are computationally more demanding, they are capable of offering more precise information, which has led to their endorsement by some legislation (Standards Australia and Standards New Zealand 2001a, Capelli *et al.* 2013b). Sironi *et al.* reported that CALPUFF air dispersion modelling and reports of odour perception had a correspondence of 86.5% (Sironi *et al.* 2010). Similarly, Sarkar and colleagues successfully produced a design incorporating olfactory intensity compared to odour concentration for individuals that fits well with psychophysical modelling, although there was elimination of some monitors whose intensity reports did not correlate with dispersion rates (Sarkar *et al.* 2003b). Comparatively, Cavalini (1994) produced exposure concentrations using established air dispersion models and compared it with community annoyance on a 0-10 scale; the correlations between the two were significant, but only moderately strong (Cavalini 1994). It appears that while the detection of odours is relatively straight forward, better understanding of annoyance requires an appreciation of an individual's cognitive appraisal and other individual-specific factors (Sucker *et al.* 2001). Other studies have found similar results, and interestingly the relationship between analytical measurement and social participation weakens when measurements of participant perception become more esoteric; detection has a stronger relationship than annoyance (Cavalini 1994, Blumberg *et al.* 2001, Luginaah *et al.* 2002, Sironi *et al.* 2010). Air dispersion modelling remains a fundamental aspect of assessing odour impact, however it has been suggested that care must be taken to reach a practical understanding of what results from these models entails (McIntyre 2000). In addition, air dispersion models often vary, and may not always agree with one another; even legislations based on air dispersion have large discrepancies (Hobbs *et al.* 2000, Sommer-Quabach *et al.* 2014). Prior research has indicated that the application of air dispersion to community engagement is variable dependant on a number of factors including averaging times, odour peaks and the behaviour of odours as particulates (McIntyre 2000, Capelli *et al.* 2013b, Sommer-Quabach *et al.* 2014). Air dispersion compared with community response is one of several methods of producing combined approaches to assess odour impact and represents a growing pool of research that incorporates multiple methodologies to produce better outcomes.

2.4 Sensor arrays

The use of sensor arrays (also known as e-noses) as odour monitoring tools has increased over time as the sensitivity of these devices has improved (Stuetz *et al.* 2000, Capelli *et al.* 2013a). There are advantages to sensor arrays with regards to their application and to a lesser extent their detection abilities. Firstly, they can be considered an alternative to other methods of odour evaluation if those methods are difficult to implement, for example when weather data is not available for air dispersion modelling (Capelli *et al.*

2013a). The sensors are also quite sensitive, and in some instances are more effective that PID (Hobbs *et al.* 1995). However, multiple sensor arrays are capable of only measuring a selected target of odorants. The repercussions are that non-targeted odours will be missed, and sensor arrays share the disadvantage with GC-MS procedures in that they cannot record synergistic or antagonistic effects between chemicals (Stuetz *et al.* 2000). In addition, humidity and temperature variations within the environment affect the sensitivity of the devices, which often leads to an inaccurate picture with regards to odour analysis (Stuetz *et al.* 2001b). A further disadvantage is that sensor arrays have not yet become as accurate as olfactory testing, which minimises their use as a tool for community investigation (Stuetz *et al.* 1998, Stuetz *et al.* 2000). With regards to evaluating community impact, sensor arrays have a role in recording gross odour incursions; however, their disadvantages for direct community understanding mean that alternatives are likely a better option (Nicolas *et al.* 2006, Bootsma *et al.* 2013).

2.5 Sensory methodologies to assess odour

2.5.1 Psychometrics- thresholds, hedonics, suprathresholds, Odour Wheels, and the Odour Profile Method

The olfactory sense is difficult to measure. Unlike vision or hearing, which contain relatively quantifiable scales of colour and decibels respectively, measurement of olfaction even in the most basic spectrum covers at multiple paradigms, all of which require separate methodologies to analyse, and all of which are subject to a litany of known and unknown variables (Doty 1991a, Press *et al.* 2000). These paradigms can be roughly divided into threshold and suprathreshold measures.

There are two types of olfactory threshold measurement. Odour Threshold (OT) is the measurement of a participant's ability to detect a particular odour. To accomplish this task, varying psychometric designs are available. Most commonly, the method of ascending limits or staircase method is used (Doty 1991b, Hayes *et al.* 2012). In regards to environmental odour testing, panellists are typically used to assess the Odour Units (OU), which is calculated as OU_E/m^3, or number of European Odour Units per square meter (Hobbs *et al.* 1995, Jiang *et al.* 2006, Sironi *et al.* 2007, Sironi *et al.* 2010). OU is somewhat similar to OT; the sample is diluted in air in a staircase method to be comparable to a panel's detection of a standard odorant, usually *n*-butanol. The OU is subsequently determined by the number of steps in the staircase required to attain this standard threshold value. Determining OU is the primary use of sealed bag olfactometers, but they may also have applications relating to olfactory identification and hedonic appraisal of the environmental odours (Nicolai *et al.* 1997, Burlingame *et al.* 2004, Suffet *et al.* 2009, Lebrero *et al.* 2011). The assessment of OU for any sample is important, as legislation typically sets guidelines for odour impact based on the number of OU that an industrial area produces (McGinley *et al.* 2001, Department of Environment and Conservation 2005). OU is assessed by the average number of dilutions taken for a group of panellists to correctly identify the sample 50% of the time; this is typically compared to a dilution of a chemical, usually *n*-butanol, that has the same detection rate (Bockreis *et al.* 2005, Muñoz *et al.* 2010, Lebrero *et al.* 2011). In regard to detection measurement, trained panellists have several advantages in regards to establishing odour impact. Panellists share surprisingly good correlation with both sensor arrays and certain analytical methods in regards to detection (Kim *et al.* 2008, Brambilla *et al.* 2010, Agus *et al.* 2012) although this relationship is at times not as noticeable (Capelli *et al.* 2008). Secondly, while quite expensive, olfactometry research tends to be cheaper than analytical methods (Brattoli *et al.* 2011). Threshold testing does offer a basic understanding of community impact, but measurements of suprathreshold odour qualities have begun to be appreciated as crucial for better community appraisal (Sucker *et al.* 2008a, Sucker *et al.* 2008b, Nicell 2009).

OI and olfactory detection (OD) fall under the purview of suprathreshold measures. The difference between the two is that OI demands that the participant has a ready definition of the odour they are exposed to, while OD involves identifying one odour as different to another (Doty 1991b). Intensity estimates and other measures of olfaction are acknowledged as being more important than previously estimated; hence research has begun to design more encompassing methodologies, including the assessment of additional odour qualities that has gone hand in hand with implementing field participants (Chen *et al.* 1999, Jiang *et al.* 2006, Suffet *et al.* 2009). The Odour Profile Method (as well as the Flavour Profile Analysis), and the associated Odour Wheel have incorporated measures of olfactory hedonics, quality, and intensity by panellists due to these measures' essential roles in determining odour impact (Richardson *et al.* 1989, Burlingame *et al.* 2004, Winneke *et al.* 2004, Sucker *et al.* 2008a, Nicell 2009, Agus *et al.* 2012). The Odour

Wheel was designed as a better way to establish odour impact, by understanding the importance of annoyance and irritancy beyond that of OU and thresholds. Varying Odour Wheels have been constructed with specialisations to assist in identification, such as the Compost Odour Wheel developed by Suffet *et al.* (**Figure 4**) (Rosenfeld *et al.* 2007, Suffet *et al.* 2009).

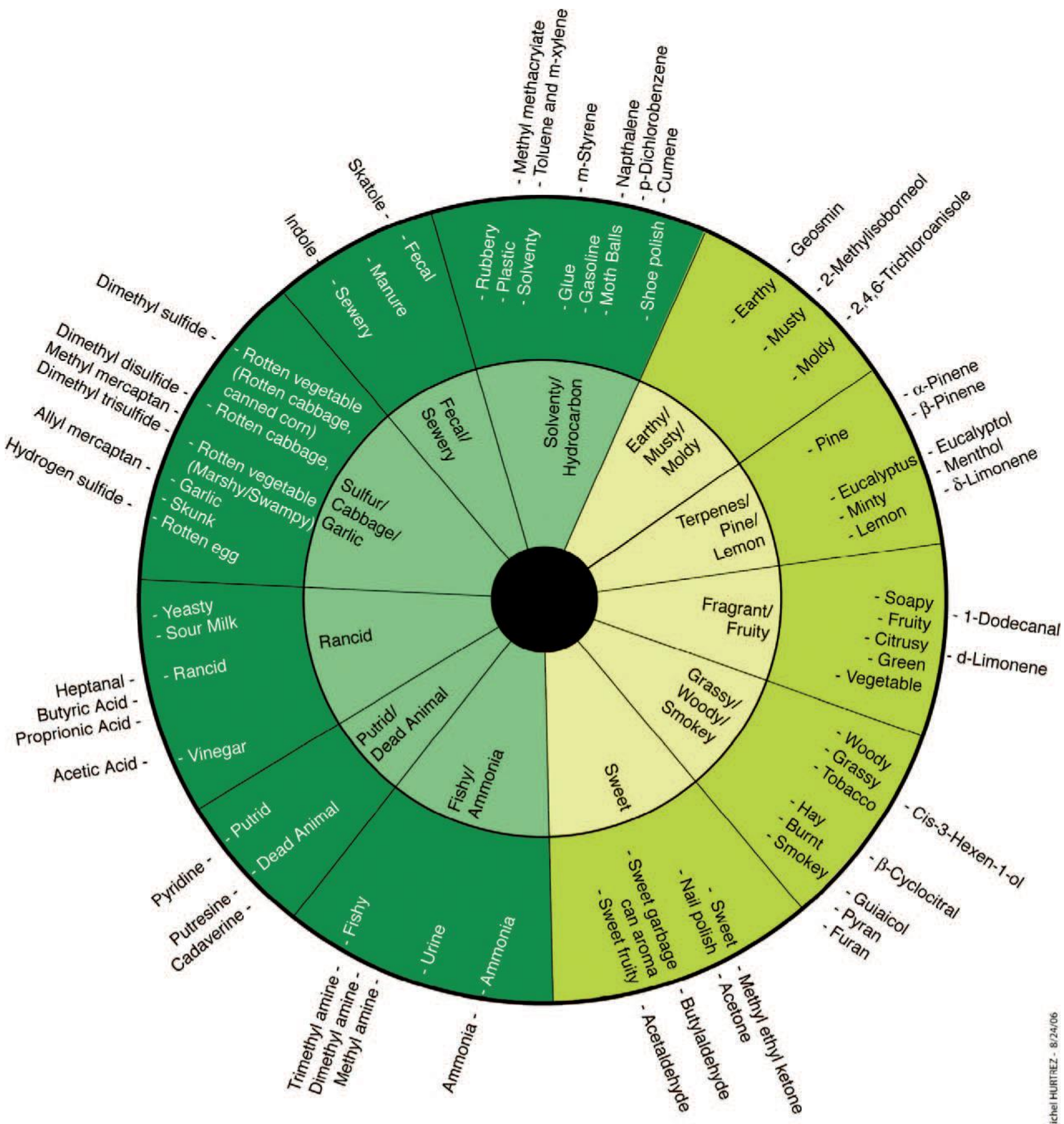


Figure 4. Example odour wheel: the compost odour wheel (originally cited in Suffet *et al.* 2009).

Another method of measurement evaluates the Frequency, Intensity, Duration and Offensiveness (FIDO) of an odour in an industrial and environmental setting; qualities, which have been assessed to provide a more accurate portrayal of elicited annoyance than threshold alone (Dalton 2003, Goldstein 2006, Henshaw *et al.* 2006, Sucker *et al.* 2008a). FIDO, or similar designs such as those suggested by Both *et al.* and Odour Wheels, are often used to assist other methods of analyses, such as GC-MS/O to better define the nature of odour impact (Both *et al.* 2004, Agus *et al.* 2012). While thresholds and OU measures are well understood, these additional suprathreshold qualities have debated importance. As an interesting example, while correlating with odour concentration, odour intensity has a debatable influence on odour impact (Frechen 2000, Gostelow *et al.* 2001, Suffet *et al.* 2009, Brattoli *et al.* 2011). Suffet *et al.* considers odour intensity as an integral part of determining odour annoyance, while Both *et al.* and Sucker *et al.* conducted research that posited that intensity as not nearly as important compared to the frequency of the odours experienced (Both *et al.* 2004, Sucker *et al.* 2008a, Suffet *et al.* 2009). However, this could be due to the separate methodologies of research, with both studies involving interviews with untrained residents which could indicate the disparity of response between panellists and the community at large. Hedonics, and similarly based measures such as offensiveness and annoyance as a measure is also contested as to its construction. Like intensity measures, the measurement of hedonics has yet to be standardised, and annoyance is sometimes considered on the same scale. In other cases, hedonics is formed as a separate measure that has a distinctly different relationship with perception (Chen *et al.* 1999, Frechen 2000, Miedema *et al.* 2000, Brattoli *et al.* 2011).

2.5.2 General advantages and disadvantages of panellist testing and sensory methodologies

Panellist testing through the use of olfactometers, field tests, or the Olfactory Profile Method (OPM) are the most popular methods of research into environmental odours (Muñoz *et al.* 2010) (**Table 3**). Panellist assessment involves training a small cohort of individuals to detect odours from industrial and environmental samples, usually using an olfactometer. Odour samples are captured and placed into sample bags, typically made of Tedlar™ or Nalophan™ (Scentroid, Canada), which are transported to the laboratory and implemented into the olfactometer Secondly, while quite expensive, olfactometry research tends to be cheaper than analytical methods (Brattoli *et al.* 2011) There are disadvantages with panellist detection methods, firstly, panellist testing is demanding in regards to stringent test conditions, as well as a constant requirement to reduce olfactory fatigue (Berglund *et al.* 1986b, Bliss *et al.* 1996, Yang *et al.* 2000, Stuetz *et al.* 2001a). In order to establish suitability as a panellist, laboratories typically remove 50-70% of applicants as unsuitable in regards to their olfactory acuity; a group, which is therefore disregarded when assessing odour impact (Leonardos 1980, van Harreveld 2004, Bockreis *et al.* 2005, Muñoz *et al.* 2010). Previous literature has suggested that panellist testing results in an underestimation of odour impact in communities (Evans *et al.* 1987a, Sucker *et al.* 2004). In addition, samples for panellist testing can be just as sensitive than those taken for analytical methods, especially with environmental variations and limited storage time; an important consideration given the large potential for these factors to affect results (Defoer *et al.* 2003, Bockreis *et al.* 2005, Laor *et al.* 2010). The nature of panellists themselves should also be taken into consideration; unknown samples can represent a health risk and should be chemically assessed for impact prior to olfactory analysis (Alexander *et al.* 1982, Standards Australia and Standards New Zealand 2001a, Department of Environmental Protection 2002, European Commitee for Standardisation 2003). This can be difficult however, as toxic concentrations for many odorous chemicals are unknown (Schweitzer *et al.* 1999). Hazard procedures are not yet a part of legislative guidelines, such as the VDI 3883, although some guidelines cite the importance of the awareness of potential toxic chemical exposure (Standards Australia and Standards New Zealand 2001a, Department of Environmental Protection 2002, European Commitee for Standardisation 2003). A further methodological issue is that only one third of laboratories in Australia and New Zealand adhere to technical standards out of those who purport to implement them, and that inter-laboratory differences can be pronounced (van Harreveld 2004, Maxeiner 2006, Muñoz *et al.* 2010, Bokowa *et al.* 2012). Practices and guidelines for these procedures vary significantly between regions, and unfortunately this variance is found in all aspects of legislation relating to odour (Verein Deutscher Ingenieure 1993, Department of Environmental Protection 2002, Freeman *et al.* 2002). While the disadvantages of panellist testing are at times exacerbated, such as poor inter-laboratory congruence as well as high panellist variance, the emphasis on a greater range of odour qualities as well as using local participants has led to better appraisals of communities (Cain *et al.* 1974, Muñoz *et al.* 2010, Agus *et al.* 2012).

Table 3. Sensory methodologies used in research into environmental odours

Type of analysis	Methodology	Advantages	Disadvantages	Examples
Panellist threshold testing	• A small cohort of panellists is tested using samples of odourous air, often sampled similarly to analytical methods. Information is recorded, and averaged, to give a result usually in OU (Sironi *et al.* 2007, Smeets *et al.* 2007, Sironi *et al.* 2010, Brattoli *et al.* 2011).	• Critical to the establishment of OU for an area is responsible for which may have legislative significance (Brattoli *et al.* 2011). • Provides a human evaluation of the detectable thresholds of an odour. • Somewhat less expensive than analytical procedures (Brattoli *et al.* 2011). • Can correlate well with analytical and sensor array measurements, although this is inconclusive (Capelli *et al.* 2008, Kim *et al.* 2008, Agus *et al.* 2012).	• Panellist eligibility is strict, meaning that threshold levels for a number of individuals is not represented through panellist testing (van Harreveld 2004, Bockreis *et al.* 2005). • Adherence to technical standards is difficult and often not achieved (van Harreveld 2004, Bockreis *et al.* 2005). • Has suggested causing an under-estimation of odour impact for communities (Evans *et al.* 1987b, Sucker *et al.* 2004).	Bambrillia *et al.* 2010 Sironi *et al.* 2007 Smeets *et al.* 2007
Field olfactometry	• Trained panellists go into field locations using specialised equipment that allows them to assess areas for OU and other measurements (Cid-Montañés *et al.* 2008).	• Removes the threat of reduced sample integrity due to at-source test procedures. • An alternative to air dispersion modelling when attempting to delineate sampling populations (Cid-Montañés *et al.* 2008, Guillot *et al.* 2012).	• Similar disadvantages experienced with any panellist based testing. • Laboratory standards of analysis, such as fresh air purges between tests may not be feasible. • Requires extensive training (Laor *et al.* 2011).	Sucker *et al.* 2004 Brandt *et al.* 2011 Newby *et al.* 2003

Table 3. Sensory methodologies used in research into environmental odours *(continued)*

Type of analysis	Methodology	Advantages	Disadvantages	Examples
Odour profiling methods	• Includes a variety of methods for supra-threshold testing of odours. These include ratings of intensity, hedonics, and odour qualities through the use of tools such as Odour Wheels (Both *et al.* 2004, Burlingame *et al.* 2004).	• Addresses the increasing emphasis on odour qualities, such as hedonics, which in turn provides enhanced understanding of community impact (Dalton 2003, Winneke *et al.* 2004, Henshaw *et al.* 2006).	• Similar difficulties related to Panellist threshold testing, and supra-threshold measures can be more difficult (Cain *et al.* 1974, Muñoz *et al.* 2010). • Further training is required to ensure panellists are effective; even so, inter-panellist differences can be significant (Suffet *et al.* 2009, Abraham *et al.* 2013).	Suffet *et al.* 2009 Burlingame *et al*. 2004 Rosenfeld *et al*. 2007 Suffet *et al.* 1999
Modelling programs	• Modelling that indicates the relationship between particular odorants and their relative annoyance at various intensities and in some cases, persistency (Miedema *et al.* 2000, Nicell *et al.* 2006).	• Data regarded several odorants, when averaged out, shows very strong correlation when predicting annoyance (Miedema *et al.* 2000).	• Singular odorants are often not very well represented by the model (Nicell 2003). • No explanatory power, nor any ability to predict the kind of reaction annoyance will elicit (Cavalini *et al.* 1991).	Miedema *et al.* 2010 Nicell *et al.* 2006 Henshaw *et al.* 2006

An important class of panellist testing is field based assessment. Panellist testing in the laboratory and in the field is perhaps the most efficient means by which to understand broad measures of odour impact. Field testing confers additional advantages when using products such as the Nasal Ranger™ (St. Croix Sensory, MN, USA), eliminating the potential dangers of sample degradation that could be experienced in analytical or laboratory panellist testing, as well as an easier opportunity to analyse different areas at different times, but on the same site (Newby *et al.* 2003, Rappert *et al.* 2005, Cesca *et al.* 2007, Muñoz *et al.* 2010, Brattoli *et al.* 2011). Field testing greatly reduces the capacity for an odour to degrade due to testing taking place almost immediately after sample collection. However, care must be taken in implementing field olfactometers, as at present there is a lack of standards for assessors implementing field tests, meaning that trained panellists may be required to travel to the tested area or further training is required (Laor *et al.* 2011). In regards to assessing community impact, field testing can be used as a method of assessing the OU exposure to specific areas surrounding an odour producing operation, making it a viable alternative to air dispersion modelling (Cid-Montañés *et al.* 2008, Nicell 2009, Guillot *et al.* 2012, Capelli *et al.* 2013b). Field testing confers further advantages to assessing community impact given that it assesses malodours at the source, as well as using human testers. However, deeper understanding may be obtained through the analysis of suprathreshold odour qualities in order to better define experiencing malodours. Suprathreshold odour qualities can be assessed using panellists, or the community members themselves which can contribute further to an appreciation of malodour exposure.

2.5.3 Olfactometers- variants, panellists, and field olfactometers

Olfactometers have emerged as the most precise way of measuring the intricacies of olfaction. As a result, olfactometers have progressively developed variations and sophistication. Despite their comparative infancy, olfactometers have been established across a broad spectrum of disciplines; primarily psychology, neuroscience, biology, food science, and environmental engineering. This range of disciplines illustrates the validity as well as the versatility of olfactometers. Perhaps owing to their versatility, cross-discipline discussion of olfactometers is rare and fewer still in modernity. This is unfortunate as exploration into olfactometer technology can be beneficial, especially if similar outcomes across disciplines are sought after. Olfactometers deserve particular attention in any odour research as they have been the most commonly used and enduring research tools in the field.

The definition of an olfactometer is difficult to delineate from other methods of olfactometry. Historically, the first olfactometers were static, typically designed as a method to have a degree of control over stimulus strength during presentation (Prah *et al.* 1995). Semi-static olfactometers, that is, olfactometers that allowed for varying concentrations, were first designed by Zwaardemaker, although Buccola's osmometer (a design that did not control odour exposure) preceded it (Zwaardemaker 1888, Zwaardemaker 1889, Berglund *et al.* 1986a, Doty 1991a, Doty *et al.* 1995a, Prah *et al.* 1995, Philpott *et al.* 2008). Dravnieks defines an olfactometer as "an instrument for the preparation and delivery of an odorant- an odour stimulus- to a chemoreceptor system" that "[measures] physiologically, electrophysiologically or psychophysically" the reactions of the subject tested (Dravneiks 1975). As the study of olfaction has progressed, Dravneiks' definition requires some amendment. With advances in research, it can be added that olfactometers can measure a subject's behaviour and attitudes if desired, and that olfactometers often have the extra advantage of recording these measurements without the need of an independent device. An olfactometer was previously considered any instrument that was capable of delivering an odour stimulus to a subject; in this inclusion sniff bottles and cotton wool dipped in odorant could be considered olfactometers (Wenzel 1948, Dravneiks 1975). Similarly, "static" olfactometers have fallen out of use in favour of "dynamic" olfactometers (Dalton *et al.* 2005). Currently, olfactometers are typically defined as devices created to facilitate stringent demands on the nature of the stimulus; be it a high degree of stimulus reproducibility, wide range of stimulus concentrations, or some other condition that is unobtainable by simpler measures of olfaction (Dravnieks *et al.* 1980, Johnson *et al.* 2007).

An olfactometer is a device that measures qualities of response to a particular odour in a method that includes dynamic elements. The dynamic elements of an olfactometer vary, but they are based on the demands of testing such as extreme concentration precision of the delivered odour, the dynamic variability of odour concentration, or the delivery of odour sources that is untenable by other methods (Bozza *et al.* 1960, Dravnieks *et al.* 1980). To this end, olfactometers have a much larger pool of both measurement techniques as well as measurement qualities. For example, olfactometers are capable of measuring or facilitating the accurate measuring of functional Magnetic Resonance Imaging (fMRI), the physiological behaviour of mosquitoes, enhancing the experience of films, and threshold testing of environment derived complex odorant mixtures (Lorig *et al.* 1999, Nakamoto *et al.* 2001, Omrani *et al.* 2010, Lebrero *et al.* 2011). No one olfactometer can accomplish all needs, however all olfactometers share several common elements: a dilution source, a method of stimulus production, as well as a method of stimulus delivery (Dravnieks *et al.* 1980, Duffee *et al.* 1980). The variations of elements are determined by cost as well as the targeted measure. Cost determines the capacity to control for variables for which there is a universal optimum, for example temperature and humidity stability. The targeted measure will determine how the olfactometer operates on three separate paradigms; the stimulus delivery precision, the stimulus delivery dynamics, as well as the stimulus delivery methodology. To that end, olfactometers have variations in their dilution source, stimulus generation, stimulus delivery, and flow control.

2.5.3.1 Demands of olfactometers

Olfactometers are used in a range of disciplines, including environmental assessment, neuroscience, and psychology. As a result several different measures are implemented. At the most basic, olfactory threshold (OT) is the assessment on whether an individual can detect an odour (Doty 1991a, Dalton *et al.* 2005, Wise *et al.* 2008). Threshold testing with olfactometers can be accomplished in a number of ways, but most often the staircase method is used (Doty *et al.* 1995b). This involves the presentation of a series of odour concentrations next to *n* blanks. The series usually starts with the weakest odour concentration, and moves to stronger concentrations as long as the participant makes incorrect guesses. That pattern is reversed when a participant guesses correctly, and their score is usually an average of the concentration levels after the first correct guess (Doty 1991a, Doty *et al.* 1995b, Wise *et al.* 2008). A similar test, the determination of OU (ouE/m^3) in environmental assessment, assesses the number of dilution iterations required for a sampled odour for a panellist to guess it equally as a reference odour concentration (typically *n*-butanol) (Hobbs *et al.* 1995, Sironi *et al.* 2007, Sironi *et al.* 2010, Brattoli *et al.* 2011). In this way the determination of ouE/m^3 behaves similarly to a staircase threshold test.

Threshold testing with olfactometers is rare in psychology; most often other “static” olfactory tests are used due to simplicity and cost (Doty 1991b, Schmidt *et al.* 2010, Hayes *et al.* 2013). In those instances that threshold testing is used, the staircase method is not usually implemented due in part to the rapid concentration changes that can disrupt an olfactometer. As a result other methods such as the method of constant stimuli or method of adjustment are attempted (Berglund *et al.* 1992a, Smeets *et al.* 2007, Hayes *et al.* 2013). An important subset of threshold, irritation threshold (the measure of irritancy on the trigeminal nerve) does have some studies using a staircase method olfactometer (Dalton 2001, Smeets *et al.* 2007, Monse *et al.* 2010). Conversely, OU assessment is a vital part of environmental analysis for odourous areas, and has legislative ramifications. Emergent within legislation, and common within psychological practice, is the measurement of supratheshold values (Sucker *et al.* 2008b, Suffet *et al.* 2009).

Olfactometers can be used to assess most suprathreshold measures include olfactory identification (OI), intensity, discrimination (OD), and hedonic appraisal (OH) (Doty 1991b, Doty 1991a, Dalton *et al.* 2005). These varying measures do not often translate into a variation of olfactometer; rather, a modification to the program or design for an experiment. In regards to OI and intensity measures, care must be taken to ensure that the olfactometer can allow for a large variation as well as an accurate precision for the flow rate. To this end, olfactometers often must have several iterations of mass flow controllers (MFC) or rotameters at varying flow limits in order to accommodate for a large flow rate range (Dravneiks 1975, Prah *et al.* 1995). Other measures, due to the dynamic qualities of most olfactometers, can be readily incorporated and recorded.

Neurological studies implementing olfactometers typically have requirements pertaining to the consistency of the odour stream, as well as the capacity for an olfactometer to seamlessly blend or intensify odorants (Kobal 1987, Lundstrom *et al.* 2010, Ng *et al.* 2011). With the addition of a quick time to rise to a particular concentration, neurological olfactometers can be seen to deliver a “square form” of odorant (de Wijk *et al.* 1996, Lundstrom *et al.* 2010). As a result, neurological olfactometers often require extreme precision and compensatory mechanisms in order to provide consistent airflow (Kobal 1987, Johnson *et al.* 2007).

2.5.4 Dimensions of most olfactometers

2.5.4.1 Dilution production

In testing situations, odorants almost always require a degree of dilution as well as a method of moving odorised air towards stimulus delivery. Most often, these tasks are accomplished by the use of a carrier gas which in some methodologies also dilutes the odour. There are a few methods of accomplishing this procedure, modulated predominantly by cost and ease of use. Filtered air derived from an air compressor pump is a relatively inexpensive and popular carrier gas (Prah *et al.* 1995, Lundstrom *et al.* 2010, Hayes *et al.* 2013). Compressor pumps can be light and small meaning that portability of the olfactometer is not constrained by the dilution source. Care must be taken to ensure proper filtration of contaminants, and air mixtures will react with some odorants which will change the nature of the odour itself (Dravneiks 1975). Somewhat more cumbersome, nitrogen derived from pressurised tanks is completely odourless, and confers far less potential for reactivity with odorous substances. As a result nitrogen is far more useful in systems where odour storage in a gaseous stage is required (de Wijk *et al.* 1996, Hartell *et al.* 1996, Monse *et al.* 2010, Muñoz *et al.* 2010). The need for a constant supply of nitrogen as well as the size of the tanks employed make any olfactometers using pressurised cylinders unfeasible for easy portability. With regards to using cylinders, the use of pressurised tanks need not be limited as being the diluting source; one study derived their odorant from a pressurised cylinder which was subsequently metered and diluted with an air stream (Smeets *et al.* 2007). A component of testing not yet discussed in olfactometer research is the ecological validity of the carrier gas. It seems possible that a response to an odour will vary if that odour is diluted in a gas that is different to the surrounding environment the odour is typically experienced in. Given that changes in other stimuli cues affect some animals for other senses, it seems likely that some olfactory tests will be affected by carrier gas variation (Delius 1992). For this reason, air, when properly filtered, may have experimental advantages over other diluents. This is because it controls for other environmental odours but is also it is a carrier gas that is constantly experienced by most test subjects and so may confer ecological validity.

Less often implemented, odorants are diluted in set amounts of a solution in order to provide varying odour concentrations. Combined with air dilution, these two methods can offer practically any concentration of an odour which can be useful for delivering extremely low concentrations of odorants, such as insect pheromones (Dravneiks 1975). However, there are two considerable disadvantages in using diluted solutions. Most obvious, solutions can often interfere with the odour being tested, either by reacting with the odorant, or producing an odour itself (Dravneiks 1975, Prah *et al.* 1995, Gamble *et al.* 2009). Secondly, the variance of vapour pressure between solvent and odorant affects stimulus strength, and in turn this strength will be further affected by successive testing using the same solution sample (Dravneiks 1975, Prah *et al.* 1995). These major disadvantages can be overcome by placing solutions on filter paper and allowing the solvent to dissolve, thereby concentrating the odorant (Sharma *et al.* 2013).

2.5.4.2 Stimulus production

2.5.4.2.1 Vapour saturation

The vapour saturation, or “Dravniek style” design is perhaps the oldest, and most used, modern olfactometer approach (Dravneiks 1975, Laing *et al.* 1994, Hayes *et al.* 2013). In essence, air passes over a large vessel containing an odorous compound (**Figure 5**). This air carries the odour in a calculated concentration, whereupon it is subsequently mixed with pure air to determine a particular odour concentration (Dravnieks *et al.* 1975, Laing *et al.* 1994, Smeets *et al.* 2007). The vessel must be sufficiently large in order to establish 100% saturation (Laing *et al.* 1994). The degree of saturation is determined by the odorant’s diffusion coefficient, air flow rate, environmental conditions, and this may be established by using Fick’s diffusion law (Dravneiks 1975, Prah *et al.* 1995). Vapour saturation methods allow for fairly quick establishment of a steady state odour stream and subsequent decline once the odour valve has been redirected (Walker *et al.* 1990). Certain specialised designs can reduce the time to establish and decline odour concentration further (Walker *et al.* 1990). The method of vapour saturation is sensitive to changes in temperature and humidity and this may present a problem when trying to compare two odours which may have different conditions required to produce full saturation (Dravneiks 1975, Sobel *et al.* 1997). Similarly designed, some olfactometers implement odour chambers that contain a sample odorant that air passes around and collects the odour from. These odour chambers and odour sources are unsuitable to establish definite full saturation; however, they are beneficial when natural odour sources are used, or when fixed odour concentration is not a concern (Turlings *et al.* 2004, Walter *et al.* 2010).

Figure 5. "Dravnieks style" olfactometers. Air passes through a vessel containing an odorous compound (darker blue area), which saturates the air flow (lighter blue colour. By calculating the air flow rate and ensuring that it does not exceed the maximum saturation rate (as determined Fick's diffusion law), a fully saturated odorant stream can be produced.

Another methodology that most often uses vapour saturation, albeit in a different configuration, is using by using a vacuum for air flow. Vacuum methods of drawing the odour are not often used, but possess advantages pertaining to odour control in head space, reduced turbulence, as well as time for odour concentrations to reach steady state (Louise *et al.* 1983). Vacuums draw the odorant through to stimulus delivery, where there is a "break" in the line allowing the participant to sniff through (Smeets *et al.* 2007). Negative pressure draws the odour past this break unless the participant is sniffing or odour channels are active, meaning that the odour is not being constantly ejected into headspace (Laing *et al.* 1994). Vacuum pressure can also be used in different ways. Both Laing *et al.* and Sobel *et al.* describe vapour saturation olfactometers in where vacuum pressure drew either odourless or saturated air depending on which channel was active. This method permitted very fast, cue-less switching between odour streams which was beneficial to fMRI and odour mixture analyses (Laing *et al.* 1994, Sobel *et al.* 1997, Smeets *et al.* 2007). The main disadvantages with vacuum-based olfactometers are their complexity of design and subsequent expense (Lundstrom *et al.* 2010).

2.5.4.2.2 Vapour diffusion

Diffusion methods involve the flow of air across a vessel which in turn determines the concentration of the odour via measuring by Fick's diffusion law and altering the air flow to adjust, as shown in **Figure 5** (Dravneiks 1975). Multiple vessels can be put within a series to increase odour concentration or produce odorant mixtures (Johnson *et al.* 2007). Diffusion olfactometers in this way do not always need to use air dilution streams like Dravniek versions, although this limits their application in instances of testing thresholds or other measures that require a variation of odour strength as well as quickly establishing steady state air flow (Dravneiks 1975, Prah *et al.* 1995). Teflon and stainless steel seem to be the only appropriate materials for producing the diffusion vessels to reduce contamination of the odour clinging to the sides and changing the odour concentration (Dravneiks 1975, Prah *et al.* 1995, Johnson *et al.* 2007). Diffusion olfactometers have applications in tasks that require continuous, steady odour concentrations for a comparatively long amount of time, such as fMRI recordings or some types of discrimination tasks (Johnson *et al.* 2007).

2.5.4.2.3 Sealed Bag Olfactometers

When collecting environmentally-derived odours, a useful method is drawing the odours into a bag and transporting them to a specially designed "sealed bag" olfactometer. While the principles of air dilution akin to other styles of olfactometers are still applied in this method, the odourised air delivery is somewhat different. Odour samples are extracted from a sample or environment to be studied and stored in specially designed bags, often made from Mylar, Tedlar, Nalophlan, or an alternative known as Solid-Phase

Microextraction (SPME) (Bulliner *et al.* 2006, Hudson *et al.* 2008a, Muñoz *et al.* 2010, Lebrero *et al.* 2011). These samples are placed in a pressurised container and connected to an outlet that is directed towards the sniffing port or mixed with pure air. As pressure on the bag increases, the odour is pushed measurably through the outlet, whereupon the odour can be manipulated in much the same way as a typical Dravniek style olfactometer (Choinière *et al.* 2013). This kind of olfactometer is typically used for environmental assessment; obtaining the OU of an environmentally-derived sample which may have legislative ramifications (Muñoz *et al.* 2010). Sealed bag olfactometers are useful to derive complex samples, but there are some particular limitations in their application. Because the odour is not derived from a sizable liquid source, the amount of odour is small, meaning that testing must be accomplished promptly, and that continuous sampling for an extended period is fairly unrealistic. In addition, owing mostly to the nature of the odours (that may be partially or wholly unknown) and the demand for several panellists to ensure the veracity of OU results, there is no guarantee that contamination or cross contamination from previous steps or samples does not occur (Brattoli *et al.* 2011). To remedy this, tubing is often thoroughly flushed between samples and steps.

Despite being the best current technology for taking odour samples, the bags and their handling carry additional risks. Firstly, the type of odour extraction will change the composition of the sample itself (Hudson *et al.* 2008a). Secondly, the conditions for the sampling and storage of these bags is crucial to fair assessment, as factors such as time, temperature and other variables at these stages will affect the odour collected (Hudson *et al.* 2008a, Laor *et al.* 2010, Muñoz *et al.* 2010, Brattoli *et al.* 2011, Le *et al.* 2013).

2.5.4.3 Stimulus delivery

Another consideration in the design of an olfactometer is the kind of port from which the odour is delivered to the test subject. The kind of odorant delivery is largely dependent on what measures are being sought. The vast majority of olfactometers either completely or partially rely on an individual's natural sniffing. At first glance, this might seem unusual as sniffing could be considered an additional, uncontrolled variable between participants. However, Laing *et al.* established that natural sniffing procured the most accurate results, and for much olfactory research, the natural sniff confers some ecological validity (Laing 1985). As a result, "blast olfactometry", that is, olfactometers that artificially force odorised air into a participant's nares, have fallen out of use (Prah *et al.* 1995). Stimulus delivery consist of four main versions; odour ports or cups, face masks, cannulas, or uses of a room for odour delivery (Ng *et al.* 2011). Odour ports and cups are multitudinous, and are used for many different kinds of olfactory assessment. However, the variation between test subjects should be taken into account whenever this kind of delivery system is implemented. Variation in this instance can include the distance between the cup and the participant's nose (which can be controlled by use of a chin rest), as well as any possible variations of where the odourised air is flowing out of the port. Face masks and cannulas do not have these disadvantages, but their lack of easy disentanglement from the participant means that headspace will not be cleared as quickly, meaning that rapid odour testing is unfeasible; typically masks are used for neuroimaging tests (Lundstrom *et al.* 2010). In the case of non-human testing, the odour delivery “room” is often the olfactometer itself, and the participant’s behaviour in the space of the olfactometer is what is analysed (Doty 1991b).

2.5.4.4 Flow Control

Prior to the introduction of MFCs, rotameters/flowmeters dominated olfactometry flow control (Prah *et al.* 1995). Manually controlled flowmeters are inexpensive, as well as being useful in instances where dynamic olfactometry is not important, but rather require steady air flows for a long period of time (Walker *et al.* 1990, Lorig *et al.* 1999). Rotameters are sensitive to downstream pressure, which may alter flow values(Jaing 2003). MFCs confer several advantages, including very precise measurement, computerised operation, as well as the potential to change air flow very quickly within an experiment (Sobel *et al.* 1997, Hayes *et al.* 2013, Sezille *et al.* 2013). While MFCs allow for practically any desired outcome with regards to flow control, they are expensive and require regular calibration, often using carbon monoxide as the calibration chemical. An alternative, considered more precise than MFCs is the use of needle valves for flow control, for example the DynaScent™ olfactometer (Jaing 2003). Needle valves are capable of precise adjustment, but are only suitable for small odour concentrations and are not capable of rapid concentration changes; successive needle valves are required for threshold testing. Historically, other methods of flow control were implemented, but within the range of modern olfactometers, alternatives of MFCs, needle valves, or rotameters are rare (Wenzel 1948, Dravneiks 1975, Prah *et al.* 1995).

2.6 Gas Chromatography: Mass Spectrometry-Olfactometry

The analysis of odours in the environment is steadily increasing in detail and complexity due to the growing number and severity of complaints towards several industry sectors (van Harreveld 2001, Harrison *et al.* 2002, Brambilla *et al.* 2010, Hayes *et al.* 2014). Varying types of odour evaluation across several domains, such as food technology, have already illustrated the increasing necessity to appreciate the respective strengths and weaknesses of any singular odour methodology (Desrochers *et al.* 2002, Cai *et al.* 2007, Niu *et al.* 2011, Brattoli *et al.* 2013). As a way to address this issue, an approach that has seen increasing implementation within odour analysis is GC-MS/O which combines both analytical and sensory information (Hayes *et al.* 2014). GC-MS/O is a method by which the strengths of chemical compositions of odours can be cross tabulated to the response and description of panellists simultaneously, thereby producing comprehensive information (Zarra *et al.* 2008, Niu *et al.* 2011, Brattoli *et al.* 2013).

GC-MS/O consists of several stages (**Figure 6**). Firstly, the GC component consists of a specific kind of detector, such as FID or PID, which will split environmental samples into specific compounds based on relative characteristic of the compounds, such as variation of charge (Hites 1997). The split ratio design means that the elute from the GC flows to both the MS and Olfactory Detection Port (ODP), which measure the relative abundance of chemicals, and allow for odour detection by panellists, respectively. The flow ratio between MS and ODP is controlled to ensure than the two separate systems are measured simultaneously. The ODP panellist provides several types of information. Firstly, an odour event is recorded throughout its experienced duration, and alongside that information, a description of the odour's intensity and quality is provided. Specialist software subsequently integrates the information from both MS and ODP (*e.g.* **Figure 7**). In addition to the integrated information, the MS data can also be matched to a chemical library to identify the types and concentrations of compounds within the sample. GC-MS/O offers the opportunity to evaluate both analytical and sensorial measurements, which in turn characterises odour samples in far more detail than any singular alternative.

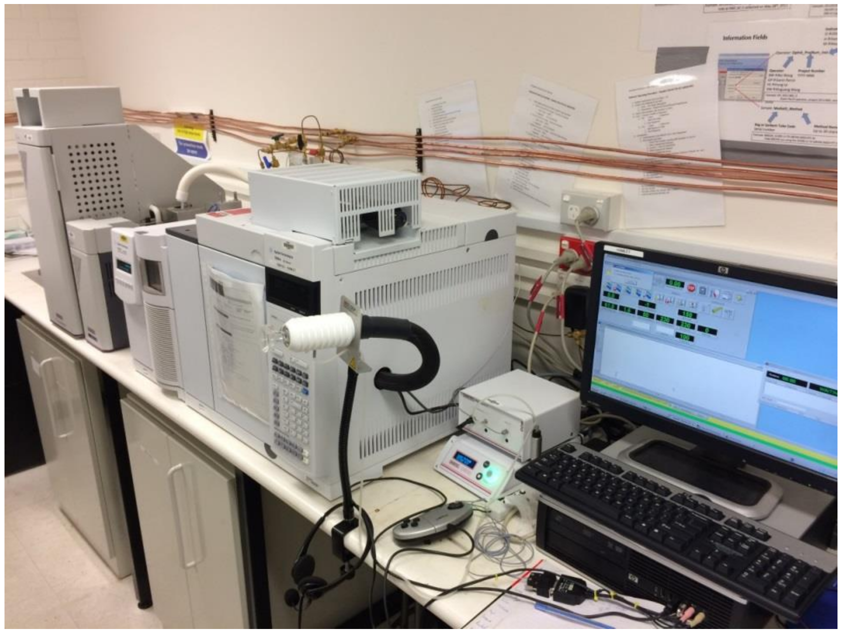


Figure 6. An example GC-MS/O set-up found at the University of New South Wales, School of Engineering. The GC component splits flow between the mass spectrometer and the sniffing port. Using the computer interface, a participant can report odour events while sniffing.

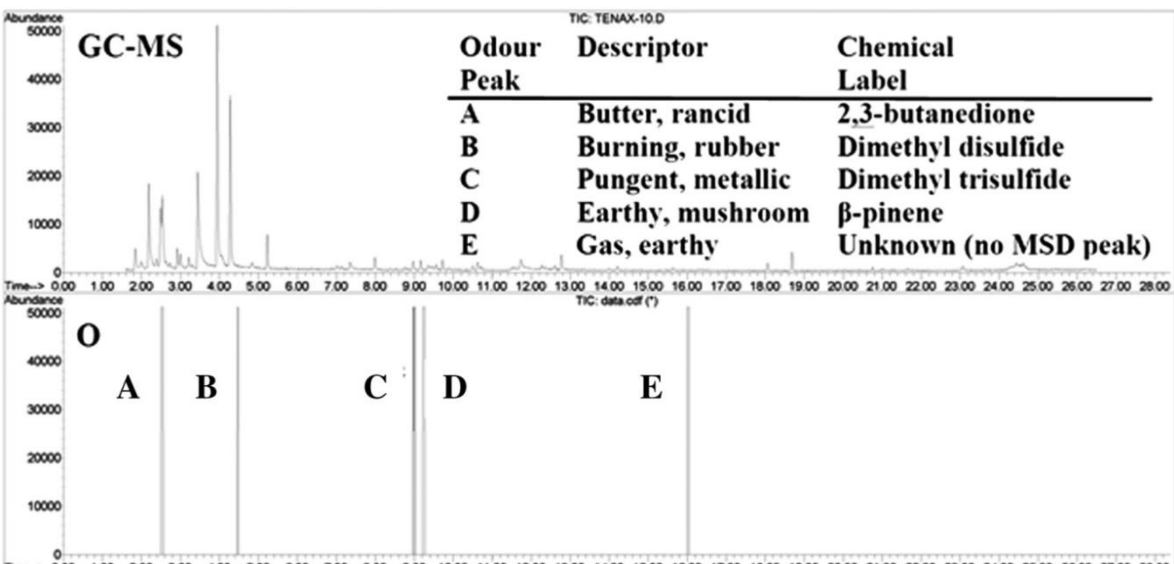


Figure 7. Example of GC-MS/O output. The MS spectra in the top panel is integrated with the ODP (bottom panel), revealing probable analytes (A-E, inset table top right) for odour contribution.

There are some drawbacks with GC-MS/O when implemented for environmental odour analysis. Firstly, as commonly experienced with most MS procedures, similar retention times for several different chemicals will “mask” the chemicals with lower abundance (Agus *et al.* 2012). This can be problematic as some odorants have low abundance but also low olfactory threshold, meaning that potentially priority odorants can be hidden in the MS spectra (Hayes *et al.* 2014). Secondly, and idiosyncratic of environmental odour analysis, GC-MS is ill-designed to assess concentrations of H_2S and sulfur compounds; significant contributors of malodour, thanks to its high volatility and retention time that means that measurement is unrealistic due to the speed of degradation (Higgins *et al.* 2006, Sivret *et al.* 2010). Finally, the detection ability of MS is not as sensitive as the human sense of smell for some odorants (Hayes *et al.* 2014). As a result, while panellists may record olfactory events, the MS and its chemical library may not be able to match an appropriate chemical culprit (Rosenfeld *et al.* 2000). In addition to these considerations, there are some methodological issues when running GC-MS/O samples. Care must be taken for the split ratio between MS and ODP. This is because there may be a difference in retention time between the detectors thanks to variation in pressuring the sample flow (Brattoli *et al.* 2013). Fortunately, the installation and implementation of device variants can overcome these difficulties (Hochereau *et al.* 2004, Brattoli *et al.* 2013). Another methodological concern is the storage conditions of the odour samples: the time and conditions of sample storage have a noticeable effect on the degradation of the sample itself (Muñoz *et al.* 2010, Sivret *et al.* 2010, Le *et al.* 2013). With these considerations, the implementation of GC-MS/O can be effective, and has included environmental odour analysis.

GC-MS/O has been embraced in several domains pertaining to odour characterisation; however, environmental malodour analyses typically have not expanded implemented methodologies beyond few standard practices. At the forefront, GC-MS/O is used almost exclusively to define priority contributing odorants of a given sample. This has been due in part to the way in which legislation based on odour control bases criteria for acceptable emissions; typically, specific odorants have set acceptable concentrations that should not be breached. The identification of priority odorants has meant that testing involves using panellists with an average olfactory sensitivity, similar to the establishment of OU by dynamic olfactometry in so doing eliminating approximately 50-70% of applicants (van Harreveld 2004, Muñoz *et al.* 2010). This in itself carries concerns relating to ecological validity; it is fair to assume that individuals with higher olfactory sensitivity (as well as members of the community with so-called Multiple Chemical Sensitivity Syndrome or MCS) will be more prone to report odour complaints (Dalton 1996, Sucker *et al.* 2004, van Harreveld 2004, Muñoz *et al.* 2010). In addition to the potential for under-representation in the community, little research has been conducted to look at the ways in which odour qualities change for individuals of high sensitivity. As a result, odour complaints from highly sensitive individuals may include reports regarding qualities of an odour otherwise undetected or characterised differently to standard panellist responses (Gross-Isseroff *et al.* 1988, Hayes *et al.* 2014). Current legislation has also affected the way in which odour sampling has been conducted. The majority of regulations in the Western world base odour control around an “at boundary” measurement (Drew *et al.* 2007). Currently, the analysis of WWTP have assessed odours from effluent, at boundary, as well as at a unit process level (Mao *et al.* 2006, Agus *et al.* 2012).

Analyses of discrete unit processes are effective as they can identify priority areas for evaluation. This analysis has been fairly rare, but by clarifying where problems occur, upstream processes can also be targeted for effective odour control procedures (Lehtinen *et al.* 2010). Using GC-MS/O for unit process analysis has advantages over other types of measurement systems such as olfactometry or sensor arrays (e-noses). Firstly, the prioritisation of specific odorants is a large advantage over gross odour measurement from olfactometry, which in itself is better suited to assessing Odour Units. Secondly, sensor arrays are limited both in targeted odours as well as sensitivity; while they may be useful for quick reports of odour anomalies; systemic issues relating to plant behaviour may go unnoticed, especially in high risk areas where small odour incursions may be a tipping point for a nearby community. Unit process analysis is not a demand of legislative practice, but is far more beneficial to odour control solutions when compared to “at boundary” measurement practices.

2.7 Sniff bottles and other crude testing materials

Occasionally within the environmental analysis spectrum, rapid testing of simple olfactory measurements is required. Oftentimes this is a way by which to establish a panellist's OT. OT trials are created by presenting a panellist with successive dilution steps of a particular test odorant (typically *n*-butanol or phenyl ethyl alcohol). Similar staircase procedures can be accomplished through the use of sniff bottles, glass beakers, or tools such as Sniffin' Sticks™ (US Neurologicals, WA, USA) (Haehner *et al.* 2009, Orhan *et al.* 2011, Brancher *et al.* 2014). Tests such as the University of Pennsylvania Smell Test (UPSIT) can establish olfactory profiles of individuals, but current application to environmental analysis is limited (Doty 1997). Additional tools, such as cotton wool injected with odorous solutions, have been used in some olfactory research but care must be taken to appreciate the limitations of simple tests (Moncrieff 1957, Pierce *et al.* 1996).

2.8 Community assessment methodologies to assess odour

2.8.1 Surveys

Survey methods are a growing part of evaluating both odour impact, and odour as a subsection of overall impact made by an industry (**Table 4**). Surveys are developed to investigate five predominant factors in regards to odour impact as defined by Jonsson: (i) interference with everyday activities, (ii) reports of feelings of annoyance, (iii) reports of physiological health changes, (iv) reports of complaints to authority, and (v) reports of various individual action to modify the environment (Jonsson 1974, Schiffman *et al.* 1995).

Survey approaches are popular for a wide variety of environmental impacts, but must deal with idiosyncratic challenges when approaching odour investigations, such as appropriate questions relating health effects, irritancy, as well as levels of community awareness of odours (Dalton *et al.* 1997a, Dalton *et al.* 1997b, Elliott *et al.* 1999, Erdal *et al.* 2008). Some of these measures, such as coping, remain contentious in regards to their involvement in understanding community impact (Cavalini *et al.* 1991, Steinheider *et al.* 1993). While somewhat difficult to produce, the analysis of odour persistence is capable within a survey paradigm (Both *et al.* 2004, Sucker *et al.* 2008a, Sucker *et al.* 2008b). Surveys have traditionally been applied using pencil and paper, but technology has facilitated telephone and internet-based research opportunities. Surveys can be difficult to construct to reduce bias, and sampling procedures must be taken into consideration to ensure fair understanding of the population (Flesh *et al.* 1974, Berglund *et al.* 1987, de Vaus 2002). Surveys allow for a more systematic and widespread analysis compared to most qualitative research, and its combination with other methods such as olfactometry can incorporate all necessary factors to access community impact. Dalton and Dilks' (1997) report on community impact that incorporated a survey to investigate health effects alongside a community-based smell test not dissimilar to panellist olfactometry. It was found that not only did malodour affect residents on a physiological level by reducing their threshold sensitivity, it also aggravated their annoyance to the odour, and this effect correlated with behavioural changes and perceived health (Dalton *et al.* 1997a). Surveys in this way can address the difficulties of establishing appropriate odour impacts. Surveys currently provide the best insight into the community while offering systematic and valid forms of inquiry. Properly constructed, surveys have been proven to discover appreciable disparities between different communities in their attitudes and behaviours, even if within environmentally similar circumstances (Robinson *et al.* 2012).

Table 4. Community research survey methodologies

Type of analysis	Methodology	Advantages	Disadvantages	Examples
Structured surveys	• Involves the assessment of communities through questionnaires (de Vaus 2002). • Topics can include health, psychosocial wellbeing, willingness to complain, and demographic characteristics that influence malodour impact (Jonsson 1974, Dalton *et al.* 1997). • Data is coded and tabulated (Marans 1987, de Vaus 2002).	• Appropriate for addressing human perception and reaction to odour annoyance (de Vaus 2002). • Appropriate for exploring the variables that influence community appraisal and reaction to malodours (Marans 1987, de Vaus 2002). • Good at assessing changes over time period if multiple questionnaire rounds are implemented (Marans 1987, Luginaah *et al.* 2002).	• Does not directly measure odour, so needs to be combined with other methodologies for appropriate analysis. • Sampling methods require consideration (de Vaus 2002). • Additional specific challenges to assessing odour exposure and impact, such as the methods to evaluate odour persistence (Both *et al.* 2004, Sucker *et al.* 2008a, Sucker *et al.* 2008b). • Cannot be used to predict the impact of an odour, only measure its influence after its introduction to the community (Flesh *et al.* 1974). • Some proposed measures of questionnaires, such as coping, have had mixed results in regards to their power and efficacy for predicting annoyance and response (Cavalini *et al.* 1991, Steinheider *et al.* 1993).	Schiffman *et al.* 1995 Cervinka *et al* 2004 Bullers 2005 Luginaah *et al.* 2002

Table 4. Community research survey methodologies *(continued)*

Type of analysis	**Methodology**	**Advantages**	**Disadvantages**	**Examples**
Qualitative research	• Semi-structured or unstructured interviews with members of a particular community across a broad range of subjects and topics (Donham *et al.* 2007, Wing *et al.* 2008, Lowman *et al.* 2013). • Interviews typically follow certain constraints, such as "information saturation", and are coded, sometimes using a particular format (such as Discursive Psychology) (Lowman *et al.* 2013).	• Capable of discovering information regarding community that might otherwise be overlooked. For example, a communities' concern of a lack of business transparency (Lowman *et al.* 2013). • Information- rich, so can create entire illustrations of how malodour can affect individuals of a community (Kolarova 1999, de Vaus 2002).	• Extremely difficult, if not impossible, to quantitate information from this kind of research (Creswell 1994). • Time consuming and requires specialist interviewer training (Flesh *et al.* 1974). • Susceptible to many sources of bias, including researchers, responders, and the questions themselves (Flesh *et al.* 1974, Baxter *et al.* 1999). • Due to its labour intensiveness, can usually only assess a very small group of individuals. To this end, sampling methods can lend to bias in reporting (Creswell 1994, Baxter *et al.* 1999). • Similar to questionnaires, cannot be used to predict the impact of an odour, only measure its influence after its introduction to the community.	Lowman *et al*. 2013 Wing *et al*. 2008 Donham *et al.* 2007
Social participation	• Local participants are included in reporting odours in some method. This may include recording complaints regarding odours, or active recruitment. Can be used alongside survey methodologies (Sucker *et al.* 2008a, Sucker *et al.* 2008b).	• Participants have shown to have strong correlation with reporting odours and air dispersion models, so could be considered an inexpensive alternative in some instances (Blumberg *et al.* 2001, Sironi *et al.* 2010). • Additional input, such as initiating sample extraction for a nearby sampler, have assisted these techniques and improved other measurement methodologies(Gallego *et al.* 2008, Sironi *et al.* 2010).	• Cannot directly report on annoyance unless additional information is garnered. • May require some training, and rarely uses large groups of the population, especially when more elaborate methods are implemented (Gallego *et al.* 2008, Sironi *et al.* 2010).	Sironi *et al.* 2010 Gallego *et al.* 2008 Blumberg *et al.* 2001

2.9 Qualitative analysis

The investigation of environmental impacts on communities in regards to assessing the human factor is dominated by qualitative methodologies (Franssen *et al.* 2002). Qualitative methodologies, broadly speaking, consist of either unstructured or semi-structured interviews, which can be face-to-face or by some other medium such as telephone conversation (de Vaus 2002). Interviews in this way have been used to assess a variety of environmental effects. As a result while some research has gathered the opinions of a community on odour, many include odour as a part of an assessment of overall community impact of an industrial area or technique (Wing *et al.* 2000, Wing *et al.* 2008, Lowman *et al.* 2011, Lowman *et al.* 2013). Qualitative research offers rich data in regards to encapsulating multiple attributes of a community's experience, and in some ways establishes reasons of community distrust, fear, or anger towards investigated industrial areas (Baxter 1997, Thu *et al.* 1997, Baxter *et al.* 1999). Other advantages of qualitative interviews include the ability to investigate the way in which communities understand the environment differently from professional investigation, and, thanks to methods of information saturation, appreciating community concerns that might not otherwise be understood (Brown 1992, Irwin *et al.* 1999, Brown 2003). Lowman *et al.* in several investigations had established that community groups are likely to desire government and official transparency, and to offer systematic communication strategies with the community to alleviate worries (Lowman *et al.* 2011, Lowman *et al.* 2013).

Qualitative research does possess some disadvantages. The design makes it almost impossible to conduct true experimental research, and data analysis is unsuitable for this kind of deductive understanding (Creswell 1994). Bias conducted by sampling difficulties, or researchers, or indeed the interview questions themselves is an issue that requires constant vigilance and acknowledgement (Flesh *et al.* 1974, Baxter *et al.* 1999, Lowman *et al.* 2011, Lowman *et al.* 2013). In addition, due to the intensive work of most semi-structured and qualitative research, only small cohorts of individuals can be realistically investigated, reducing the potential to understand the community as a whole (Thu *et al.* 1997, Wing *et al.* 2000, Lowman *et al.* 2011, Lowman *et al.* 2013). As with all methodologies assessing community impact, investigation using individuals of that community needs to be carefully considered as the relationship between the two factors is complicated, and as some argue, fundamentally different (Craik 1987, Evans *et al.* 1987b). For these reasons, qualitative research should never be seen as the “end-all” investigation tool regardless of its in-depth techniques. Despite these disadvantages, qualitative research is a useful tool for greater understanding of individuals of a community, and provides the ability to inform quantitative research regarding public beliefs, attitudes, and concerns (Kolarova 1999).

2.10 Social participation

Social participation involves the use of members of the community as true reporters who are directly tied into the research goals. Social participation can be implemented in a variety of ways. Most commonly, investigations have provided willing community members with journals to record odour events (Berglund *et al.* 1999, Winneke *et al.* 2004). The use of community members as field "panellists" is a productive method of procuring odour effects (Cid-Montañés *et al.* 2008, Cheng *et al.* 2012). Essentially, community members are recruited, given appropriate briefing, and are expected to report on odorous activity using a systematic methodology, typically through the use of an "odour journal" to document odour events (Bonnin *et al.* 1990, Freeman *et al.* 2002, Sarkar *et al.* 2003a, Sarkar *et al.* 2003b, Nicolas *et al.* 2010). Numerous legislative guidelines, such as the VDI 3883 from the Association of German Engineers, are available for most countries and outline appropriate procedures for field panellists as well as assessment of odour complaints (Verein Deutscher Ingenieure 1993, Freeman *et al.* 2002). In general, these guidelines emphasise the need to convey accuracy in reporting odour, as well as instilling appropriate motivation for the task (Verein Deutscher Ingenieure 1993, Freeman *et al.* 2002). These procedures are advantageous in regards to establishing a community viewpoint of odour effects as well as a broader understanding of odour exposures, but are affected by the biases of community members, and are usually unmonitored. Community members in this kind of evaluation are unlikely to be trained as thoroughly as laboratory panellists, despite sharing similar disadvantages. To be expected, some community members are more appropriate for this kind of investigation compared to others (Verein Deutscher Ingenieure 1993, Laor *et al.* 2011).

2.11 The impact of malodour on communities

The challenge of most methods of quantitative odour assessment is to appreciate the problem of perception (Stuetz *et al.* 2001a, Yeshurun *et al.* 2010, Lebrero *et al.* 2011). While analytical and olfactometric methods of odour measurement are accurate in regards to the assessment of odorant concentration, the *perceived* influence and detection of odours by members of the community is both overlooked and complicated; some researchers have even suggested a “true” encapsulation of the experience to be impossible (Scorgie *et al.* 2007). Analytical methods are unlikely to appreciate odour annoyance appropriately, given that annoyance has been considered to be best approached as a type of psychological stress (Winneke 2004). Individual differences such as age, marital status, occupation, and gender, create variations of reactions to environmental odour except at very strong or very weak levels (Jonsson 1974, Bliss *et al.* 1996, Dalton 1996, Winneke 2004, Keller *et al.* 2007, Claeson *et al.* 2011). In the case of demographics and lifestyle choices such as age, gender, and smoking habits, these perceptual differences are modulated further by physiological variables in olfactory perception (Ahlström *et al.* 1987, Evans *et al.* 1995, Bowler *et al.* 1996, Doty 1997, Davies *et al.* 1999, Hayes *et al.* 2012). The cognitive appraisal of odours can also be affected by past experience, perception of risk, or even the community itself in regards to its awareness and perception of environmental issues, and these factors remain contentious as to their effects within prior research (Lazarus *et al.* 1978, Winneke *et al.* 1996, Galetzka 1999, Shusterman 1999, Longhurst *et al.* 2004, Yeshurun *et al.* 2010, Robinson *et al.* 2012). The intermittent nature of many environmental odours may also lead to either olfactory adaptation or sensitivity for an individual, altering their ability to detect the odour through the physiological changes odours themselves elicit (Doty 1991a, Dalton *et al.* 1997a, Press *et al.* 2000).

Cognitive appraisal of an odour profoundly influences what reaction that odour is likely to elicit, and, conversely, odours cause mood and behaviour changes when an individual perceives to detect them, whether odours are present or not (Lazarus *et al.* 1978, Rotton 1983, Knasko *et al.* 1990, Knasko 1992, Schiffman *et al.* 1995). This sort of discrepancy based on cognitive influence is prevalent in the environment. Shusterman points out that the same sort of concentration of hydrogen sulfide from a boiled egg is likely to invoke complaints when it is assessed to be derived from a nearby refinery; the odour concentration is far below irritation levels yet still causes somatic complaints (Shusterman 1999). This kind of cognitive influence is pervasive throughout investigations pertaining to environmental odour. The report by Dalton *et al.* indicates how the interrelationship between cognition and physiological changes from actual odour concentrations can produce idiosyncratic behaviours and attributes. They discovered that odour-affected community members were both sensitised, and had adapted to, the odours that permeated from industrial sources (Dalton *et al.* 1997a). This curious state had originated through a community member’s concern for the effect on their health from an industrial odour, which had summarily increased their aversion and sensitivity to detect and subsequently avoid the odour (Dalton *et al.* 1997a). However, since community members had been perpetually exposed to industrial odorants, they had adapted at a peripheral (*i.e.* physiological) level to the odours. Summarily, while they community members were poorer at detecting industrial odours, they were more averse and exhibited more negative behaviour when they perceived them (Dalton *et al.* 1997a).

The situational placement of odour sources (real or perceived), and their assigned attributes has profound influence on how an odour is appraised (Yeshurun *et al.* 2010). Dalton and colleagues conducted a number of experiments that recorded participant's estimation of various odours' intensity, pleasantness, and danger (Dalton 1996, Dalton *et al.* 1997b, Dalton 2002). Groups were separated by the definitions given to them of the odour they were each tested on; a positive, neutral, or negative description. It was found that participants in the negative description group tended to rate odours as more dangerous, more intense, and less pleasant, while the reverse was found for the positive descriptor group, and somewhere in-between for the neutral description group (Dalton 1996, Dalton *et al.* 1997b). This finding was repeated more recently by Koyabashi *et al.* with the suggestion that this effect only seems to work when there is intermittent odour exposure (Kobayashi *et al.* 2008). The reason for this phenomenon is not clearly understood, but may have something to do with an alteration of olfactory adaptation by the odour causing re-attendance due to the sporadic exposure (Stevenson 2001, Kobayashi *et al.* 2008). Given the intermittent nature of many industrial odours, cognitive appraisal in this regard is likely to apply and suggests that appealing to the community regarding the safety of experienced odour concentrations may be effective in produce less negative reactions (Blumberg *et al.* 2001, Wing *et al.* 2008, Sironi *et al.* 2010, Lowman *et al.* 2013).

Appropriate information may be a useful tool for community satisfaction, given that odours have often been considered toxic by members of the public, reinforcing the need to address public perception effectively in the face of enhanced media attention and community groups attempting to cause outrage (Lees- Haley *et al.* 1992, Dalton *et al.* 1997b, Elliott *et al.* 1999, Robinson *et al.* 2012). This kind of "inoculation" against outrage has been used to good effect for a number of similarly topical and controversial relationships with the community, some of which possess concerns over odour emissions (McGuire 1961, Kemp *et al.* 2012). In this way, community concerns have the potential to be alleviated not necessarily by odour abatement, but via alternative methods such as effective education.

2.12 Health effects of malodour

One major property of the sense of smell is to warn an individual about potential health hazards, to that end, odour often implies danger from industrial sources for local communities; this in turn often leads to more health complaints by those who perceive the odour (Neutra *et al.* 1991, Distel *et al.* 1999, Elliott *et al.* 1999, Köster 2002, Luginaah *et al.* 2002, Moffatt *et al.* 2003). Several previous investigations have found that, if present, odour elicits the largest number of complaints from a community regarding an industrial area, and in addition signifies that area as “dangerous” far more than any other description (Wakefield *et al.* 2000, Harrison *et al.* 2002, Luginaah *et al.* 2002, Adams *et al.* 2003, Jenkins *et al.* 2007). Neutra *et al.* analysed several areas around hazardous waste sites in California and found that individuals who perceived odour were the reason for the significant difference of health effects between those who lived close to hazardous waste and those who did not, with odour perceivers having significantly lower health records (Neutra *et al.* 1991). Interestingly, even a “dummy” question relating to toothache (for which odour exposure should have no influence on even as a stressor) had higher incidence rates for people who detected odours; this was suggested to indicate an odour-worry paradigm that reveals the effect of odour and health (Neutra *et al.* 1991). Despite the strong relationship found between reported health effects and odour, it has also been suggested that this relationship is mediated by psychosocial variables, meaning that odour exposure analysis will not reveal a clear explanation to health effects; this has also been the case for dose-response relationships between odour levels and annoyance (Luginaah *et al.* 2002, Cervinka *et al.* 2004).

The health effects of odours themselves may be related to their cognitive appraisal, but it is still mired in difficulties. To begin with, there are multiple competing hypotheses as to the pathophysiological reasons behind odours causing health effects, ranging from innate odour preferences, to stress-induced illness, to mass psychological hysteria (Shusterman *et al.* 1991, Shusterman 1999, Schiffman *et al.* 2000, Shusterman 2001). It has also been suggested that perceived health effects are among the most important factors when individuals consider registering a complaint (Kolarova 1999). An additional, and difficult delineation is between odour and olfactory irritation, a separate factor that affects an individual's trigeminal nerve (Silver *et al.* 1991, Schiffman *et al.* 2000). In any case, odour exposure causes an increase in reported health effects, even with no toxic concentrations (Neutra *et al.* 1991, Shusterman 1999, Winneke 2004, Schiffman *et al.* 2005). Health effects are often recorded in research, and compared against controls to determine the severity of health issues, even if their exact cause is not fully understood (Shusterman 1999). To this end, governments have responded by producing parameters of odour production from industrial sources, stating that concentrations far below toxic concentrations must not be breached (Verein Deutscher Ingenieure 1993, Standards Australia and Standards New Zealand 2001b).

The types of health complaint resulting from environmental malodour vary, but include damage to respiratory health, nausea, eye irritation, stress, drowsiness, diarrhoea, sleep disturbance, as well as alterations in mood (Shusterman *et al.* 1991, Schiffman 1998, Schiffman *et al.* 2000, Zarra *et al.* 2008, Sucker *et al.* 2009, Lebrero *et al.* 2011). Long term exposure has had stronger effects on mood, including increased anger, depression, fatigue, and confusion (Schiffman *et al.* 2005).

2.13 Modelling odour impact

Appropriate estimations for hedonic and intensity for individual odorants remains hard to predict and establish (Sucker *et al.* 2008b). Despite this, there have been several attempts to create models of odour annoyance; for example, Miedema *et al*. developed a model for the relationship of highly annoyed residents and defined odour exposure concentrations, derived from similar work regarding noise (Miedema *et al.* 1988, Miedema *et al.* 1998, Miedema *et al.* 2000). This involved a hybrid survey/field olfactometry study; annoyance was recorded by residents, while odour exposure was assessed using panellists (Miedema *et al.* 2000). One interesting finding of this work was that incorporating the hedonic quality (established using a small cohort of panellists) of the odours as a factor separate to annoyance produced more accurate models (Miedema *et al.* 2000). While modelling provided either non-linear or constant terms, the correlations were very strong when considered as a group (Cavalini *et al.* 1991, Miedema *et al.* 2000).

Nicell *et al*. developed a similar model to establish the relationship between an odour annoyance, concentration, and persistence expressed by a sigmoid curve (Nicell 1994, Henshaw *et al.* 2002, Nicell 2003, Henshaw *et al.* 2006, Nicell *et al.* 2006). Contrasting methodologically, this model based itself on the reported scores of a large number of trained panellists, establishing annoyance as a self-rating of how annoying an odour would be when exposed to it for eight hours on a pictorial 0-10 scale (Springer 1974, Nicell 2003). This model has been extended for use with air dispersion modelling, capable of providing a predicted annoyance across a range of odour concentrations and intensities (Henshaw *et al.* 2006).

Elliot *et al*. in multiple papers has developed a framework based upon environmental stress and risk perception that determines the four broad factors that influence psychosocial effects of waste facilities with a logistical regression framework. These include the characteristics of the stressor, the individual, the social network, and the community (Taylor *et al.* 1991, Elliott *et al.* 1993, Elliott *et al.* 1997). Explanatory variables were found to be zones of testing (that is to say, specific regions and proximity to the facility), social networks, health effects, and presence of children in the household. Further research from this group included odour frequency and annoyance as a components and found that they had a significant relationship with reported health effects and overall satisfaction with the nearby waste facility (Luginaah *et al.* 2002).

These studies, while comprehensive, have some challenges when interpreting the contributions of odour data. Odour frequency was recorded as either less or more than once a month, meaning that a detailed understanding of the frequency factor was unavailable. Similarly, odour annoyance was measured in a small scale that has not been established as well as other measures (Both *et al.* 2004). Furthermore, there was no attempt to characterise, identify, or measure the odours experienced. Measurement of odour exposure was determined by distance from the facility, and while this is an accepted measure, the design did not determine with any veracity the low odour areas established for control, nor did it comprehensively sweep the surrounding area, instead selecting three independent zones (Luginaah *et al.* 2000). In summary, while these studies provide useful and important frameworks for community satisfaction and indicate some interesting trends relating to industrial-sourced odour, more in-depth analysis of odour is required.

While Miedema *et al*. and Nicell *et al*. have produced good correlations of annoyance and concentration, this is only for group responses; both methods tend to be poorer when considering individual odorants (Miedema *et al.* 2000, Nicell 2003). Odour annoyance scales have yet to be standardised. As a result, as with other examinations of annoyance, all scales need to be compared with each other and other measures to ensure validity and decrease the risk of participant sabotage (Evans *et al.* 1987a, Longhurst *et al.* 2004). Another issue that both groups of research have considered is that there are several communities (or individual) - specific factors that affect the accuracy of their models. Miedema *et al.* suggest from a legislative viewpoint, that annoyance and concentration should be the only considerations in order to provide equity and consistency [94]. However, this policy may ignore factors necessary to community satisfaction; with this study having to exclude a chemical factory from analysis possibly caused by higher annoyance derived from the community's negatively judging the tested site (Miedema *et al.* 2000). Finally, as suggested by Cavalini, while these models provide good correlations, they still do not explain the factors that influence affected individuals to be annoyed, while others in similar situations are not (Cavalini *et al.* 1991).

2.14 Dose-response relationship

As suggested by Winneke *et al.*, the assessment of psychological factors improves our understanding of why correlations of odour concentration and reaction to that odour are low, yet the actual concentrations of these odours still require attention (Winneke *et al.* 1996). While cognitive appraisal plays a crucial role in the assessment of annoyance for community members, the relationship between variations in odour concentration and community awareness is at times noticeable or very strong when combined methodologies are implemented. The correlation between observed odour concentration and the reaction of communities to that odour is known as the dose-response relationship. Research that has investigated this relationship has involved combined methodological approaches revealing crucial information regarding odour impact on communities. Cervinka *et al.* concluded that there was a strong correlation between sulfur concentrations in the canal air and annoyance experienced by residents in the surrounding vicinity (Cervinka *et al.* 2004). This research provided further clues regarding the relationship between cognitive appraisal and odorant concentration. The authors reported that nitrates were added to the canals and drastically reduced sulfur concentrations, which was predicted by the technicians working on the project to produce a suitably drastic reduction in odour annoyance. This was not the case, rather, there was a significant but only moderate reduction in odour annoyance, and this reduction was less pronounced in the lower areas of the canal where there was larger amounts of wastewater and increased canal diameter (Cervinka *et al.* 2004). It can be reasonably assumed that there was a larger amount of sulfur in the lower areas due to its larger size and surface area; slight reductions in annoyance correlated to drastically reduced sulfur concentrations. So while cognitive appraisal and the human nose as a detection instrument still “perceived” sulfur despite recorded very low concentrations, the attempts at odour abatement were still measurably and reliably registered as a dose-response relationship, albeit a very non-linear one.

2.15 Perceived control

Perceived control is a psychological concept that deserves particular attention when assessing the effect of environmental odours. Perceived control is defined as a person’s ability to control desired goals and avoid negative outcomes (Alloy *et al.* 1993, Kosslyn *et al.* 2004, Bullers 2005). As a result, local environment and community issues tend to produce both challenges to perceived control, as well as possess mechanisms to re-assert perceived control. In many cases, the re-assertion of perceived control is made in the form of community groups and social participation. An analysis of perceived control can lead to an understanding of expected community behaviour and marks an analysable aspect of survey design described by Jonsson (Jonsson 1974, Zimmerman *et al.* 1988, Bullers 2005). Perceived control is negatively affected when an individual is faced with an unpredictable and uncontrollable stimulus; therefore the intermittent and unpredictable nature of odorant exposure from many industrial facilities is likely to exacerbate the issue (Rotton 1983, Kosslyn *et al.* 2004, Kärnekull *et al.* 2011). However, perceived control remains under researched for environmental odours; as a result its influence is not entirely clear. A study by Bullers and colleagues found that perceived control did not seem to affect either levels of distress or health symptoms, rather, perceived control was suggested to be a way to predict behavioural outcomes of distressed individuals (Bullers 2005). This could still be regarded as useful; however, as it may explain behavioural differences between two groups of similarly annoyed individuals within a community as well as provide cues for different solutions to community dissatisfaction. Elliot *et al.* (1997) concluded that community-engagement and “empowerment” efforts that preceded the construction of a landfill site led to its relative acceptance by the community as time progressed(Elliott *et al.* 1997). Community engagement in general is seen as crucial to effective industry community relations (O'Faircheallaigh 2013, Dare *et al.* 2014). Further research is needed in this area, as Bullers *et al.* indicated that sampling was non-random, which could have shaped the participant’s behaviour as not being indicative of the community (Bullers 2005).

2.16 Pre-existing conditions and malodour

Another aspect to consider is the effect of odours on psychological conditions. Multiple chemical sensitivity syndrome (MCS) has been a recent topic of inquiry in regards to industrial and environmental odours, and relates to some individuals indicating hypersensitivity to odours, including an array of health symptoms and a perceived heightened olfactory acuity (Cone *et al.* 1991, Dalton 1996, Winneke 2004, Berglund *et al.* 2006). Past research has indicated that MCS may be purely a psychosomatic condition, however those with MCS are still far more likely to make complaints regarding odorous substances (Winneke 2004, Papo *et al.* 2006). Arduous odours have also been suggested to exacerbate other psychological conditions such as Post-Traumatic Stress Disorder (PTSD) as well as depression depending on the experienced odour quality and frequency (Schiffman *et al.* 2000, Nimmermark 2004, Lowman *et al.* 2013). In addition, conditions relating to breathing difficulties such as asthma have also been reported to exacerbate under environmental malodourous conditions (Schiffman *et al.* 2005). Considerations of these conditions are likely to be essential to produce complete community satisfaction.

2.17 Summary

Research into industrial and environmental odours has been extensive, rigorous and powerful. Despite this, improved detection of odorants and their interrelationship is ongoing and necessary to elucidate a progressive picture of odour impact. Other methods of analytical detection, such as specific odour detection, have a role to play in monitoring but are unlikely to produce deeper understanding of what underpins odour impact. Conversely, the research of cognitive appraisal and human perception of odours in the environment has been comparatively recent, and still requires refinement. We still do not know why odour irritates one individual and not another, nor do we know how to appropriately evaluate the relationship between environment, community, and odour (Cavalini *et al.* 1991, Cervinka *et al.* 2004). This leaves research in a difficult situation; analytical understanding of odour composition and concentration is hamstrung by the nescience play of community acceptability. Furthermore, addressing community complaints in some instances may not involve odour abatement, but rather some other method such as increased transparency between community and industry. In short, there is a definite lack of understanding regarding industry attitudes towards communities with regards to environmental malodour.

Due to the multitudinous approaches, the analysis of odour impact on communities is at times disjointed; the investigation sits at a crossroads between the analytical methods of firmly establishing chemical and environmental factors, and the understanding of the human element of odour perception. Systematic, rigorous testing combining these two broad concepts offers the best opportunity to understand the complex relationship between odour and community. The integration of measures, such as GC-MS/O, community involvement alongside panellist testing, as well as comprehensive surveys grants the best opportunity to understanding odour impact and this has been shown with similar investigations (Elliott *et al.* 1993, Doria Mde *et al.* 2009). It should also be noted that the expanse of research, such as the case of olfactometer design, means that researchers may have to go further afield to discover effective methodologies. Known variables and specificities of odour perception have begun to illustrate its complicated relationship with the environment, and future research needs to both take these variables into consideration, as well as investigate hitherto unknown impact modifiers (Pierrette *et al.* 2009). It is unlikely that every variable that affects odour impact can be feasibly investigated, but understanding factors of large influence will lead to objectives of the research field being met, resulting in satisfactory outcomes for both communities and industrial producers.

Chapter 3

Management of Complaint Information

Chapter 3. Management of Complaint Information

3.1 Introduction

In order to operate, legislative requirements pertaining to internal complaint management procedures must be met by Australian water companies. Guidelines for complaint management and odour measurement standards are provided in the Australian/New Zealand Standard Guidelines for Complaint Management in Organizations (AS/NZS:10002:2014) and the Australian/New Zealand Standard: Stationary Source Emissions (AS/NZS 4323.3:2001). These guidelines cover appropriate management strategies and frameworks to which Water Utilities (such as Sydney Water, SA Water, and Hunter Water) base their procedures and policies (Sydney Water 2011). However, pre-existing infrastructure to handle complaints is often not effective with regards to appropriately handling environmental malodour reports and effects (Keil *et al.* 2011, Lowman *et al.* 2011). In particular, a lack of standardisation and effective odour reporting are cited as diminishing the ability of complaint management as a research resource (Keil *et al.* 2011). Nevertheless, complaint databases have the potential to form an important tool for malodour research and community engagement when effectively administered (Kaye *et al.* 2000, Blumberg *et al.* 2001, Sivret *et al.* 2012).

We investigated the complaint management procedures for Sydney Water, SA Water, and Hunter Water (hereafter "Australian water companies") as to their effectiveness in addressing malodour concerns. In particular, we have assessed six New South Wales-based Waste Water Treatment Plants (WWTP) in regards to their odour control methods, as well as using them as examples of what current complaint data can achieve in terms of community complaint mapping. Additionally, we have made comparisons with legislation from other regions as to examine Australian water companies' complaint handling efficacy. Finally, we have made a series of suggestions as to improve current complaint management methodologies with minimal disruption or cost to current practices. With regards to current odour measurement standards, we compare the effectiveness of these standards to alternatives, and investigate how odour measurements in this way can be merged with complaint management resolutions. We found that standardisation of complaint entries, integration of complaint management and WWTP policies, as well as modifications to community engagement practices should be prioritised in order to improve customer and community experiences with Australian water companies.

3.2 Methods

Complaint data information was obtained via Supervisory Control And Data Acquisition (SCADA) system from three Australian water companies: Sydney Water, SA Water, and Hunter Water and subsequently scrutinised. The respective database information was assessed by its ability to fulfil two separate goals. Firstly, this assessment was based on how readily information from respective databases could be integrated with odour abatement and monitoring technology, such as air dispersion. Secondly, the information was assessed with regards to its form to characterise odour complaints in an effective way, for example the use of hedonic scales, or the ways in which complaint receiving was standardised. Additional information on the actions of separate WWTPs was obtained from plant manager interviews from the six plants investigated.

3.3 Complaint databases

We received a portion of the complaint database from Sydney Water that included any complaints pertaining to “odour” over the period of time between 2004 and 2014. Complaint information from Sydney Water is stored on a secured database within their SCADA system. This database contained 1945 complaints, a significant proportion of which were based around WWTPs. Sydney Water, Hunter Water, and SA Water all incorporate odour complaints as a part of a broader range of complaint types within their database. Unfortunately, the fields and design of the database do not lend themselves to effective odour mitigating strategies. Each complaint taken up by the standard system of the company has several entry fields. **Table 5** illustrates the list of Sydney Water’s fields for complaint data, as well as whether the field is included in SA Water or Hunter Water.

Table 5. Description of fields in Sydney Water's Complaint Management SCADA database, with comparison to SCADA databases from SA Water and Hunter Water

Field	SA Water	Hunter Water
SR# - an internal coding system.		**X**
Category – the type of communication. This section of the database only listed "Complaint".		
Sub Category – the sector of Sydney Water that this communication pertained to.	**X**	
Summary – a variable that describes the complaint, ordinarily in three or fewer sentences.	**X***	**X*****
Owner – description of who is responsible for resolution.		
Source – the origin of the complaint. This was most often "Customer" or occasionally "Managing/Agent".		
Channel – the method by which communication occurred; most often "Phone".		
Contact Last Name		
Premise – the address at which the complainant resided, although this occasionally entered as where the complaint occurred.	**X****	**X**
Received date – the date at which the communication was received. All dates included the day as well as time in 24-hour format, although the 24-hour format was most often ignored.	**X**	**X******
Facility name – the name of the facility in question. This was entered in approximately one third of all complaints with some WWTP-specific complaints not including it.	**X**	**X**
Project – a description of the project that the complaint related to (if any).		
Account – this referred to if a complaint was related to a long standing relationship with Sydney Water. Account types included nearby companies or group, or individuals who have made multiple complaints.		
Status – the current status of the complaint; all were listed as "Closed".	**X**	
Communication Record – this field was never filled.		
Created by Name – the individual or service that entered the complaint.		
Updated by Name – the individual or service that updated the complaint details.		
Group – The group within Sydney Water assigned to resolve the problem. This field was unclear as to how specific groups were designated.		
Contact First Name – it is unclear as to why this field was substantially distant from the "Contact Last Name" field.		

Table 5. Description of fields in Sydney Water's Complaint Management SCADA database, with comparison to SCADA databases from SA Water and Hunter Water *(continued)*

Field	**SA Water**	**Hunter Water**
Ownership – whether Sydney Water accepted a complaint as their responsibility. All entries were entered as "Accepted" which suggests that we were not given "Unaccepted" complaints.		
Responded date – The date at which a complainant was communicated with. This field was entered in about one third of cases.		
Resolved date – the date at which a complaint was resolved.		
Closed date – the date at which a complaint entry was closed. This time was uniformly one minute after the "Resolve date".		
Expected resolution date – the date at which a complaint was expected to be resolved. This time was uniformly one minute after the "Closed date".		
Created by – a code for the sector that created the complaint entry.		
Updated by – a code for the sector that updated the complaint entry.		

X = included in SCADA database
*For SA Water this included a location to a road but no address, as well as a Latitude and Longitude.
** The summary field for SA Water was not an "open" field, but rather consisted of a selection of options, one of which included "Fault, Water, Supply, Quality, Wastewater Odour".
***Listed as "Prob" for which the only case was "Odour".
****Listed as "Date/Time".

Unfortunately, only a small proportion of these fields found in the SCADA databases outlined in **Table 5** are pertinent to the evaluation of an odour complaint. Fields included in the reporting of a malodour event can be found in an example in **Table 6.** Comparatively, SA Water and Hunter Water had fewer fields as well as fewer means by which to evaluate odour complaints. SA Water's "Summary" field was based on the type of complaint experienced as opposed to a description of the complaint itself; of note, their complaint locations were based on Latitude and Longitude as opposed to street addresses. Comparatively, Hunter Water's complaint database used "Prob" as a field for the summary of the complaint, and was most often described as "Odour". Due to the paucity of information available, we chose to focus on assessing Sydney Water's complaint database and focus on the six sites of interest to the Cooperative Research Centre (CRC)-Low Carbon Living project.

Table 6. An example of fields pertinent to resolving odour complaint in Sydney Water's complaint database

Type	Category	Sub Category	Summary	Source	Premise	Received date	Status	Resolved date	Closed date
Complaint	Odour	Network-Wastewater	MIGRATED 10497C Complaint received from [redacted] Golf Club re. odours emanating from STP.	Customer	*Address*	20/09/ 2006 0:00	Closed	20/09/ 2006 23:59	20/09/ 2006 0:00

STP= Sewage Treatment Plant

As can be seen with **Table 6**, despite Sydney Water's better detail with regards to characterising complaints, the information that is typically expected with regards to odour incursions, such as time, intensity, quality of the odour, is not available (Lebrero *et al.* 2011). Descriptions of further actions taken with regards to a complaint entry beyond the "Resolved date" field are unknown, and did not specify whether further engagements (if any) were satisfactory to the complainant. Often, it appeared as if the complaint logger would specify a resolved date merely to complete the complaint application by specifying the resolved date a minute after the received date.

Further barriers to the effectiveness of the complaint database were understood in terms of complaint logging standardisation. The qualities of the summary field varied between entries in terms of both language used and detail. Additionally, even fields such as "Address" were challenging to interpret: sometimes they represented the complainer's address, whereas in other complaints, the address indicated where the complainant experienced the odour. Additionally, since most of the complaint migration originated at each WWTP, complaints would often use language and descriptions that would apply only to operators with knowledge of the WWTP in question, further reducing the complaint database as a viable tool for overarching research.

3.4 WWTP-based complaints, community engagement, and odour abatement technology

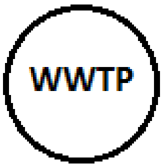
As mentioned previously, odour control is determined by the Australian/New Zealand Standard: Stationary Source Emissions (AS/NZS 4323.3:2001) and in some cases also is considered by measurement of a few odorants known to generate complaints (Standards Australia and Standards New Zealand 2001b, Sydney Water 2011). These standards are predominantly concerned with appropriate mapping procedures to determine OU concentrations without consideration of odour characteristics. Unfortunately, this impairs assessment considering the explicit importance of hedonic tone and odour intensity for community acceptance (Landerausschuss fur Immisiionsschutz 2003, Both *et al.* 2004).

In addition to the complaint system that encompasses Sydney Water, specific biosolids-processing at WWTPs have undertaken idiosyncratic methods of community engagement, as well as invested in odour abatement technology. There appears to be little upper management-WWTP communication regarding complaints or community engagement. To that end, many community actions are undertaken by the plant managers. These practices are discussed in **Chapter 6**.

3.5 Complaint Mapping and introduction to WWTPs

The six WWTPs included in our assessment composed of different unit process configurations, but all sites used anaerobic digestion which was the focus of our research. Relying on current complaint database methodology, we produced six complaint maps pertaining to the six WWTPs and their local communities based on the complaint information received by Water Utility. While these Figures (**Figures 7-12**, found below in **Sections 3.5.1-3.5.6**) are valuable in understanding the degree and severity of odour complaints in their respective regions, they are far from comprehensive. This is due in large part to incomplete complaint data received from WWTPs, which often neglected to list correct address information. Therefore, marker indications were made on a case-by-case basis, often necessitating the deletion of the complaint due to insufficient information. This issue was compounded by the fact that different site WWTPs often reported addresses and complaints in different ways, and the meshing of separate databases often produced duplicates or questionable entries. According to several Plant Managers (PM), they have been made aware of different numbers of complaints than those indicated by Sydney Water's central database and in-bound complaints are handled differently for some WWTPs. As a result, while this represents Sydney Water's odour complaint database, it is unknown if this is a fully representative cohort. In addition to logistical difficulties, these complaint maps cannot be considered accurate representations of a community's attitudes towards their respective WWTP due to the behavioral differences between communities that may cause under- or over-representation by complaints (Robinson *et al.* 2012). With this in mind, these complaint maps represent perhaps the most information that can be gleaned from current odour complaint management systems. A key for the various markers of the complaint maps is outlined in **Table 7**.

Table 7. Complaint map marker key for **Figures 7-12**

Marker	Key
	1 complaint
	2-10 complaints
	11-15 complaints
	16-25 complaints
	42 complaints
	Approximate location of Site's WWTP

3.5.1 Site 1 WWTP

Site 1's WWTP is located in an industrial area that is almost completely blocked from residential encroachment. Regardless, local Council has previously requested meetings with Sydney Water and the potential noise and odour impact of Site 1 WTTP. Site 1 WTTP offers tours around the treatment plants for schools and visitors, including a recent tour for a volunteer community group.

Site 1 has an annual wastewater flow of 13 000 ML/yr with primary and secondary treatment. The design for anaerobic digestion consists of two parallel primary digesters. Odour control at Site 1 includes foul air extraction that is treated through biofilters to deal with Hydrogen Sulfide (H_2S) and Volatile Organic Compounds (VOC), as well as chemical scrubbers to control H_2S and ammonia. Site 1 WWTP receives a small number of complaints due in part to how the plant is visually and odour-hidden due to its industrial location (**Figure 8**), as well as wastewater treatment pumped to Site 4. Overall, the environmental impact of Site 1 WWTP is considered minimal, and remains largely hidden due to its mainly industrialised location.

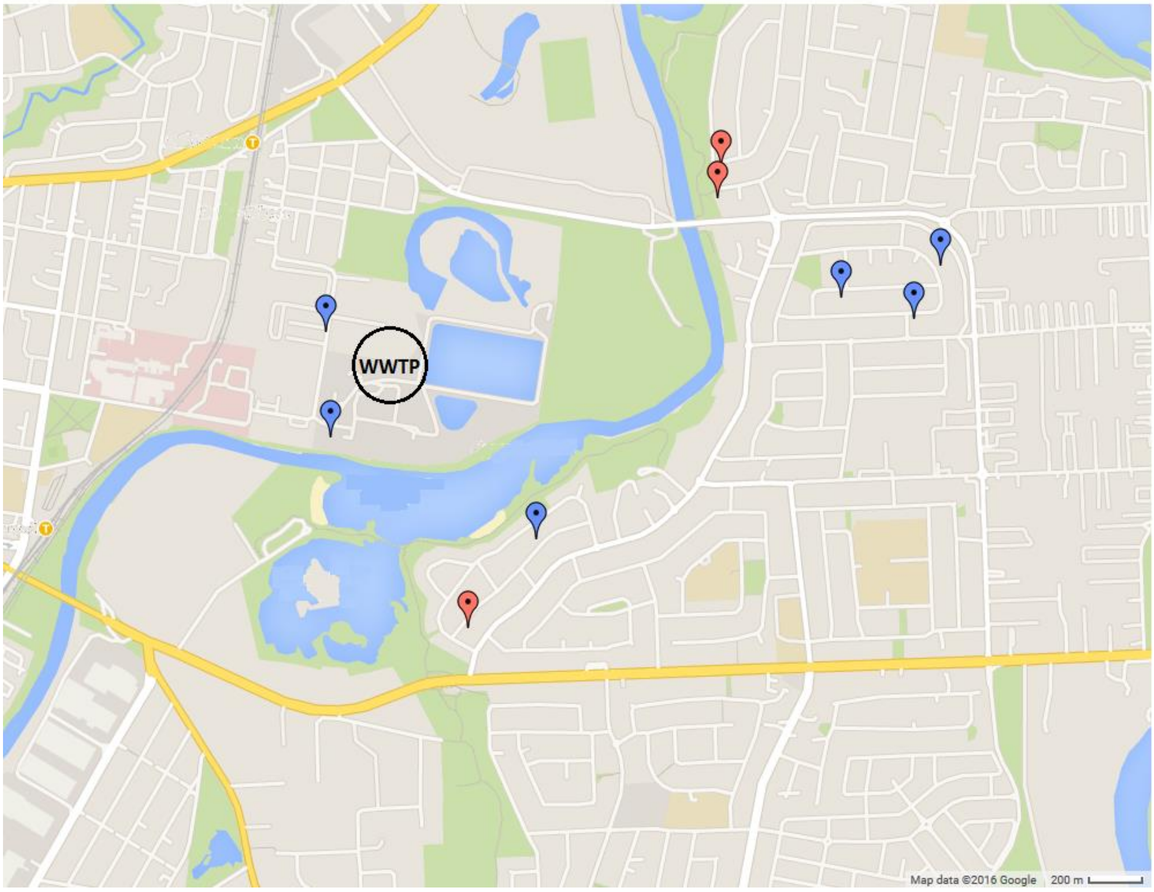


Figure 8. Site 1 WWTP Complaint Map

3.5.2 Site 2 WWTP

Site 2 WWTP's proximity to industrial customers, residential areas, as well as the neighbouring golf course has meant that community engagement has been a priority not only from an odour abatement perspective, but also in regards to water quality.

Management has met with industrial customers regarding recycled water in a monthly meeting, while discussions with the local community have included meetings at the local Retired Services League club on non-standard occasions.

Community engagement practices for Site 2 involves contacting a complainant to identify the specific nature of the issue for clarification, and then a face-to-face meeting about what process should be taken to resolve the complaint. Several residents were supplied with odour log books for time, wind direction, and odour quality which provided the WWTP with detailed information on odour events. Management at Site 2 has stated that the process to remedy potential odour and noise complaints may take up to two years, and only if it is approved by Sydney Water (with a driver of odour abatement strategy being a large number of complaints). The outcome of this decision is then communicated to the complainant. Throughout this time, regular communication is established. Tours for the plant have been offered, but to date, interest has been low. Recently, some nearby areas have been designated for residential areas, to which the WWTP have taken a proactive view towards communication with the building developers.

Site 2 experiences an annual wastewater flow of 16 000 ML/yr with primary, secondary, and tertiary treatment. Anaerobic digestion consists of four parallel primary digesters as well as a single secondary digester. Odour abatement at Site 2's WWTP has included improving the biosolids pickup area to include hoppers that dump the product directly onto trucks which are subsequently covered. The biosolids area is enclosed and fitted with odour scrubbers in 2006 which has caused a noticeable drop in complaints. Contour modelling for odour impacts is regularly assessed. Recently, Site 2's WWTP has had a decline in complaints received. However, it still represents a moderate risk due to its history as well as close proximity to residential areas, with the most complaints regarding malodours from biosolids truck routes (**Figure 9**).

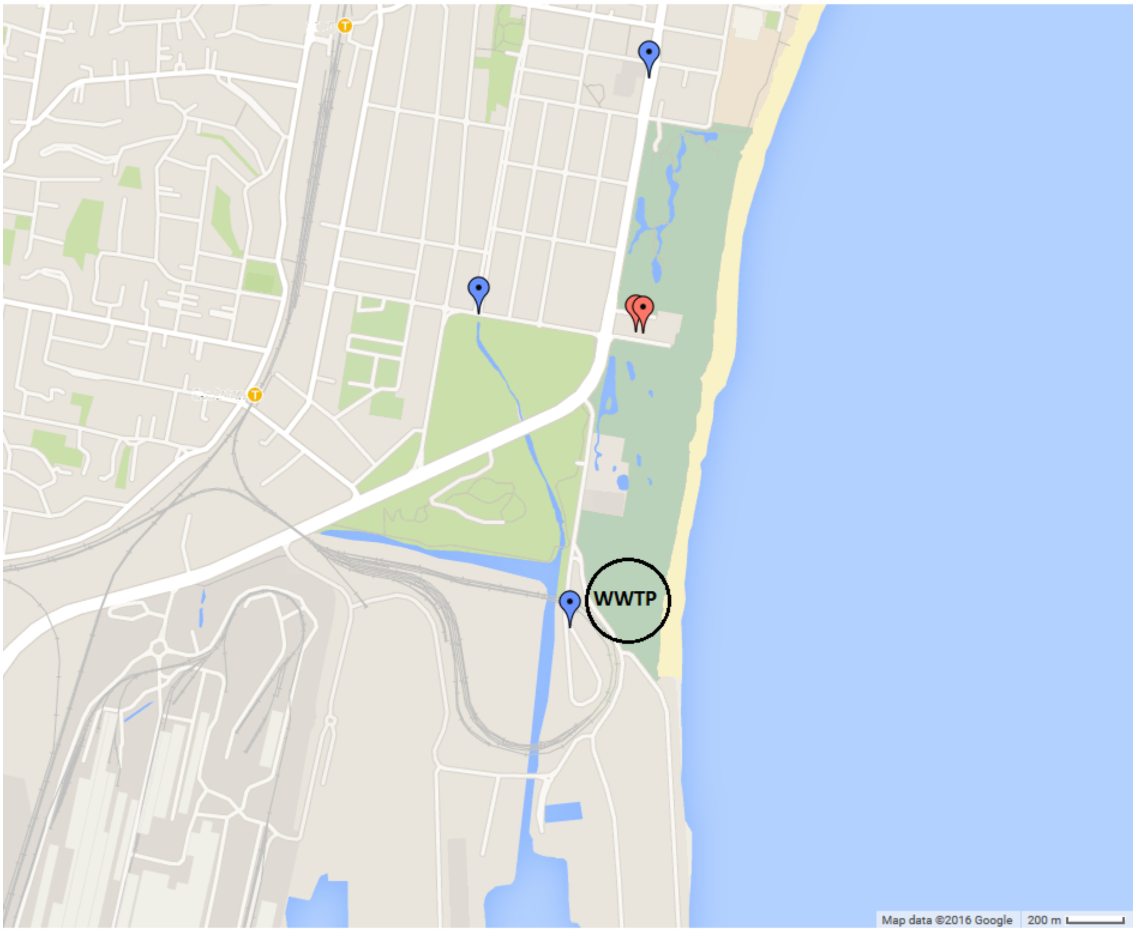


Figure 9. Site 2 WWTP Complaint Map

3.5.3 Site 3 WWTP

Site 3's WWTP is a small plant that is bordered by residential areas some 200 metres away. Despite the proximity of the community, Site 3 WWTP receives few complaints per year and has little interaction with the community. The biosolids themselves have been reported to have very little odour or other issues compared to other WWTPs in Sydney Water; this may be due to the exclusive residential catchment of the WWTP as suggested by its manager. While WWTP2 (**Figure 9**) indicates a moderate level of complaints, it should be considered a low priority for several reasons. Firstly, there is a minimal number of multiple complainants which characterise highly active communities such as those at Sites 4 and 6. Secondly, this plant is not "protected" by industrial works or distance from residences and still produces a small level of complaints, indicating the comparative low odour risk of its products. Thirdly, odour containment policies at this site are in their relative infancy, and any increase to complaints over time should be easily remedied by standard odour control technology.

Site 3 has an annual wastewater flow of only 5 000 ML/yr with primary and secondary treatment. Anaerobic digestion is accomplished through one primary digester. Trucks transporting biosolids are the WWTP's biggest concern, and the biosolids loading area is fitted with wey cells, and the trucks themselves covered to minimise odour risk. Deodourisers had been previously used by the biosolids transport trucks. Surprisingly, this action resulted in more complaints, with complainants stating that the trucks smelled like "urinal cake" (**Figure 10**). Truck movements are minimised to a fortnightly plan and approved transport routes are set. The plant is upgrading to high *g* centrifuges, which is an odour concern due to production of malodours during the relative shear of the product.

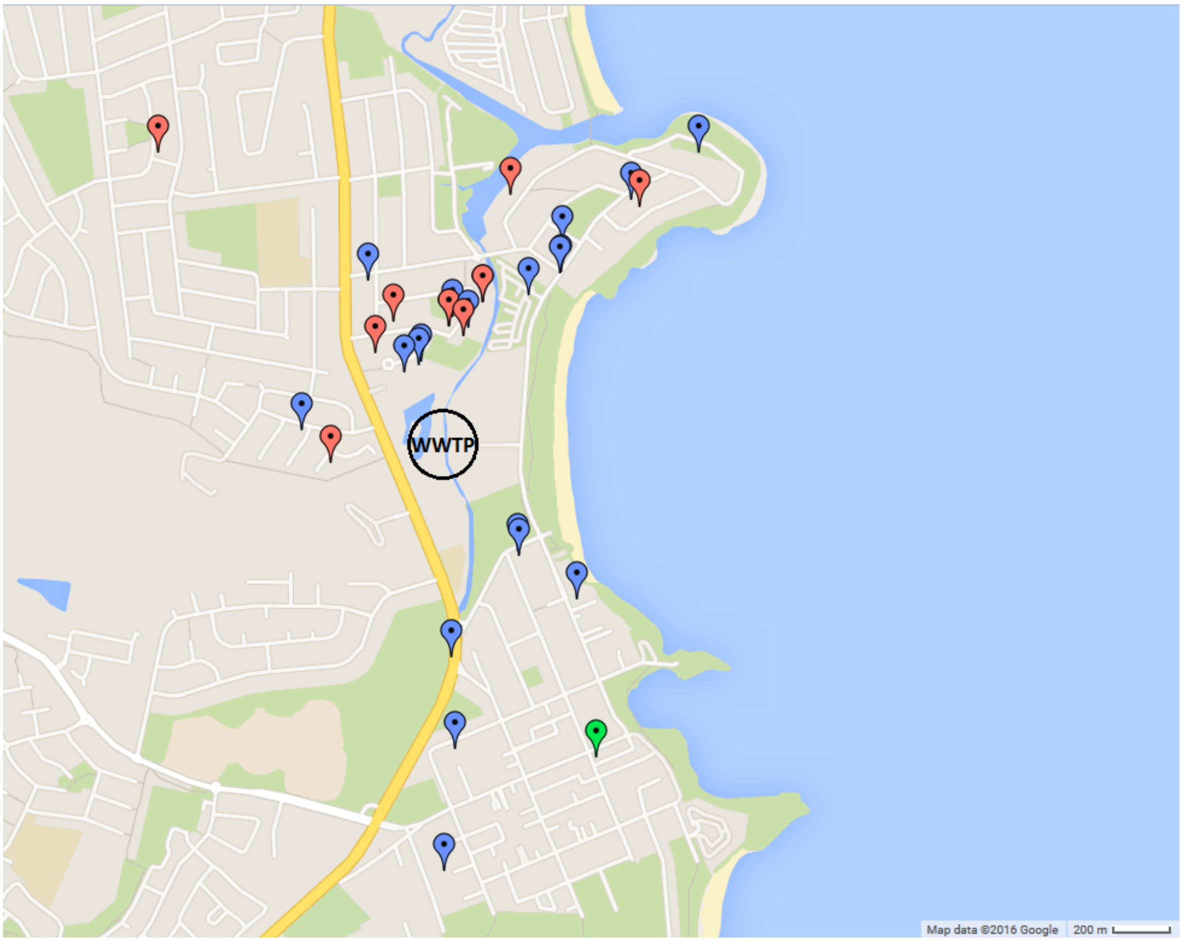


Figure 10. Site 3 WWTP Complaint Map

3.5.4 Site 4 WWTP

Site 4 experiences very high levels of consumer complaints. Site 4 has a very active local community, with a meeting with Sydney Water personnel organised every three months. These meetings are primarily concerned with presenting plant performance and reports on ongoing upgrades and represents a consultation with the local community.

Site 4 is a large WWTP with an annual wastewater flow of 170 000 ML/yr. It is responsible for primary treatment only, with two parallel anaerobic digesters. Recent odour abatement improvements have included exchanging six low-velocity stacks for one large stack with upgraded scrubbers and controls. However, it has been reported that nearby residents occasionally experience malodour from the scrubbers. Currently, the odour ventilation system is being re-designed, including changes made to the chemical scrubber, replacing the media in the biofilter, as well as identification of potential leaks in ducts. Biosolids now bypass the biofilter and instead are processed through a wet chemical scrubber. Internal reports by Sydney Water investigating sources of fugitive emissions found likely odour sources are the screening, grit collection, and sedimentation tank areas.

The efforts made by Sydney Water to the Site 4 WWTP have been driven by community interest, as well as improvement to biosolids quality. The size of the WWTP and its relative proximity to residents means that it still is responsible for a large number of odour complaints and represents high risk (**Figure 11**).

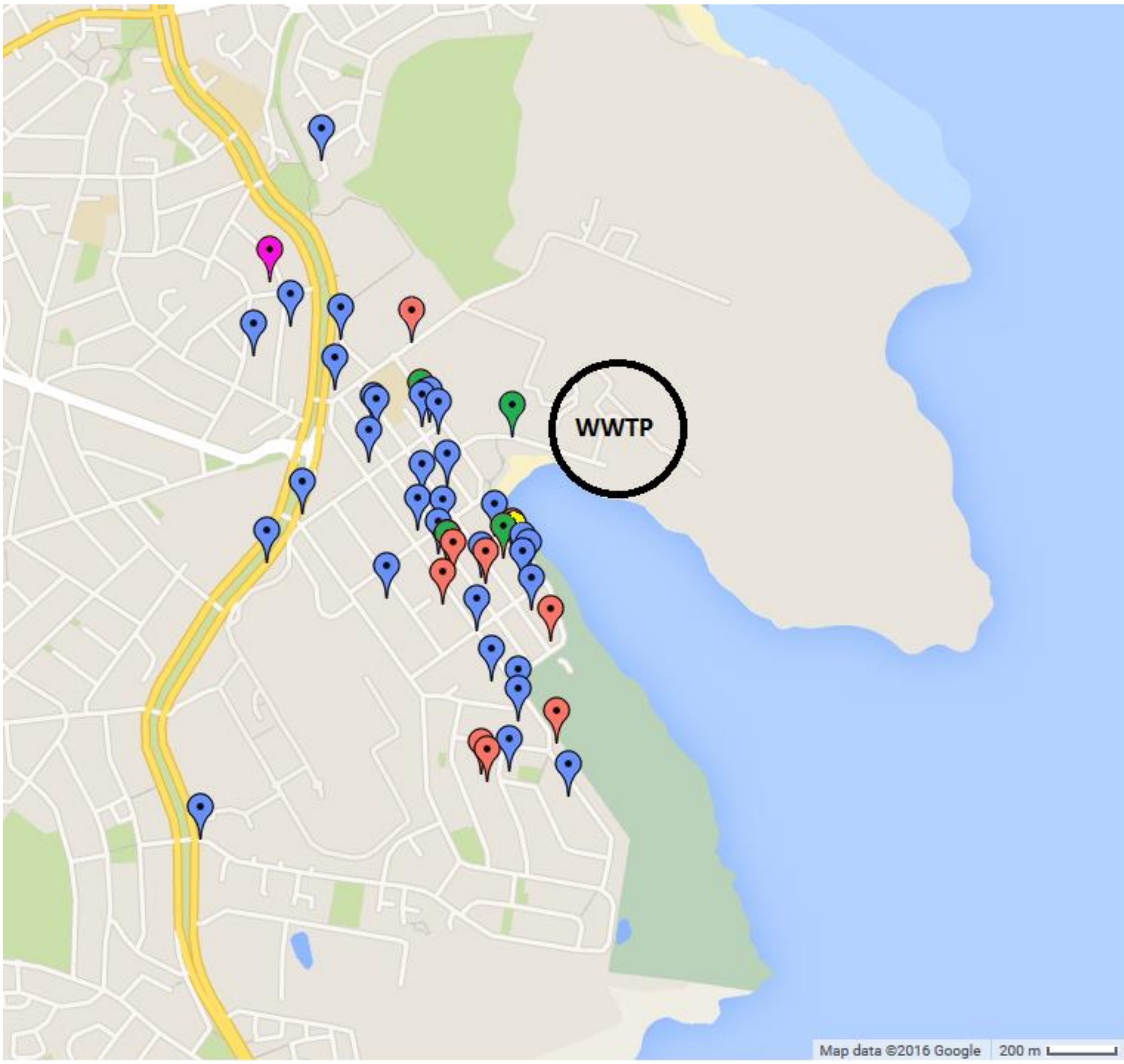


Figure 11. Site 4 WWTP Complaint Map

3.5.5 Site 5 WWTP

Site 5 WWTP is a moderately sized WWTP that has previously enjoyed considerable distance from residential areas. Communication to the local community has been previously low, but with the emergent residential area approximately 300 metres away, newsletters, open days, and the odour project itself have been publicised to improve visibility. Opened in 2015, this new residential area consist of approximately 400 new households.

Site 5 processes 19 000 ML/yr of wastewater flow. Biosolids processing consists of primary, secondary, and tertiary treatment with a single primary digester. Odour abatement at Site 5 has included covers over sedimentation tanks to minimise odours, but complaints have been received when covers must be removed for maintenance, which has caused potentially high risk emissions. This may be cause for concern if appropriate residential reporting measures are not undertaken when maintenance is required.

Historically, Site 5's complaint levels have been very low, due in part to its distant proximity to either residents or other industry (the closest of which has drawn attention away from the WWTP due to separate controversies). However, the recent new development increases the risk of complaints in the future (**Figure 12**). Site 5 provides a novel investigation opportunity due to its emerging district, as an established plant with previously infrequent recorded complaints.

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Figure 12. Site 5 WWTP Complaint Map. New residential building district ("R") is located approximately 300m from Site 5.

3.5.6 Site 6 WWTP

Site 6 is a large plant that receives complaints from multiple sources (**Figure 13**). Unlike other plants on this list, Site 6 has a separate complaint handling system with a pro forma, a design that is overseen by a community relations manager. This modified complaint process involves obtaining precise details regarding the odour time, event, and quality, then a representative of the WWTP will travel to the location to detect the odours in person. This practice is recommended by the EPA; both the EPA and WWTP wished to reduce the enormous numbers of non-descriptive and potentially frivolous complaints which is acceptable under AS/NZS 10002:2014 (Australia/Standards New Zealand Committee QR-015 Complaint Handling 2014). Log books have also been provided three members of the community with a fields for dates, times, odour quality, and intensity.

Site 6 has a number of avenues of interaction with the local community. Complaints are received from the local council quite often, but unfortunately there is no "spreadsheet" with regards to how these complaints are processed; most often there is an odour complaint but very little additional information such as time, location, and qualities of the odour. Community consultation group meetings occur every three months, and there are also odour forums with the local council. The number of multiple complainants, including those considered frivolous, indicates an extremely active community.

Site 6 is among the larger WWTP and has an annual wastewater flow of 110 000 ML/yr with primary treatment only. Its anaerobic digestion is accomplished through two parallel primary digesters as well as one secondary. Site 6’s WWTP has a disproportionate number of truck complaints which has led to restrictive times and routes for truck loading; 7:30-18:00 on weekdays (except public holidays), with outloading before 10:30. These restrictive measures have led to no additional complaints despite a recent upswing in truck numbers. However, complaint information regarding trucks is inherently more complicated to report compared to WWTP complaints due in part to complaints often being made while complainants are commuting; address and/or road information is often difficult to obtain which has meant Site 6’s complaint map has required significantly more guesswork. Odour abatement techniques include resealing covers and chemical scrubbers. Recent improvements have been made to central odour control facility scrubbers. Several methods of observation are routinely implemented including H_2S monitoring, air dispersion modelling, as well as customer surveys carried out by Sydney Water in the local region.

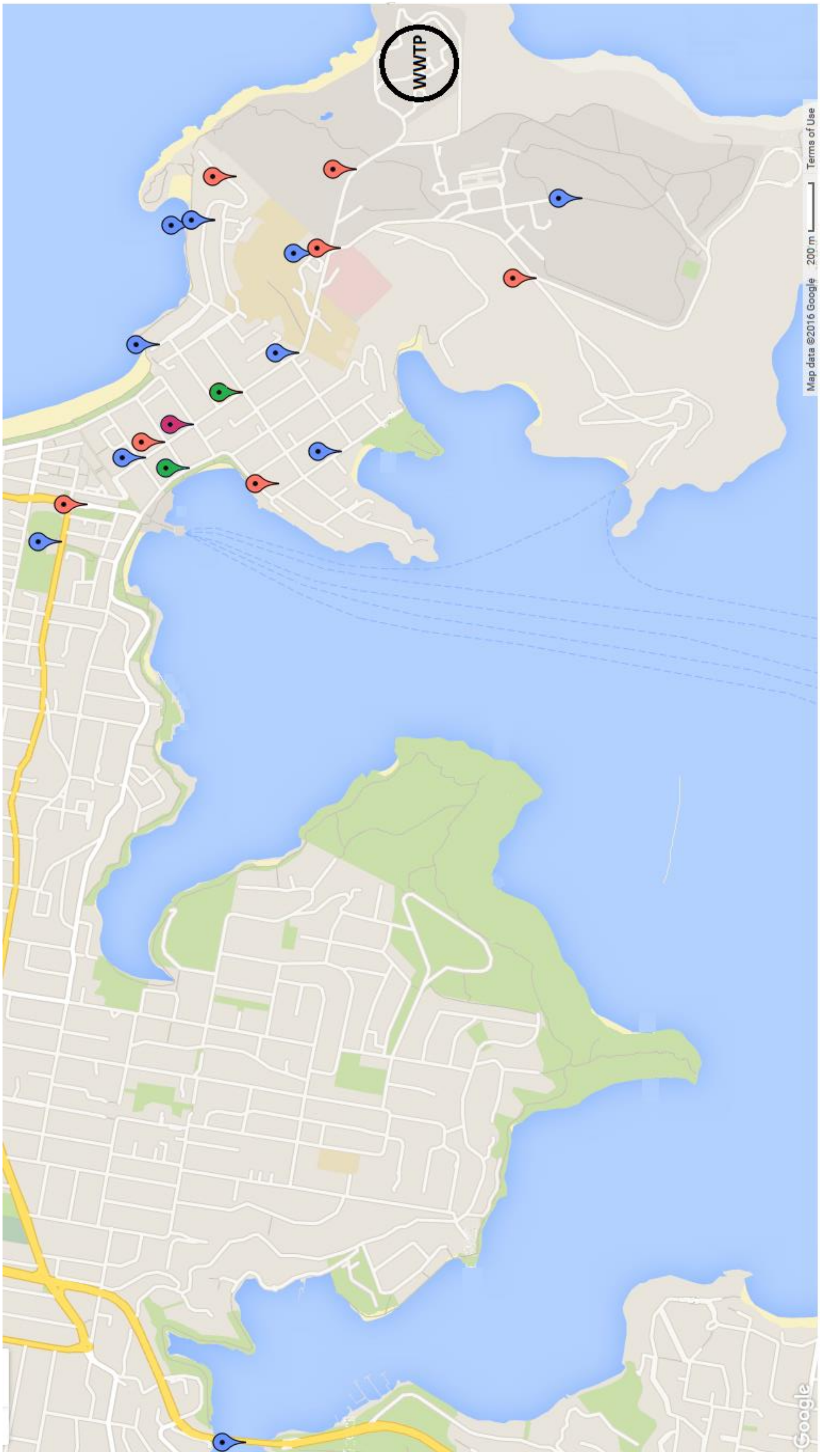

Figure 13. Site 6 WWTP Complaint Map. The levels of truck complaints and unspecified addresses has required more guesswork than other complaint maps (**Figures 7-11**).

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3.6 Overall complaint trends

A summary of complaint data relating to odour for the six sites, as well as Land Application is shown in **Figure 14**. Complaints were divided into odour complaints regarding the site itself, complaints regarding trucks carrying biosolids, the number of complaints that were caused by multiple complainants (that is, complainants who have complained more than three times), and the number of multiple complainants identified. As previously noted, the disjointed complaint management system exposes these results to error. Additionally, land application complaints are likely to be made not only to Sydney Water, but the biosolids transportation companies, the NSW Environment Protection Authority (EPA), or local governments; as a result, this Figure is likely an underestimation.

Figure 14 also illustrates the variation between different WWTPs and their type and number of odour complaints. With the exception of Site 6, the number of complaints from multiple complainants is approximately 50% of site complaints. As this analysis of odour complaint data indicates, the effect of the community can be determined by only a small proportion of its population who are willing to make multiple complaints (Kemp *et al.* 2012, Robinson *et al.* 2012). As indicated by prior literature that makes delineations between “active” and “non-active” communities, the sites can be relatively divided between the non-active Sites 1, 2, 3 and 5, and the active Sites 4 and 6 (McGuire 1961, Kasperson *et al.* 1999, Robinson *et al.* 2012).

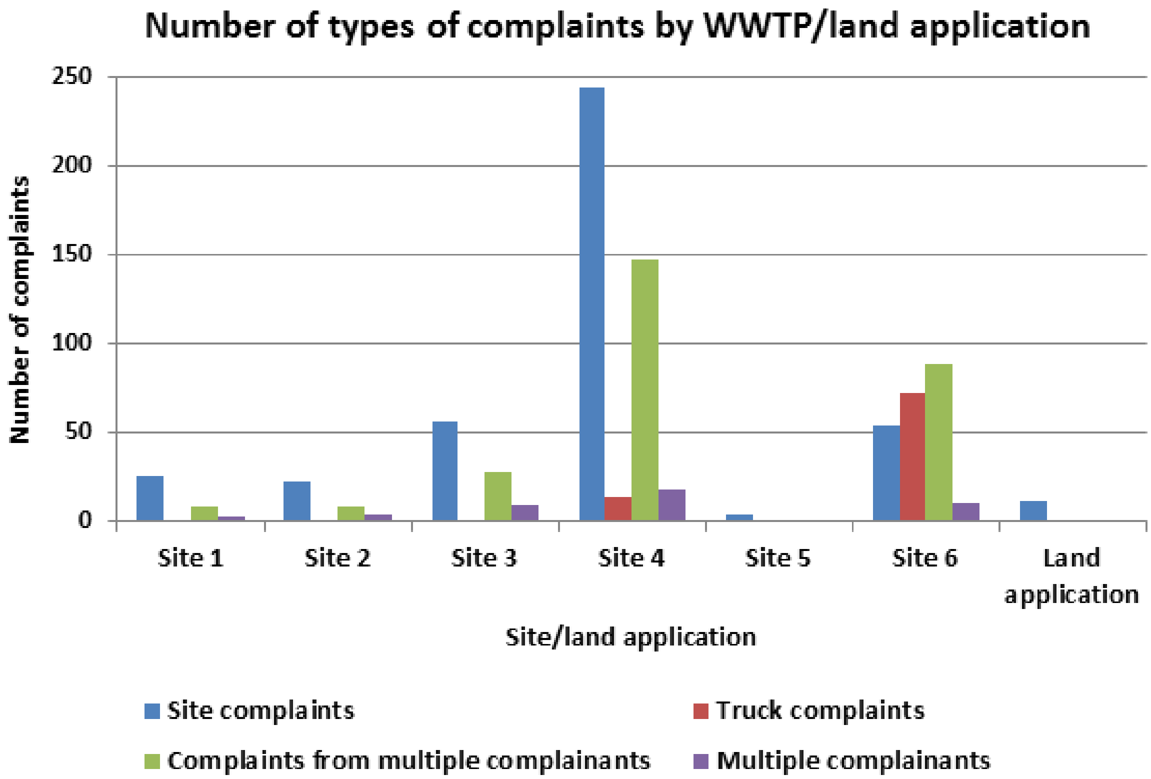

Figure 14. Number and types of odour complaint as sorted by WWTP/Land application

3.7 Discussion and Summary

Overall, the integration of WWTP community engagement policy and the overarching complaint database system is poor. A concerning aspect for biosolids acceptance is a lack of oversight with regards to complaint handling. It is simply not known where complaints regarding biosolids are likely to be lodged, meaning that a potentially enormous community annoyance remains unchecked. Without appropriate adjudication, a biosolids product could become untenable due to public outcry (Australian & New Zealand Biosolids Partnership 2010, Pritchard *et al.* 2010, Ryan *et al.* 2010, Robinson *et al.* 2012).

Complaint minimisation is a legislatively important goal; however, there are further alternatives to consider (Kaye *et al.* 2000, Both *et al.* 2004). Alternatives that engage complaints to assess malodour can be found in non-Australian policies and legislation and highlight the value not only for measurement of additional odour characteristics, but community engagement beyond complaint management (Both *et al.* 2004). A European counterpart, the Guideline on Odour in Ambient Air (GOAA), provides a similar methodology to the AS/NZS 4323.3:2001 with some key differences; namely, the acknowledgement of values beyond OU as important to odour annoyance as well as increased focus on field observers as assessors (Landerausschuss fur Immisiionsschutz 2003). The GOAA is complimented by the Association of German Engineers (VDI) Standard 3883 which comprehensively defines ways in which to determine annoyance and odour intensity, as well as ways to engage the community regarding odours, such as the use of odour log books, surveys, and field observers (Verein Deutscher Ingenieure 1993). Of note, the VDI 3883 acknowledges the discrepancy between laboratory and community reactions to odour, and that odour impact is changed by “moderator values” including person, environment, and situation (Verein Deutscher Ingenieure 1993, Cervinka *et al.* 2004, Winneke *et al.* 2004, Sucker *et al.* 2008b). These articles also receive extensions in practice and recommendation; for instance Sucker (2009) produced dialogue procedures for ameliorating community dissatisfaction within the context of the VDI 3883 and GOAA (Sucker 2009). The VDI 3883 is a good example of combining complaint policies with overall community engagement policies. However, implementation of many of these practices would require an enormous shift in current attitudes and implementation within

Australia. As an alternative, the Code of Practice on Odour Nuisance from Sewage Treatment works by the Department for Environment, Food, and Rural Affairs in the UK offers a system that is more compatible with Australian standards. The Code identifies FIDOL as the principle in determining nuisance; **F**requency, **I**ntensity, **D**uration, **O**ffensiveness, and **L**ocation which establishes the importance of odour qualities beyond that of OU (Department for Environment 2006). The Code also provides basic guidelines to assist in logging odour complaints which includes determining complaint frequency, odour qualities, and the pattern by which these complaints occur (Department for Environment 2006). Additional useful guidelines are proposed for odour amelioration, including determining best practice resolution, as well as the use of site operators as odour monitors (Department for Environment 2006). These comparatively smaller steps should allow for low cost implementation for Australian odour complaint management.

Based on this international community engagement alternatives and their recommendations, there are some inexpensive implementations that should be adopted by Australian water company complaint management. Of prime importance is the necessity to enact effective odour characterisation (Both *et al.* 2004), which will require the complaint taker to establish an odour event. An odour event is characterised by the time, the duration, the intensity, and the quality of the odour experienced (Department for Environment 2006). Time and duration are relatively straightforward measures; however, classifying intensity and quality may be more difficult. Intensity can be measured in a simple numerical scale; as a recommendation this can be rated 1 (undetected) to 10 (overwhelming) (Berglund *et al.* 1992b, Distel *et al.* 1999, Sucker *et al.* 2008b, Curren *et al.* 2013). Odour quality is a further difficulty as Odour Wheels are popular, but are not currently in a format that is able to be used by untrained community members (Rosenfeld *et al.* 2007). Further difficulty is with the nature of olfaction itself; defining odour qualities is often a difficult task (the so called "tip-of-the-nose" phenomenon) for untrained reporters (Doty 1991b, Doty 1991a). What could work as a solution is a generalised set of categories that the complaint taker could supply to the complainant. This could be constituted as a question such as "Did the odour smell like wood, like a sewer, or like a beach?". By using contextual cues about a familiar location to the complainant, a particular odour's quality could be tentatively established (Doty 1991a, Doty 1991b).

The complaint flow cycle can also be improved. This should involve the standardisation of complaint structure despite the varying sources of complaint receiving origin. A centralised complaint monitor could alleviate this issue, and then subsequently disperse the information throughout the company (**Figure 15**).

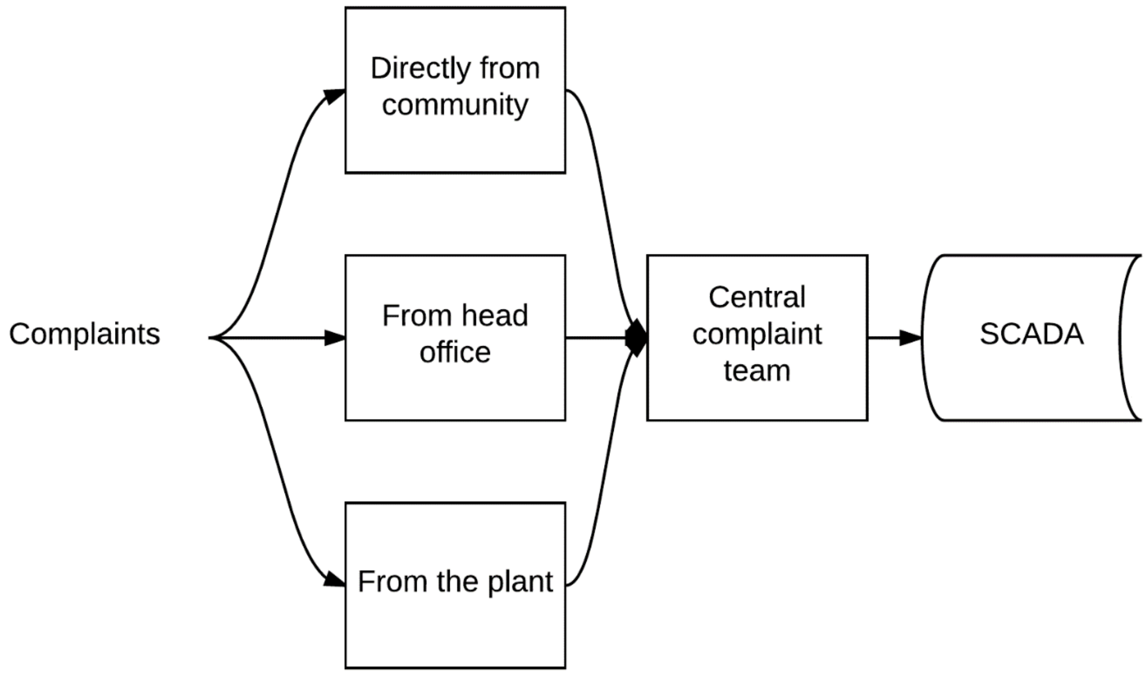

Figure 15. Proposed complaint flow method. This standardises complaint log structure and reduces confounding events such as double entries.

This Chapter provided a beginning point for other investigations. In particular, the knowledge of complaint management alerted us of its importance and relative lack of understanding when forming and implementing the industry survey and plant manager interview components of **Chapter 6.** While the reporting of odour events in current methodologies is very limited, it did provide a measure of the odour influence of the six WWTPs for both distance from plant, as well as a crude idea of relative community's satisfaction. To that end, this Chapter provided distribution and selection information when implementing the **Chapter 5** community survey.

In conclusion, odour complaints can be useful tools when abatement practices are to be considered despite their inherently reaction-based nature as well as their potentially poor relationship with actual community annoyance levels (Blumberg *et al.* 2001, Sucker 2009). Odour complaints need several additional qualities in order for appropriate evaluation. Establishing the location, time, and duration of an odour complaint are the minimum requirements for comparison to practically all odour assessment methodologies, or indeed to establish any patterns of environmental behaviour. Further description, such as odour quality, is more complicated due in part to the nature of olfaction and how it is treated by untrained community members and/or complaint receivers, but may offer improved evaluation techniques (Richardson *et al.* 1989, Sucker *et al.* 2004). Additionally, the establishment of best practice solutions can only be determined by recording and reporting reactions to resolutions attempted, which is lacking in the current complaint handling methodology. Appropriate management of odour complaints is an important, but not comprehensive, facet to approaching community engagement.

Chapter 4

Broadening perspectives of GC-MS/O

Chapter 4: Broadening perspectives of GC-MS/O

4.1 Introduction

As discussed in **Chapter 2**, the combination of analytical techniques, including GC-MS/O, is an attempt to encapsulate all data relating to odour that would otherwise be unable to be assessed through independent methodologies (van Harreveld 2001, Harrison *et al.* 2002, Brambilla *et al.* 2010, Hayes *et al.* 2014). The establishment of odour characteristics and odorant contribution is of primary importance to assess environmental malodour (Trabue *et al.* 2011, Agus *et al.* 2012). However, as research by van Harreveld illustrates, the pathway from which an odorant produces an odour complaint is complicated (van Harreveld 2001). Adding to the difficulty of establishing a meaningful route from odorant to complaint is the consideration of the variations within the community with regards to olfactory sensitivity (Doty *et al.* 1984, Doty 1997, Keller *et al.* 2007). This Chapter will discuss the ways in which GC-MS/O is currently implemented to create the odorant-to-complaint path, and will investigate novel alternatives that will offer a GC-MS/O methodology with improved ecological validity.

Varying methods of odour evaluation across several domains, such as food technology, psychology and neuroscience, have already illustrated the increasing necessity to appreciate the respective strengths and weaknesses of any singular odour methodology (Desrochers *et al.* 2002, Cai *et al.* 2007, Niu *et al.* 2011, Brattoli *et al.* 2013). GC-MS/O is a method by which the strengths of chemical compositions of odours can be cross tabulated to the response and description of participants (termed "panellists") simultaneously, thereby producing comprehensive information (Zarra *et al.* 2008, Niu *et al.* 2011, Brattoli *et al.* 2013). GC-MS/O offers the opportunity to evaluate both analytical and sensorial measurements, which in turn characterises odour samples in far more detail than any singular alternative.

GC-MS/O has been embraced in several domains pertaining to odour characterisation; however, environmental malodour analyses typically have not expanded implemented methodologies beyond a few standard practices (van Ruth 2001). At the forefront, GC-MS/O is used almost exclusively to define priority contributing odorants of a given sample. This is largely due to the way in which legislation based on odour control bases criteria for acceptable emissions; typically, specific odorants have a set acceptable concentrations that should not be breached (Standards Australia and Standards New Zealand 2001b, Van Harreveld 2003, Vossen 2004, Bockreis *et al.* 2005, Mao *et al.* 2006, Drew *et al.* 2007). The identification of priority odorants has meant that testing involves using panellists with an average olfactory sensitivity, similar to the establishment of OU by dynamic olfactometry in so doing eliminating approximately 50-70% of applicants (van Harreveld 2004, Muñoz *et al.* 2010). While this method is capable of effective calibration and testing, there are multiple variations outside of Australia that consider the addition of sensory impact such as the VDI 3883 where perspectives regarding the olfactory hedonics and character are additionally considered; these variations are discussed in **Chapters 2 and 3** (Sucker *et al*. 2004). This in itself carries concerns relating to ecological validity as it is fair to assume that individuals with higher olfactory sensitivity (as well as members of the community with so-called MCS) will be more prone to report odour complaints (Dalton 1996, Sucker *et al.* 2004, van Harreveld 2004, Muñoz *et al.* 2010). In addition to the potential for under-representation in the community, little research has been conducted to look at the ways in which odour qualities change for individuals of high sensitivity. As a result, odour complaints from highly sensitive individuals may include reports regarding qualities of an odour otherwise undetected or characterised differently to standard panellist responses (Gross-Isseroff *et al.* 1988, Hayes *et al.* 2014).

Another topic of investigation is the areas for which GC-MS/O samples are taken. The majority of odour regulations base odour control around an “at boundary” measurement (Drew *et al.* 2007). Currently, the analysis of WWTPs have assessed odours from effluent, at boundary, as well as at a unit process level (Mao *et al.* 2006, Agus *et al.* 2012). Analyses of discrete unit processes are effective as they can identify priority areas for evaluation. Analysis of unit processes has been fairly rare, but by elucidating where problems occur, upstream processes can also be targeted for effective odour control procedures (Lehtinen *et al.* 2010). Additionally, as discussed in **Chapter 2**, there are methodological limitations of GC-MS/O that should be considered.

In this Chapter, we will research the odour samples of unit processes taken from three WWTPs using GC-MS/O to produce a characterisation of the odours experienced. This analysis will also investigate the importance of assessing panellists of varying olfactory sensitivity, as well as the ways in which GC-MS/O can be used to expound further detail regarding environmental emissions. In order to control for limitations of GC-MS/O, further analytical tools have been used for further analysis (Agus *et al.* 2012). We demonstrate that the measurement of non-average participants is crucial to understanding the odour impact that affects communities.

4.2 Experimental Methods

4.2.1 Panellist selection

Two panellists were selected based on their olfactory threshold of *n*-butanol; a standard technique for establishing olfactory sensitivity (Doty 1991b, McGinley *et al.* 2001, Muñoz *et al.* 2010). The Average Sensitivity Panellist (ASP) possessed a *n*-butanol detection threshold of 36 ppb, while the High Sensitive Panellist (HSP) registered 9ppb.

4.2.1.1 Analytical equipment

Gaseous samples of emission streams were generated using a dynamic flux hood in compliance with the Australian Standard Method (Standards Australia and Standards New Zealand 2001c). Sorbent tubes (TenaxTA, Markes International, United Kingdom) were used to collect samples for GC-MS/O analysis. These emissions were by purged with a nitrogen flow of 5L/min, then captured on TenaxTA sorbent tubes at a flowrate of 100mL/min for 10 minutes using air pumps (SKC Inc, PA, USA). Samples for H_2S analysis were also collected in Tedlar bags using air pumps (SKC Inc, PA, USA), and H_2S

concentration was subsequently determined by Jerome analysis (Arizona Instruments, USA).

Sorbent tubes were desorbed using a Unity thermal desorber (Markes International, UK) coupled with an Ultra automatic sampler (Markes International, UK). A U-T11PGC cold trap (Markes International, UK) was used to gather the sample prior to GC injection. The sample was subsequently analysed using a 7890A Agilent Technologies GC coupled with a 5975C Agilent Technologies MS and Gerstel ODP 3 olfactory detection port (ODP). The GC carrier gas was ultra-high purity helium. The flow ratio between MS and ODP was maintained at 2:3 respectively. The ODP also implemented a small humidifier that provided a reduced risk of olfactory fatigue for panellists. NIST02 (NIST Mass Spectrometry Data Center, MD, USA) and Wiley8 (Wiley Registry, USA) spectral libraries were used for spectra matching and compound identification for GC-MS results.

Panellists had several tools at their disposal. For each detected odour, a panellist would record the length of time the event occurred (through the length of button press). In addition, each odour has a four-point intensity scale from 1 (low) to 4 (very high) as well as an odour quality descriptor through voice recording that was later tabulated.

In order to accurately measure sulfur and sulfur compounds, a 355 Sulfur Chemiluminescence Detector (SCD, Agilent Technologies, USA) used double bag samples measured over several days to produce average concentrations.

4.2.1.2 Study approach

MS and ODP data was combined by first comparing each respective "odour event" (*i.e.* when participant registered an odour occurring) and comparing it to the retention times of odorants recorded by the MS. In order to establish likely odorant candidates, chemicals were investigated that had retention times within 0.2 minutes of the odour event. This was carried out in order to account for time discrepancies between the response of the panellist recording an odour event and the retention time of the odorant within the MS. Other MS results, independent of the ODP, but measured simultaneously, were used to assist in odour identification. By using the average concentration of priority odorants, and dividing that by the odorant's threshold, we produced an Odour Activity Value (OAV) for each odorant which we then established on a unit process level making comparisons between each of the priority odorants and their relative contributions to the malodour (Ruth 1986, Rappert *et al.* 2005, Nuzzi *et al.* 2008).

The three WWTP sites (Sites 1, 2, and 3) were selected that each had variations in their process (**Figure 16**). These Sites and their unit processes were selected as having good variation between each to compare for the suitability of their processes with regards to odour control.

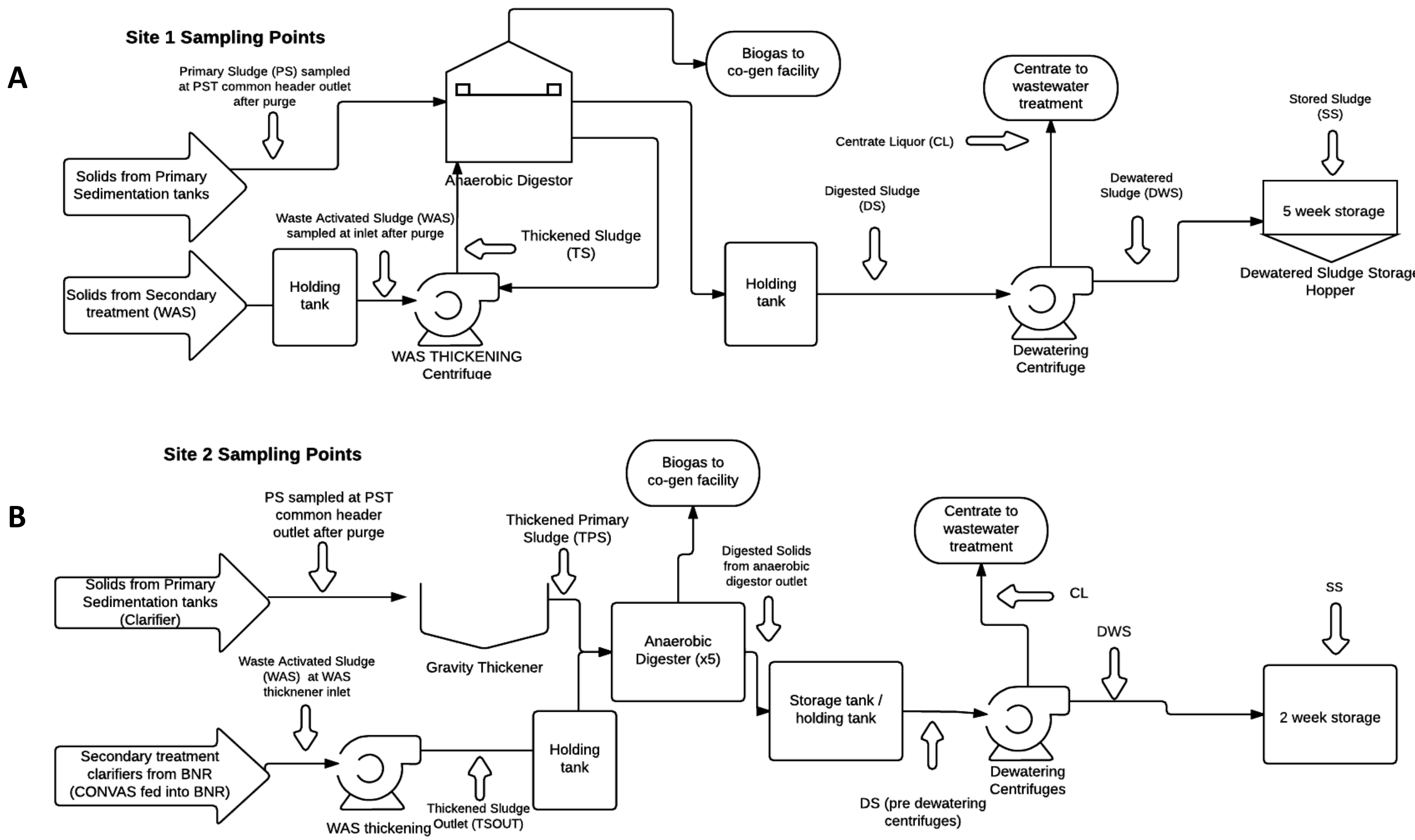

Figure 16. Unit processing sampling points at 3 WWTPs. Panels: (A) WWTP Site 1; (B) WWTP Site 2; (C) WWTP Site 3

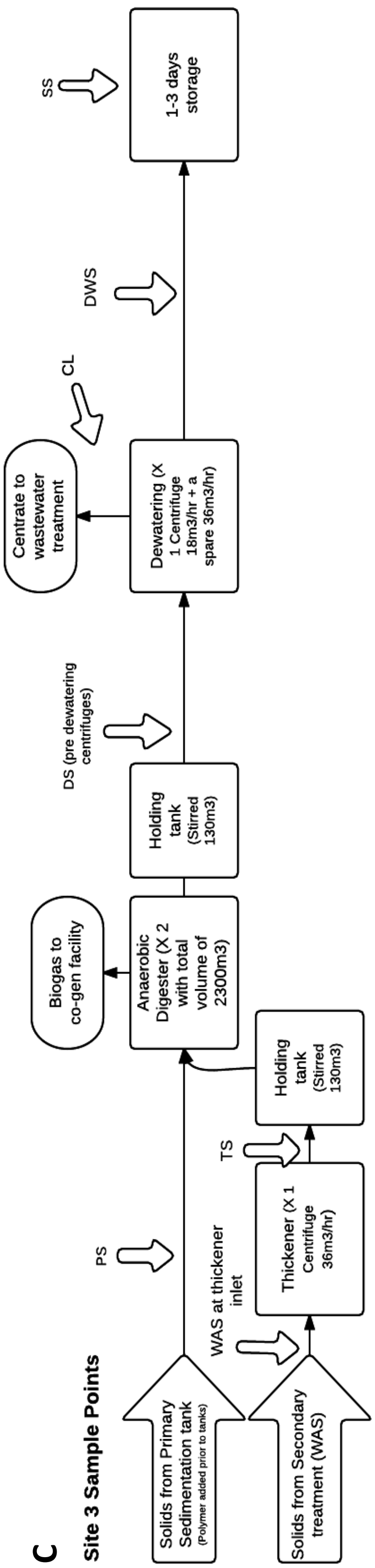

Figure 15. Unit processing sampling points at 3 WWTPs. Panels: (A) WWTP Site 1; (B) WWTP Site 2; (C) WWTP Site 3 (*continued*)

4.2.1.3 Odorant prioritisation and analysis of the variation between ASP and HSP

Data analysis will investigate the variation of response between ASP and HSP, as well as predicting areas of concern for the WWTPs. In order to accomplish this, we recorded the number of odour events between panellists, and compared how these odorants synchronised with identified compounds within the MS library. In addition, we used the odour descriptors as additional information to better understand the odour samples. Priority odorants will be established by identifying their frequency of detection, as well as odour qualities. Averages of VOCs were provided using GC-MS/O and GC-MS results. Sulfur compound averages were established using the SCD. Some MS recordings did not include measurable amounts of the compound; in this instance, the entries were established at being the 2x the square root of the Machine Detection Limit designated for the odorant.

4.3 Results

4.3.1 Variation between H_2S measures and recorded odour events

There was considerable variation in number of odour events between ASP and HSP (**Figure 17**). ASP recorded 73 odour events with 18 (25%) of those matched to the MS library, while HSP recorded 121 odour events with 19 (16%) matched. Bivariate Spearman's correlation on both ASP responses and HSP responses compared to H_2S levels revealed no relationship except for Site 1 and ASP (p= 0.001, **Table 8**).

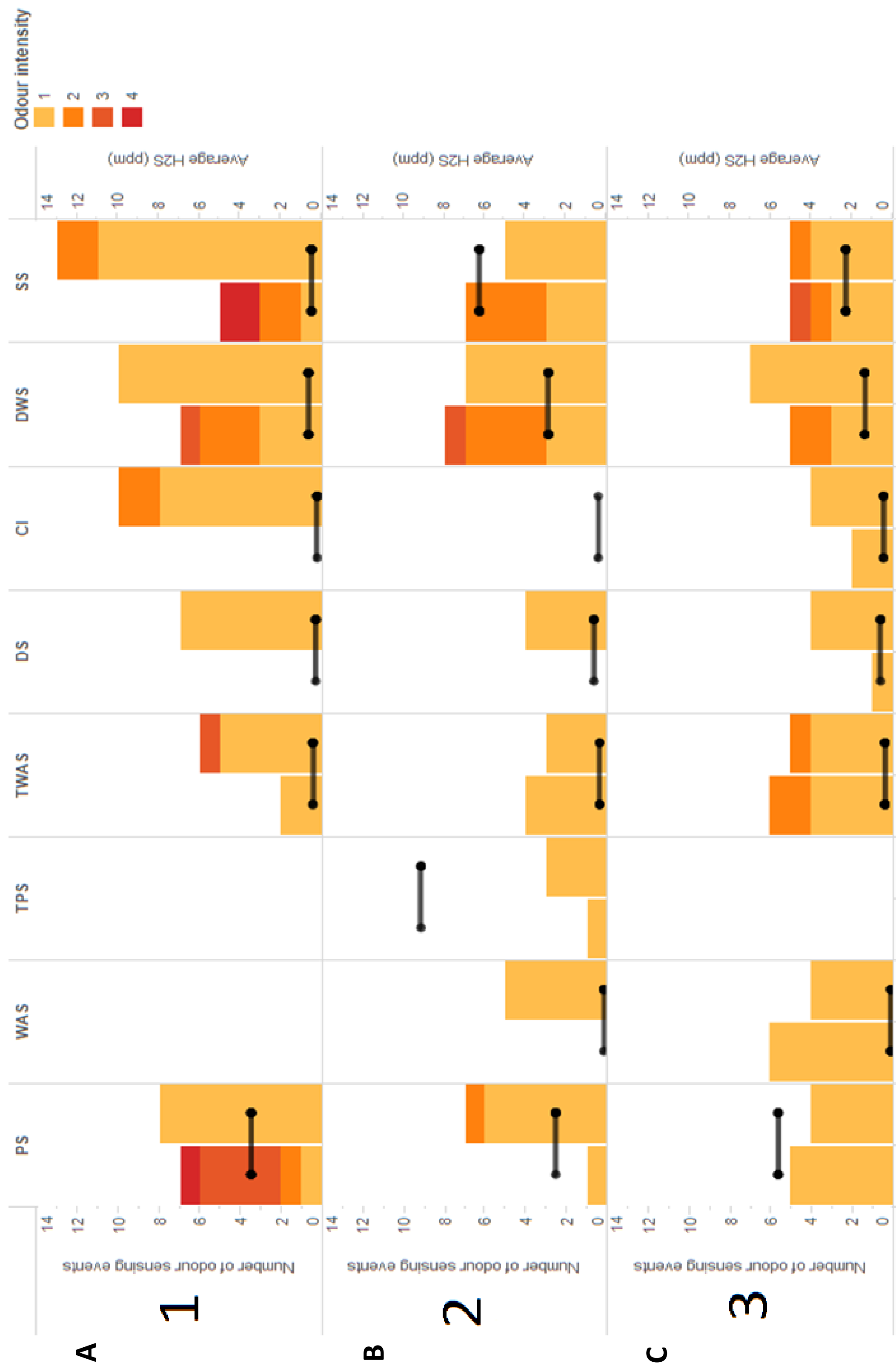

Figure 17. Total odour events and averaged H_2S for each Site's unit processes .Panels: (A) WWTP Site 1; (B) WWTP Site 2; (C) WWTP Site 3

Table 8. Correlation between H_2S levels, ASP, HSP, and Total

Site	ASP	HSP	Total
1	**r_s= 0.971, *p*= 0.001**	r_s= 0.029, *p*= 0.957	r_s= 0.600, *p*= 0.208
2	r_s= 0.528, *p*= 0.179	r_s= 0.206, *p*= 0.624	r_s= 0.287, *p* = 0.490
3	r_s= -0.371, *p*=0.413	r_s= 0.179, *p*= 0.701	r_s= -0.145, *p*= 0.756

Bold indicates significant *p*-value ($p<0.05$)

4.3.2 Identified odorants

As previously stated, matching chemical species with recorded odour events was low. However, by using the observations made by the panellists during specific retention times, we were able to add further odorant detections as well as clarify some previously identified odours that were likely masked (**Table 9**). This information was then used to determine the prevalence of particular odours. After odorants were appropriately identified, there were considerable differences between what was detected and described for ASP and HSP (**Table 9**).

Table 9. Variation of detection for priority odorants between ASP and HSP and descriptors

Family	**Compound**	**ASP Descriptor**	**HSP Descriptor**
Aromatic	m-Xylene	Piggery	
	p-Cresol	Urine, piggery	
	o-Cymene		Musty
	m-Cymene	Urine	Musty
	Benzene,1,2-dichloro-		Musty, garbage
	p-Xylene		Garbage
Alkane	Dodecane		Fishy/nutty
Terpinene	Terpinolene	Chemical	
Alkane	Cyclohexane,1,4-dimethyl-,cis-		Garbage
	Nonane		Rotten
Primary alcohol	1-Propanol	Sulfur	
Volatile Sulfur Compounds (VSC)	Sulfur dioxide		Garbage
	Dimethyl sulfide		Garbage
	Dimethyl disulfide		Burning
	Dimethyl trisulfide	Chemical, sulfur	Rotten, rotten vegetables

Figure 18 (next page) illustrates the relationship between odorant concentrations and their risk for detection for both panellists. Outliers with regards to both panellist identification as well as prevalence within the odour samples tested were removed.

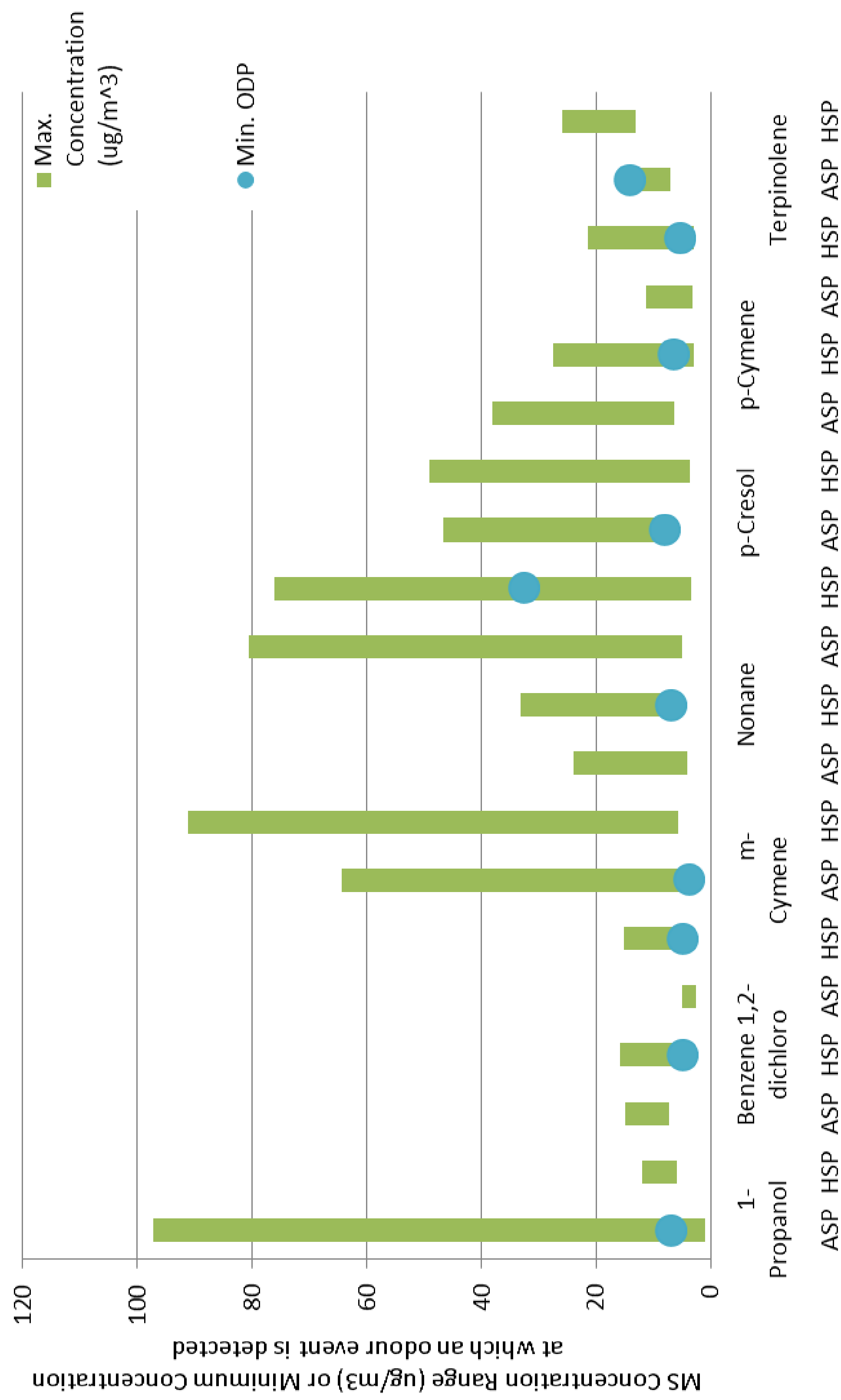

Figure 18. Concentrations and proportion of detections of odorants

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4.3.3 Priority odorants

Priority odorants were identified as being predominantly dimethyl trisulfide, as well as *p*-cresol, cymene, and dimethyl disulfide. Smaller but considerable odorants were benzaneethanamine, sulfur dioxide, toluene, nonane, and benzene 1,2-dichloro- (**Figure 18**). Priority odorants were also considered in the context of established literature where VSCs as well as *p*-cresol have been determined as particularly foul smelling, and subsequently have higher risk of odour impact (Sucker *et al.* 2001, Wood *et al.* 2001, Adams *et al.* 2003, Singh *et al.* 2008). While there were more GC-MS recordings of Dimethyl Disulfide (DMDS) compared to Dimethyl Trisulfide (DMTS), these were in smaller concentrations and garnered fewer responses from both panellists.

4.3.3.1 Priority unit processes

Focusing on these priority odorants, the most at-risk Site 2's Suspended Solids (SS) and Dewatered Sludge (DWS) measures consistently indicated very high levels of DMTS and comparatively smaller and lower frequency recordings sporadically at the other sites (**Figure 19**). Site 2's DWS and SS also had several recordings of *p*-Cresol, with smaller recordings at the Primary Sludge (PS), DWS, and SS of Site 1 and the Thickened Sludge (TS) and DWS of Site 3. Cymene differed from other priority odorants in that its highest concentrations were established at Site 1 and 3 DWS with some also present at Site 2 SS. Relative contributions of priority odorants were determined by their Odour Activity Value (**Figure 19**). Site 2's DWS and SS presents the most serious areas for unit process investigation.

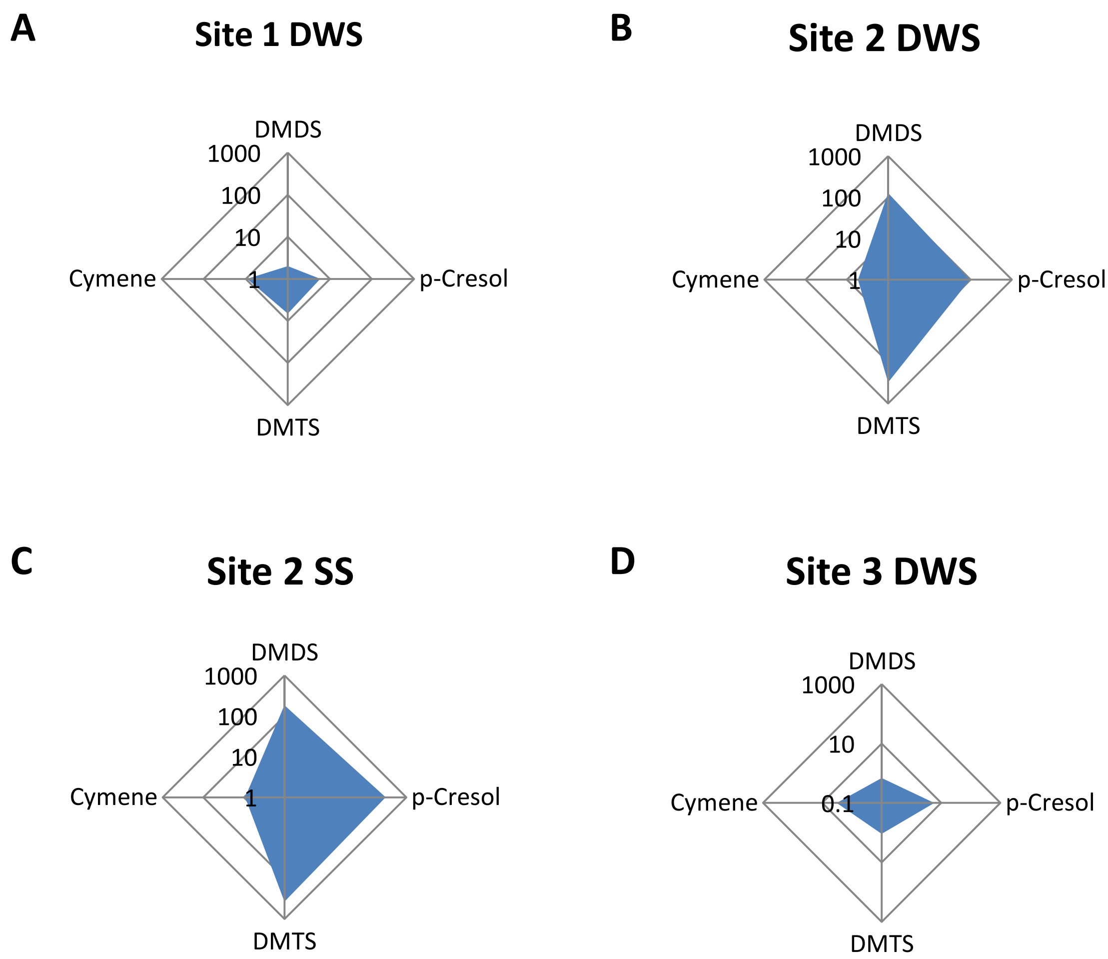

Figure 19. Relative Odour Activity Value (OAV) contribution of priority odorants. Panels: (A) OAV of Dewatered Sludge at Site 1; (B) OAV of Dewatered Sludge at Site 2; (C) OAV of Suspended Solids at Site 2; (A) OAV of Dewatered Sludge at Site 3.

4.4 Discussion

4.4.1 Comparison between ASP and HSP

Based on results obtained in this Chapter, we recommend differing solutions for the sites investigated. Site 3 consistently had many odours detected by HSP, a pattern that was similar for ASP except for Digested Sludge (DS) and Centrate Liquor (CL). Priority odorants were detected mostly at the DWS stage for all plants, which also had relatively high concentrations of H_2S. The comparison between ASP and HSP was crucial to understanding odour impact as some odours that qualified as priority, yet were not detected by the other panellist such as *p*-cresol.

This Chapter investigated the changes in response to environmental malodours of highly sensitive and average sensitive panellists. Overall, we found high variation between HSP and ASP panellists in the choices of odour descriptors, as well as number of recorded instances of odour perception. Despite this, the actual proportion of correct matches to the MS library were very similar between the two panellists. This may signify that panellists share a similar signal/response relationship when other factors, such as variation between human and MS sensitivity, are considered. Recording these relationships may signify suitability of panellists barring other methods of investigation. Of particular importance, this research illustrates the strong variation between panellists and identified odorants. ASP recorded multiple instances of *p*-cresol with a high consistency for odour description, yet this odorant was not detected by HSP. The understanding of this kind of disparity is crucial to improving the ecological validity of GC-MS/O; both of these odorants were sufficiently prevalent to be defined as priority despite their distinctness for detection for panellists.

Odorant characteristics were varied between both panellists and prior research. This supports the notion that there is a strong variation of odour qualities depending on the sensitivity of the recipient (Keller *et al.* 2007). Other reasons for the variation could include differences in odour strength between previous investigations and the concentrations experienced by the panellists (Burlingame *et al.* 2015). Between panellists it was noted that while there were discrepancies, both ASP and HSP converged on most priority odorants for both frequency of detection as well as intensity.

4.4.2 Evaluation of sites and unit processes

This Chapter revealed key focus areas for each of the three sites investigated. Perhaps unsurprisingly, the unit processes with the strongest odours were those that succeeded anaerobic digestion, and that the priority odorants were all identified as those with microbial origins.

Site 2 had very high H_2S concentrations for SS, DWS, and TPS, and as such interventions to reduce malodours should focus here. The prevalence of high levels of DMDS and DMTS indicate protein degradation within the stored sludge but with this information it is unclear as to why Site 2 would have significantly higher levels of VSCs compared to the other two sites (Munir *et al.* 2011). Pathways for the production of VSCs suggest that Site 2 has higher levels of methyl mercaptan which should be addressed in order to reduce the odour risk that the VSCs possess (Higgins *et al.* 2006).

p-Cresol at all sites encountered has both industrial and bacterial origins, and is most likely present due to the anaerobic processes which are implemented by these WWTPs (Singh *et al.* 2008). Similarly, cymene is a product of microbial action (Esmaeli *et al.* 2012). The odour impacts of Sites 1 and 3 are considerably lower and should not be highly prioritised for implementation of odour abatement strategies.

4.4.3 Identification of odorants

GC-MS/O is essential to establishing appropriate odour qualities. While H_2S remains an important measure for environmental malodour, this Chapter supports the hypothesis that it is not appropriate in low H_2S processes and it not a representative measure of odour impact within the wastewater process (Gostelow *et al.* 2000, Cheng *et al.* 2009). Furthermore, data presented in this Chapter also shows very little relationship between high H_2S and detected odour events which means that current over-reliance on H_2S detection misses critical aspects of the overall odour profile of a WWTP.

The research presented here demonstrates the considerable variation in both olfactory threshold (OT) and olfactory identification (OI) between panellists of high and average sensitivity. It should also be noted that ASP experienced odour events not detected by HSP. This suggests that the current standard of using *n*- butanol as a marker of overall olfactory performance is inadequate; alternatives or multiple odorant threshold testing could improve this situation (Hayes *et al.* 2012, Croy *et al*. 2009). The methodology proposed here can be useful for the management of odour complaints from members of the community. By developing a “high sensitivity” database, the identification of odours from likely high-complainant individuals can be considered more useful for malodour producers whose odours are at a near average threshold levels as opposed to voluminous emanations. This is particularly useful as these situations are often beyond the detection abilities of other monitoring systems, such as sensor arrays (Stuetz *et al.* 2000). The descriptors used here from both panellists also contributed to the construction of a WWTP Odour Wheel (**Figure 20**) (Fisher *et al.* 2017).

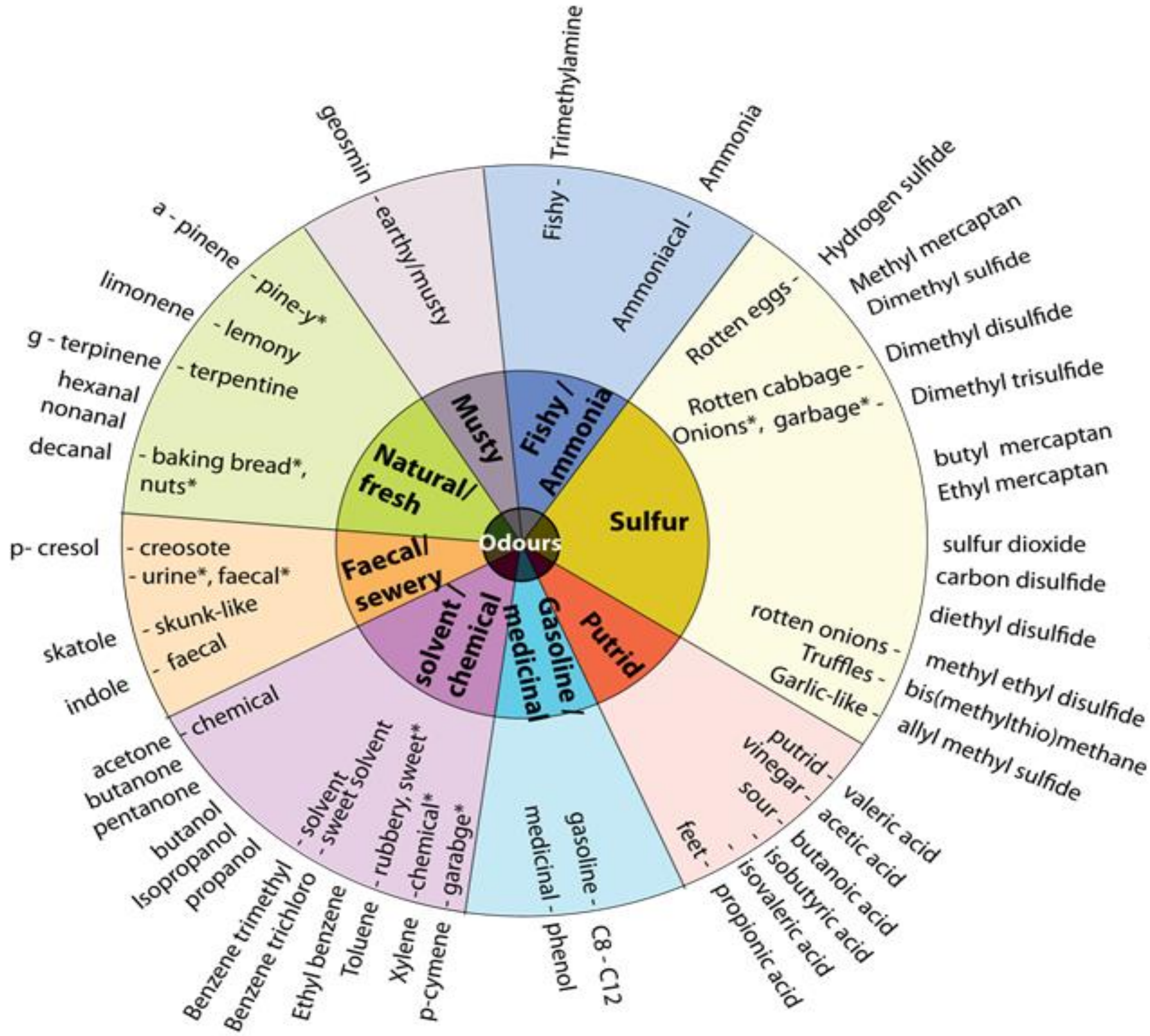

Figure 20. WWTP Odour Wheel, reproduced with permission from Fisher *et al* (2017). The research presented in this Chapter partially contributed to this Odour Wheel's design.

With all GC-MS/O research, there are some considerations to be made with regards to its implementation. The demands of sniffing a sample continuously for fifteen minutes has been debated in preceding investigations in relation to olfactory fatigue (Kristensen *et al.* 1953). While the panellists used in this experiment did not report any discomfort, it is possible that some contributing odorants were missed between sniffs. It should be noted however, that a natural sniff style is considered superior to any trained variants (Laing 1985). In addition, prior research has indicated that variations of response criteria between individuals is present in olfactory research as it is with all stimuli testing which current procedures do not control for (Fritjers 1980, Trabue *et al.* 2011). While some alternative methods in neuroscience studies may solve the problems of panellist response discrepancies, it is considerably too invasive and expensive for multitudinous testing that environmental odour assessment demands (Trabue *et al.* 2011, Lapid *et al.* 2013). As a result, the standard method of GC-MS/O measurement that was undertaken here represents current best practice. Finally, the human nose is still more sensitive than GC-MS technology. This means that non-identified odorants may either be lower than the detection of the GC-MS, or due to human error (Kleeberg *et al.* 2005, Muñoz *et al.* 2010). The relative paucity of library matches with odour events significantly reduced the available identified odorants for analysis. A future goal in this research area should involve the improvement of the sensitivity and lexicon of these analytical techniques.

This Chapter also highlighted that current measurement techniques in the environmental malodour space can be expanded. **Figure 17** and **Table 8** both indicated the disparity between reported odour events and the concentration of H_2S and as such illustrate two considerations. Firstly, these figures illustrate one of the shortcomings of GC-MS/O and its current inability to assess H_2S means that any assessment must be considered within that context. Conversely, these figures also show that current dependency on H_2S monitoring to determine odour impact is insufficient. **Figure 18** displays a novel way to determine odour risk. This Figure shows the levels of odorant concentration across the suite of odour samples, as well as the minimum odour concentration for either participant to detect the odorant. In this way, the figure shows that any concentration above the minimum detection level represents an odour risk for that participant. This technique offers a new perspective on the way in which priority odorants can be assessed (Bazemore 2005, Kleeberg *et al.* 2005, Tjandraatmadja *et al.* 2010, Parcsi *et al.* 2011). Future research into this area should aim to make this measure more sophisticated, by considering the frequency of detection above the minimum detection level, involving averages of the concentrations across the samples, as well as synergising these results with the odour qualities such as the odorant's annoyance.

Environmental assessments using GC-MS/O are conscripted mainly to chemical identification using the detection frequency methodology, however other measurement techniques in other investigations provide more information, such as dilution to threshold; which provides the contributions of specific chemicals to an odour(Hattori *et al.* 2003, Delahunty *et al.* 2006, Bader *et al.* 2009, Brattoli *et al.* 2013). Techniques such as AEDA and CharmAnalysis™ have the ability to produce complex OAVs, which are somewhat analogous to OUs that are commonly investigated in environmental research (Delahunty *et al.* 2006, Nuzzi *et al.* 2008, Brattoli *et al.* 2013). While OU represents the number of dilutions required for an odour sample to be at a threshold level, OAV is the impact of an odorant within a sample based on its concentration relative to its threshold level (Brattoli *et al.* 2013). Trabue and colleagues used OAV measurements to assess the contributions of different odorants to a cattle feedlot. These authors found that limitations of OAV included an over reliance on prior threshold values despite large variation of those values, as well as misrepresentation of low-concentration odours (Wright *et al.* 2005, Trabue *et al.* 2011). However, Trabue *et al.*'s research also shows that, with effective tools, OAV results can produce information that in some ways is more meaningful than frequency detection in that concentration of the odorants can be objectively compared (Delahunty *et al.* 2006, Trabue *et al.* 2011). By implementing OAV analysis more extensively, environmental odour research can mitigate or offer alternatives to olfactometer trials that would otherwise comprise an entirely separate research method (Muñoz *et al.* 2010).

The use of OAVs to determine odorant contribution, as well as various methodologies to calculate non-measurable but detected odour events, does much to overcome some of the limitations inherent to GC-MS. The use of OAVs is slowly increasing in environmental odour research, and while they differ somewhat to other disciplines, this research has indicated that OAVs can provide illustrative recommendations for priority areas (Rappert *et al.* 2005).

4.5 Summary

The potential for GC-MS/O technology can be broadened beyond what is currently standardised in order to produce meaningful information on the odour impacts experienced by communities. More research is required to better understand the variation of response for individual odour reports. Other disciplines that use GC-MS/O have incorporated methodologies such as OAVs that can be adopted for environmental odour analysis. Data presented in this Chapter contributed to the design of the updated Odour Wheel, as well as highlighting the importance of acknowledging variances in olfactory sensitivity to improve community engagement outcomes.

Chapter 5

Survey of Community Attitudes and Behaviour to Odours

Chapter 5. Survey of Community Attitudes and Behaviour to Odours

5.1 Introduction

As previously explored in **Chapter 2**, surveys comprise a large proportion of the investigative techniques to assess the impact of environmental malodour on communities. Within the context of this Thesis, the Community Survey presented in this Chapter provides both independent goals of investigation, as well as contributions to the Thesis as a whole. This survey design and analysis reconciles the varied approaches towards community surveys administered in prior literature, as well as providing information to improve future community engagement policies.

Surveys have been used extensively in environmental odour research. In this context, surveys are valuable as they allow for relatively detailed analysis of a multiple of factors (Dillman 1983, Sheatsley 1983, de Vaus 2002). Despite their value and fairly widespread use, there are very few established survey tools or methodologies; instead, investigation tend to source items from outside the field of research, or design new items (**Table 10**). Within the context of environmental odour investigations, the research space has trends relating to its focal points, sampling strategies, as well as measurement tools.

Table 10. Prior surveys in environmental odour literature

	Sampling method	**Sample type**	**Measure**	**Methodology**	**Conclusions**
Schiffman *et al*. 1995	Unspecified recruitment.	44 matched participants; persons living near hog farms versus control; Interviews	Mental health and wellbeing	Profile of Moods Questionnaire (POMS)	Odour exposed group had results that indicated significantly more tension, depression, anger, fatigue, confusion, as well as less vigour.
Dalton 1995	Recruitment through announcements in neighbour-hood.; Compen-sated $5 for 30 minutes of time.	92 participants from odour-exposed community; 102 from nearby unexposed community roughly matched; Interviews	Health and wellbeing, and odour tests	Environmental Survey, Health Symptom Survey, Olfactory Sensitivity Test, Environmental Odour Standard Test. All tests were designed for this survey.	Groups did not differ on olfactory threshold test. Odour exposed group reported “sewage” odours are more intense. With regards to health scores, odour exposed community reported environmental odours as more annoying, had more health issues, and had alterations in behaviour.
Steinheider *et al.* 1993	Unspecified recruitment.	Four German cities, with *n*= 400, 539, 400, and 200, respectively. Varying degrees of odour incursion for each city; Interviews	Health and relationship to annoyance and coping	Survey consisting of: coping list (akin to Cavalini 1991), questions pertaining to demographics, odour annoyance, socio-emotional and somatic effects, perceived health	Odour frequency is a good predictor of annoyance. One exception showed that age, perceived health, and coping type were better predictors than environmental stressors.

Table 10. Prior surveys in environmental odour literature *(continued)*

	Sampling method	**Sample type**	**Measure**	**Methodology**	**Conclusions**
Luginaah *et al*. 2002	Cross-sectional recruitment based on three socio-economic zones.	Two surveys, first conducted in 1992 (*n*=391) and second in 1997 (*n*=427); Telephone interview	Relationship between health, odour exposure, odour annoyance	Survey consisting of health questions, Psychosocial functioning (SF-36 Health Survey), odour exposure, and environmental factors	While odour exposure is a good predictor of annoyance, only a weak relationship between distance and health symptoms was found. It is suggested that odour exposure and annoyance are mediators of health complaints. These findings were generally supported by Elliot *et al*. 1999.
Cavalini 1994	Weighted random distribution sample of addresses.	Collection of surveys, totalling *n*=887; Mailed survey	Health and relationship to annoyance and coping	Odour annoyance, health complaints, socio-emotional effects of odour, health threat of odour, coping strategies, demographics	Odour exposure is the best predictor of odour annoyance, as is the perception that malodour is a health threat. Coping was not a good predictor. Air dispersion modelling provided a reasonable predictor of odour annoyance. These conclusions are in congruence with Cavalini *et al.* (1991).

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Table 10. Prior surveys in environmental odour literature *(continued)*

	Sampling method	**Sample type**	**Measure**	**Methodology**	**Conclusions**
Bullers 2005	Snowball sampling and flyers.; Each participant paid $7.50 for their time.	High exposure group *n*=48; control group *n*=34; Telephone interview.	Perceived control and its relationship to physical and mental wellbeing.	Pearlin's Mastery scale (to assess perceived control), CES-D depression scale, physical health symptoms, demographics	Residences closer to industrial hog farms have increases in physical health symptoms mostly relating to respiratory and sino-nasal health. In addition there is an increase in mental distress for closer residences. Perceived control does not seem to be a significant factor.
Cervinka *et al.* 2004	Four separate surveys invited every affected household to participate.	Number of households ranged between 132-307 per survey; with an average of 1.7 persons per household; Correspondence followed by mail survey.	Odour annoyance	All questions used within guidelines set out by the VDI 3883	The dose response relationship to odour abatement and annoyance is not clear, although reductions in malodour do cause a drop in odour annoyance. Other environmental stressors, such as noise, complicate the relationship.

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Table 10. Prior surveys in environmental odour literature *(continued)*

	Sampling method	**Sample type**	**Measure**	**Methodology**	**Conclusions**
Shusterman *et al*. 1991	Three separate studies that used a systematic house selection	Total of n=2040 respondents surveyed; Mail survey, interview, or phone interview.	Wellbeing, odour frequency, and “odour worry”.	Common health symptoms, questions relating to environmental worry, medical care utilisation, other health issues.	Strong correlation between odour frequency, poor health, and environmental worry. Suggests that odours serve as a sensory cue to invoke stress related illness.
Winneke *et al*. 2004	Six separate areas using random survey distribution. Areas were categorised as either “pleasant”, “neutral” or “unpleasant”.	Total of n= 1456 respondents.	Odour annoyance	Standardized questions regarding hedonic tone, presumably from the VDI 3883.	Odour frequency and hedonic tone were very good predictors of odour annoyance. The intensity of the odour was not a good predictor.

Surveys within the scope of environmental odour research can be broadly separated into three main categories with regards to their topic of focus. To begin with, a strong focal point of environmental odour research has been the investigations of health effects; typically associated with respiratory problems, but interestingly several studies have indicated a predilection for unrelated symptom reporting for odour-exposed individuals (Neutra *et al.* 1991, Winneke *et al.* 1996, Dalton *et al.* 1997b). While physical health symptoms are fairly well understood, the assessment of the mental effects of odour exposure is confusing and under-researched (Bullers 2005). One reason for this complication is that several measures, such as perceived control, depression, coping methods, and stress, are inter-related (Winneke *et al.* 1996, Yang *et al.* 2010). Taking into consideration that explanatory methods for malodour effects are not yet established, finding the appropriate explanation and suitable remedies remains a future goal of research (Neutra *et al.* 1991, Winneke *et al.* 1996). Surveys have also looked at the olfactory variation within odour-affected communities: this includes odour annoyance but also considerations regarding olfactory threshold, identification and other measures of olfactory ability (Sucker *et al.* 2009). This method of research is attempted in a variety of methods, of which surveying is a key component. Finally, prior research has focused on community behaviour wherein odour is a mediator of reactions (Kemp *et al.* 2012, Robinson *et al.* 2012). Understanding community behaviour within the context of environmental malodour is important within the perspective of industrial operations (Kemp *et al.* 2012, De Gisi *et al.* 2015). This research can vary from observing the relationship between community and industry, identifying what role odour plays in complaint making, what paths communities can take to address grievances, or assessing what factors elicit specific community behaviour compared to others (Elliott *et al.* 1999, Blumberg *et al.* 2001, Brown 2009, Rae *et al.* 2009, Sucker 2009, Robinson *et al.* 2012, McDevitt *et al.* 2013). These three focal points of olfactory survey research are evidently inter-related, and therefore comprehensive surveys are a desirable endeavour as they may help to establish the nature of this inter-relationship (Sucker *et al.* 2001).

Survey measurement tools are derived from the objectives of researcher. Evaluations for health effects have yet to be standardised although they most often rely on previously established survey tools (Elliott *et al.* 1999, Luginaah *et al.* 2000, Luginaah *et al.* 2002). An emphasis has been placed on developing tools that are quick to complete, given the nature and breadth of surveys required for most types of odour research (Dillman 1983). Odour evaluations are comparatively more effective, and are often based on other forms of olfactory research as well as several studies investing in training for community panellists that can involve an understanding of what types of odour they are exposed to, or how to fill out appropriate paperwork to log odour events (Verein Deutscher Ingenieure 1993, Cid-Montañés *et al.* 2008, Brancher *et al.* 2014). Due to the demands of training, this means that most odour studies are prohibited from large scale sampling. Tools to establish community behaviours are varied; often behavioural questions are paired with odour or health related inquiries to ascertain the effects of these factors (Evans *et al.* 1987a, Elliott *et al.* 1999, Donham *et al.* 2007).

Sampling strategies for environmental odour research has had a focus on the distance between residences and WWTPs (Neutra *et al.* 1991, Dalton *et al.* 1997a). There has been a variety of survey methods to select for specific candidates, including snowball sampling, poster recruitment, telephone calls, as well as cross-sectional designs (Dalton *et al.* 1997a, Luginaah *et al.* 2002, Cervinka *et al.* 2004, Bullers 2005). As previously mentioned, odour studies typically have small numbers of non-random participants, given the training that is typically required. Studies looking at health have varied, but overall have investigated trends of common health ailments across large numbers of community members (Cone *et al.* 1991, Neutra *et al.* 1991, Shusterman *et al.* 1991, Shusterman 1992). Community-mediation surveys often require an in-depth analysis, and as a result, there are often fewer respondents, and in some cases different approaches (*e.g.* qualitative research) are required (Bullers 2005, Wing *et al.* 2008).

Overall conclusions, due to the breath of research, as well as the lack of established tools, are difficult to confirm. Health effects of odours, the most commonly researched area, does tend to indicate that odour exposure based on frequency and annoyance, do cause a plethora of health effects including those which would be considered unrelated to odour exposure i.e. non-respiratory or sino-nasal (Neutra *et al.* 1991, Shusterman *et al.* 1991, Zarra *et al.* 2008). However, the mechanism by which these health effects manifest is highly contentious (Neutra *et al.* 1991). The effects of odour become even more confusing when mental wellbeing, and measures such as perceived control and coping, are considered (Cavalini *et al.* 1991, Steinheider *et al.* 1993, Bullers 2005). Odour-measurement centred surveys are somewhat more successful in that explanatory means are self-evident: bad odours are more annoying (Winneke *et al.* 1977, Perrin 1987, Miedema *et al.* 1988, Winneke *et al.* 2004). Further studies into the mediators of odour annoyance have provided some intriguing results. Cervinka and authors found that noise modulates annoyance of odours by lessening the effect of the odour itself, but also reducing the efficacy of odour abatement (Cervinka *et al.* 2004). Some studies have also noted that the frequency of the odours experienced, as opposed to their intensity, elicit stronger annoyance (Winneke *et al.* 2004, Sucker *et al.* 2008b). The multi-varied methods and aims of community behaviour research means that there is little in regards to consensus beyond the effects of odour and health and the likely reactions on the community (Knasko 1992, Dalton *et al.* 1997a, Luginaah *et al.* 2002).

Our survey presented in this Chapter will address some of the queries brought up by prior research by incorporating a comprehensive survey that will include measures relating to wellbeing, olfactory disturbance, as well as community behaviour.

5.2 Survey description

All materials were approved by University of New South Wales (UNSW) Ethics (project HC13621, **Appendix 1**). The Community Survey consisted of 31 questions and covered topics of health, mental health and wellbeing, community involvement, environmental odour perception, odour hedonic appraisal, industry appraisal and involvement, legislative beliefs, as well as demographic information (**Appendix 2**). Overall, the survey was estimated to take approximately fifteen to twenty minutes and summarily represent a fairly easy task (Moser *et al.* 1971). The questions were arranged in such a way that the true nature of the investigation was not immediately recognisable in order to elicit a more reliable response as opposed to making the survey an opportunity to vent frustrations which would skew results (Sucker *et al.* 2001). Each survey began with asking a participant to input their six digit code for the survey. This code was essential to entry into the prize draw, and assisted researchers in determining the approximate location of the participant. The six digit code was originally placed inside the envelope, but poor response rates, incorrectly filled surveys, and two phone calls all indicated that some participants were having difficulty finding the code paper. Subsequently, code papers were stapled to the front of the survey.

5.2.1 Questions 1 to 5: Health, and mental wellbeing.

Mental and physical health are perhaps the most often investigated issues when researching environmentally-sourced causes of discontent (Shusterman 1992, Shusterman 1999, Luginaah *et al.* 2000, Luginaah *et al.* 2002, Lowman *et al.* 2013). However, the application of health questions may also cause difficulty with regards to potentially enraging communities- a concern felt by industrial partners of the CRC project. As a result, health questions were heavily modified from past literature to fulfil the requirements of the industrial partners.

5.2.1.1 Question 1: "How fit do you feel for someone your age?"

Question 1 was a 5-point Likert scale that asked the participant with responses "A lot less fit", "a little less fit", "about average", "a little more fit", and "a lot more fit". This question was used to indicate the general wellbeing of the participant. The term "fit" replaced "healthy" during survey construction due to the concerns made by some industrial partners of the CRC who felt that this would raise concerns within the community.

5.2.1.2 Question 2: "In the last 4 weeks have you experienced any illness or symptom? Please describe."

Question 2 was a descriptive question that allowed for any entry. Health issues are a core component of the effect of environmental and particular health issues are brought about by odour exposure (Shusterman 1992, Schiffman *et al.* 2005, Rosenfeld *et al.* 2007). This question was designed to look at the variance of health related issues to exposed versus non-exposed participants, and whether this followed health trends found in prior research. This question was heavily modified following concerns from industry partners regarding the risk of causing disturbances within the community or "leading" participants. Originally this question was a multiple choice checklist that consisted of examples of health effects derived from prior research (Neutra *et al.* 1991, Dalton *et al.* 1997a, Sucker *et al.* 2004). After surveys were collected, this response was coded into multiple categories: none/miscellaneous, respiratory, arthritis, gastrointestinal, flu/cold, stroke, mental health, muscular, headache, injury, and gout.

5.2.1.3 Question 3: Perceived Control

Question 3 consisted of the short-form test of perceived control as designed by Pearlin *et al.* (Pearlin *et al.* 1978, Bullers 2005). These questions are coded 1 to 5 with higher scores indicating better perceived control (items 5 and 6 are reverse coded). Perceived control as a symptom or indicator of environmental odour exposure is controversial and under-researched and represents an individual's belief in their sphere of influence; poor perceived control can lead to anxiety and depression (Bullers 2005).

5.2.1.4 Question 4: Depression

Question 4 is the short-form Center for Epidemiologic Studies-Depression (CES-D) scale. Items are scaled from 0 to 3 then added together; therefore, relative higher scores indicate depression (Devins *et al.* 1985). Items 4, 8, 12, and 16 were reverse coded. Depression is a common complaint with regards to individuals suffering from environmental odour exposure, and may also form a relationship with perceived control as well as heightened potential to report health effects (Watson *et al.* 1989, Lowman *et al.* 2013).

5.2.1.5 Question 5: Major Life Changing Events

Question 5 consisted of the Holmes & Rahe checklist (Holmes *et al.* 1967). This question was included in order to monitor participants whose results from Questions 1-4 may be based on major, life changing events as opposed to effects caused by their environment.

5.2.2 Questions 6 to 10: Community Factors and Involvement

Community involvement has had a confusing effect on malodour experiences that needs further investigation (Neutra *et al.* 1991, Cervinka *et al.* 2004, Robinson *et al.* 2012). These questions were phrased to avoid any community outrage (Robinson *et al.* 2012).

5.2.2.1 Questions 6: "What things do you like about your neighbourhood?" and Question 7: "What things do you dislike about your neighbourhood?"

"Neighbourhood" was chosen over "community" so that participants were more likely to discuss concepts within a nearby vicinity of their home, as well as being more likely to discuss environmental factors, as opposed to concepts such as community beliefs or overarching trends of Sydney and so on(Jonsson 1974, de Vaus 2002). This question investigated whether community members had odour complaints with no prompting whatsoever(Sucker *et al.* 2004). After surveys were collected, responses were coded into multiple categories: closeness to beach, closeness to relatives, ambiance/environment, friendliness, lack of traffic, and miscellaneous.

5.2.2.2 Question 8: "Do you believe you have a more sensitive sense of smell than most?"

This question is derived from previous research that has determined it to be a useful indicator of an individual's likelihood of causing a complaint and have more severe reaction to environmental malodour (Mackay-Sim *et al.* 2006, Papo *et al.* 2006, Kärnekull *et al.* 2011). After surveys were collected, responses were coded into multiple categories: workload, difficulty parking, poor infrastructure, lack of amenities, traffic, environment complaints, noise, distance from services, unfriendliness, miscellaneous, and none.

5.2.2.3 Question 9: “Do you consider yourself to be a part of the community?”

This question was used to investigate whether the effect of community engagement has an effect on causing odour complaints as has been previously indicated (Robinson *et al.* 2012).

5.2.2.4 Question 10: “Are there noticeably bad smells or odours in the community that impact you in some way?”

This question forms the crux of determining whether the participant experiences environmental malodours. As a result, this question separates non-affected and affected community members. This question had further instructions for participants to skip Questions 11 to 16 if they did not experience odour complaints.

5.2.3 Question 11 to 16: Defining Environmental Malodour

Investigations regarding the qualities of environmental malodour have experienced difficulties with odour characterisation due to the inherent nature of olfaction. The most effective means of documenting odour events are probably odour log books, such as those explained in the GOAA (Sucker *et al.* 2008b). However, while log books are an effective means to measure odour, they do not account for factors that influence the effects that environmental malodours cause. In addition, in the context of a community wide survey, modifications are required. Firstly, to limit the burden on community members, questions about odour events need to be discussed as a trend, so that multiple reports can be avoided. Secondly, the odour questions need to be very easy to understand as all participants are untrained. Thirdly, there is a limit to the number and type of questions asked of a participant; the shorter the survey, the more likely it is to be completed (de Vaus 2002).

5.2.3.1 Question 11: "Where do these bad odours or smells come from? Please list, starting with the worst. Feel free to put up to a maximum of three sources. If you indicated "no" for the previous question, please proceed directly to question 17. Please start with the odour that you believe affects you most. If you do not know where a bad odour comes from, please state "don't know"."

Participants in this question had the ability to list three separate odour sources. These three odour sources were kept for a separate analysis throughout Questions 11 to 16.

5.2.3.2 Question 12: "What are the smells and odours most like? Please indicate what source the odour is from based on the previous question, and tick all the odour/smell types that apply. So for example, if on the previous question you put "petrol station" in the number 1 slot, tick the categories you feel the petrol station smells most like."

Question 12 was used to evaluate the types of odour that participants experienced. This question used a Tick All That Apply (TATA) methodology over a "short form" of the various Odour Wheels currently available (Burlingame *et al.* 2004, Rosenfeld *et al.* 2007, Snyder *et al.* 2013). The use of Odour Wheels requires some training, as a result only the most basic terms were chosen dependent on information accrued in **Chapter 4** and further collaborative analysis (Vandegrift 1988). There was an expectation that untrained participants would be able to determine the odour type in a simple sense, as a result we use descriptors only from the "inner" Odour Wheel that were the most broad based. In addition, terms that could be unfamiliar, such as "terpenes" and "sulfur" were removed.

The items included were: Offensive (rancid or sewer-like); Fishy; Chemical (like burnt plastic or petrol); Medicinal (like alcohol or disinfectant); Floral (like flowers or incense); Vegetable (like rotten cabbage or onion); and Fruity (like apples or citrus). In order to reduce items and remove any potentially confusing factors for untrained participants, the "earthy" term that is often used in Odour Wheels was left out as it was considered unlikely to cause complaint (Suffet *et al.* 2009).

5.2.3.3 Question 13: "What do you do when the odours affect you at home?"

This Question was used to evaluate the behavioural changes of participants when exposed to odours at home. This question consisted of several items, all of which could be ignored or selected as "only when I smell the bad odours" or "most of the time". The items were compiled from prior research and included: "not letting children play outdoors", "closing the windows", "stopping or not have barbecues or other outside social events", "stops me from walking around the neighbourhood", "stops me from hanging out laundry", "stops me from gardening", and "other" that had space for a separate description (Dalton *et al.* 1997a, Wing *et al.* 2008).

5.2.3.4 Question 14: "How often do you smell these bad smells and odours at home?"

This Question was included to assess the prevalence of the malodours and was constructed with the assistance of industry partners. For each selected odour, participants were asked indicate the frequency of experiencing them: Several times a day; At least once a day; At least once a week; At least once a month; and Once in a while.

5.2.3.5 Question 15: "How annoying are these smells and odours? Please tick a number 1-10 with 1 being "not annoying at all" and 10 being "unbearable"."

This Question used a standard annoyance scale to investigate the annoyance of each of the odours listed (Jonsson 1974, Nicell 1994, Henshaw *et al.* 2006).

5.2.3.6 Question 16: "How likely are you to take any of these actions in the future regarding these smells and odours?"

These items listed in Question 16 were compiled from the range of actions currently most used and available to communities to protest environmental malodours, and were considered important items to industrial partners. Each item was gauged on a 5-point Likert scale ranging from "very likely" to "very unlikely". These items were arranged randomly, but have are ranked in order of increasing severity: To sign a petition if presented with one; To contact your local council or other official; To complain to your local council or other official; To complain to the company you feel is responsible; and To help organise community action to tackle the issue.

5.2.4 Question 17 to 21: Opinions of industry

In order to obtain non-prompted responses from participants, the WWTPs in question were not mentioned within the survey. As an advantage, we were able to investigate the Community's understanding of what industrial practices were occurring. By investigating other industries through this survey, we were able to compare public opinions of wastewater treatment as opposed to other industries.

5.2.4.1 Question 17: "How odourous/bad smelling do you think these industrial sites are? Please indicate by ticking from 1 to 10, with 1 being "not at all offensive" and 10 being "unbearable to be around"."

This Question included items for intensive livestock farming, wastewater treatment, manufacturing, chemical processing, construction, waste management, agriculture, and compositing. Similar to Question 15, this question used a 10-point annoyance scale. This question was used to evaluate the perception of wastewater treatment malodour compared to other odour-causing industries.

5.2.4.2 Question 18: "Please state your nearest (i.e. local) industrial site that you know of and indicate what kind of industry it is."

This Question established the visibility of industrial sites including the nearby wastewater treatment areas. As previously mentioned, offered an opportunity for comparative analysis of wastewater treatment to other types of industry.

5.2.4.3 Question 19: "What is the industry type for this site?"

This Question qualified the participant's knowledge of the industry type experienced. The items available for selection were intensive livestock farming; wastewater management; manufacturing; chemical processing; construction; waste management; agriculture; compositing; and other (which included an ability to specify).

5.2.4.4 Question 20: "Please indicate the degree to which you agree or disagree to the following statements."

Question 20 consisted of 12 items on a 7-point Likert scale that ranged from "strongly agree" to "strongly disagree". These questions were centred on the participant's beliefs and attitudes towards the previously selected industrial site. These items were designed so as to comprise a tool for industrial evaluation by communities. These items were:

- I am satisfied with the procedures used to involve citizens in the local industrial sites' *decision making*
- Decisions about my local industry sites have been made in an *open way*
- I feel I am adequately informed about local industries and their risks
- Local industrial sites including the one I am most close to, are being managed well
- The local industrial site is an important part of the community
- The local industrial site is an important part of the region
- I am concerned by the local industrial site
- I feel that the local industrial site is causing a noticeable environmental impact
- I feel that the local industrial site is noticeably affecting my social life
- I feel that the industrial site is noticeably affecting my environment through its smell
- I am, overall, comfortable with the nearby industrial site
- I am worried about the nearby industrial site

5.2.4.5 Question 21: "Please answer true or false for the following questions. If you do not know the answer, please tick "don't know"."

These three items provided statements designed to evaluate the participant's knowledge of odour and legislation as a true/false qualifier. These items were:

- Odour can cause an environmental impact
- Current legislation sets defined limits on how much odour an industrial site can produce
- According to legislation, the environmental impact of odours posed by my local industrial site are very low

5.2.5 Question 22 to 31: Demographics

To date, there is a relative paucity of research into whether variance in demographics results in different behaviours when exposed to environmental malodour (Elliott *et al.* 1999, Dalton 2003, Bullers 2005). Most of the demographic information here was altered to reflect systems as used by industry partners. The placement of demographic questions was designed to improve survey completion (Roberson *et al.* 1990).

5.2.5.1 Question 22: "Please indicate your age category (in years)."

Age was designated through nine categories, ranging from under 20, up to 81 years and over.

5.2.5.2 Question 23: "What is your occupation?"

Occupation was a description box.

5.2.5.3 Question 24: "Please indicate your average household income (in dollar $ amount)"

This Question had nine selections in $10,000 increments, up to a maximum of $81,000+.

5.2.5.4 Question 25: "Please indicate how long you have lived in the local area."

This Question could be answered with the following options: Less than one year; Less than five years; Less than ten years; Over ten years and Whole life.

5.2.5.5 Question 26: "What is your highest level of education?"

This Question ranged from "no formal schooling" to "postgraduate degree". An "other" category with space for specification was included.

5.2.5.6 Question 27: "How many people live in your household?"

This Question was answerable up to a maximum of 8+ occupants.

5.2.5.7 Question 28: "Which of the following best describes your household?"

This Question included several items as used by industrial partners when assessing communities. These items included:

- Single person under 40 years
- Two or more single adults under 40 years sharing
- Couple under 40 with no children

- Family with children who are all or mainly under 12 years
- Family with children who are all or mainly aged 12-18 years
- Family with children who are mostly aged 19+ living at home
- Couple over 40 years
- Single person over 40 years
- Other (with room for specification)

5.2.5.8 Question 29: "Do you…"

This Question asked whether the participant owned, rented, or had some other arrangement with regards to their residence.

5.2.5.9 Question 30: "Are you…"

This Question pertained to the participant's gender.

5.2.5.10 Question 31: "Are you a member of any local community organisation(s)? If so, which ones?"

This Question, similar to Question 9, investigated whether individuals were active in their community. Slightly less than a complete A4 page was allocated for participants to list their community affiliations.

5.3 Survey Distribution

5.3.1 Survey Area Selection

The Sites were selected based on several criteria. First, it was important to investigate the variations and similarities in communities with high and low complaints. Secondly, these sites should have relatively similar environmental and socio-economic factors. Finally, the sites were considered with regards to confounding variables, such as other types of odour-causing industry or geography that could cause unusual odour spreads, with less complicated sites being favoured. With these variables in mind, we removed Sites 1 and 2 due to their close proximity with industrial sites. Site 3 was also removed from consideration as its number of complaints represented the median for the WWTPs we investigated. In addition, Site 6 and another additional site (not investigated in this Thesis) were removed from consideration as industrial partners considered the area “too risky” for survey investigations.

As a result, we selected Site 4 and Site 5 as the two independent variable sites. Site 4 provided a high number of complaints as well as no industrial barriers that would otherwise skew attribution of odorants. One potentially confounding variable was that at the 2-3km distance, there was several industry sites, including a shipping dock and paper mill. Comparatively, Site 5 received very few complaints until 2015 when a new residential site opened close to the WWTP. There are also industrial works relatively close (approximately 500 metres) in the form of a landfill station and disused refinery, but these were even further from the residential sites surveyed. Both sites carried odour risks pertaining to the coastline and mangroves, both of which are capable of producing strong and offensive odorants including sulfur (Sherman *et al.* 1998, Bandaranayake 2002).

In addition to the sites surveyed, a control site ("Control Suburb") was also needed for comparisons of survey results. A control site to establish baseline community results was selected in accordance with several conditions. Firstly, the location must be within the Sydney region and as a result, serviced by Sydney Water. Secondly, the control suburb must be geographically similar by being situated on a coastline and within similar commuting distances to Sydney's Central Business District compared to Sites 4 and 5. This site also must not have any industry sites within close proximity or any readily apparent environmental odour sources. Finally, and most importantly, the control site's Socio-Economic Indexes for Areas (SEIFA) score based on the 2011 Australian Census was within a standard deviation of the SEIFA scores for Sites 4 and 5, meaning that comparisons between sites were controlled with relation to socio-economic qualities (Australian Bureau of Statistics 2011).

5.3.2 Construction of the Survey

The paper version of the survey consists of 8 A3 80gsm pages folded into a 16-page A4 "saddle stitched" (*i.e.* two staples to create a spine) booklet. This survey booklet included a title section with the UNSW shield and then continued to the survey itself with the last page blank. All questions were stated in size 14 sans serif font, with sub-sections in size 12 font. The information/consent form was a double sided A4 80gsm colour page that included the UNSW logo. The code form was 1/3rd of an A4 page that included a code specific to the survey, as well as instructions on how to use the code. This code form, as well as the survey itself, provided an URL for the online version of the survey, available via https://www.surveymonkey.com/r/communityannoyancesunsw. The envelope that contained all materials was a C4 envelope with the UNSW logo. The envelopes were labelled with the address of the dwelling to improve participant confidence as to the legitimacy of its contents (Fox *et al.* 1988). A self-addressed C5 envelope was provided in the survey pack as a means by which to return the survey. Survey packs contained an information/consent form, a code form, an A5 stamped reply envelope, and the survey itself. The code form and the survey provided a website link to complete the survey online if the participant so wished. All survey materials were approved by UNSW Ethics code HC13621 (**Appendix 1**).

5.3.3 Random Allocation and Distribution of Surveys to Participants

The surveys were distributed using a stratified random distribution design (de Vaus 2002). In order to establish the limits of the effects of the WWTPs surveyed, the surrounding community was surveyed out to a radius of three kilometres as indicated by the complaint maps (discussed in **Chapter 3**) of the Sites.

The number of dwellings in locations within three kilometres of the WWTP was established by using several tools. Firstly, Google Maps (Google, accessed January 2015) provided an approximate guide for the number of dwellings within a set area, as well as providing the format for establishing distances in relation to the WWTPs. However, it was imperative to consider apartments and other areas wherein multiple dwellings existed on a single block of land (de Vaus 2002). To accomplish this, we used Land Zoning Maps for the suburbs in question, which were obtained from the websites of the respective councils. The Zoning Maps for Site 4 and the control suburb were able to provide accurate information with regards to the number of dwellings per apartment block, with a limited number of errors. Comparatively, while the Site 5 Land Zone Map did provide a rough idea of where the multiple-dwelling zones were, we had to travel to Site 5 and record the number of dwellings per multiple-dwelling complex.

The random selection of these dwellings was accomplished by adding up the number of dwellings within a given zone then using Python programming language (Repl.IT Cloud Coding Environment, Neoreason Inc) to randomly determine which dwellings would be surveyed (**Figure 21, Panel A**). Using the same counting method to determine the number of dwellings within a zone, the selected areas would be picked based on the random allocation of hits (**Figure 21**, **Panel B**). Owing to the variance between number of dwellings per zone, some zones were exhausted of dwellings before the thirty surveys could be distributed, whilst other zones had thousands of dwellings.

A

```
import random

items = [0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 1, 1, 1, 1, 1, 1, 1, 1,
1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1]

from random import shuffle
x = [[i] for i in items]
shuffle(x)

print x;
```

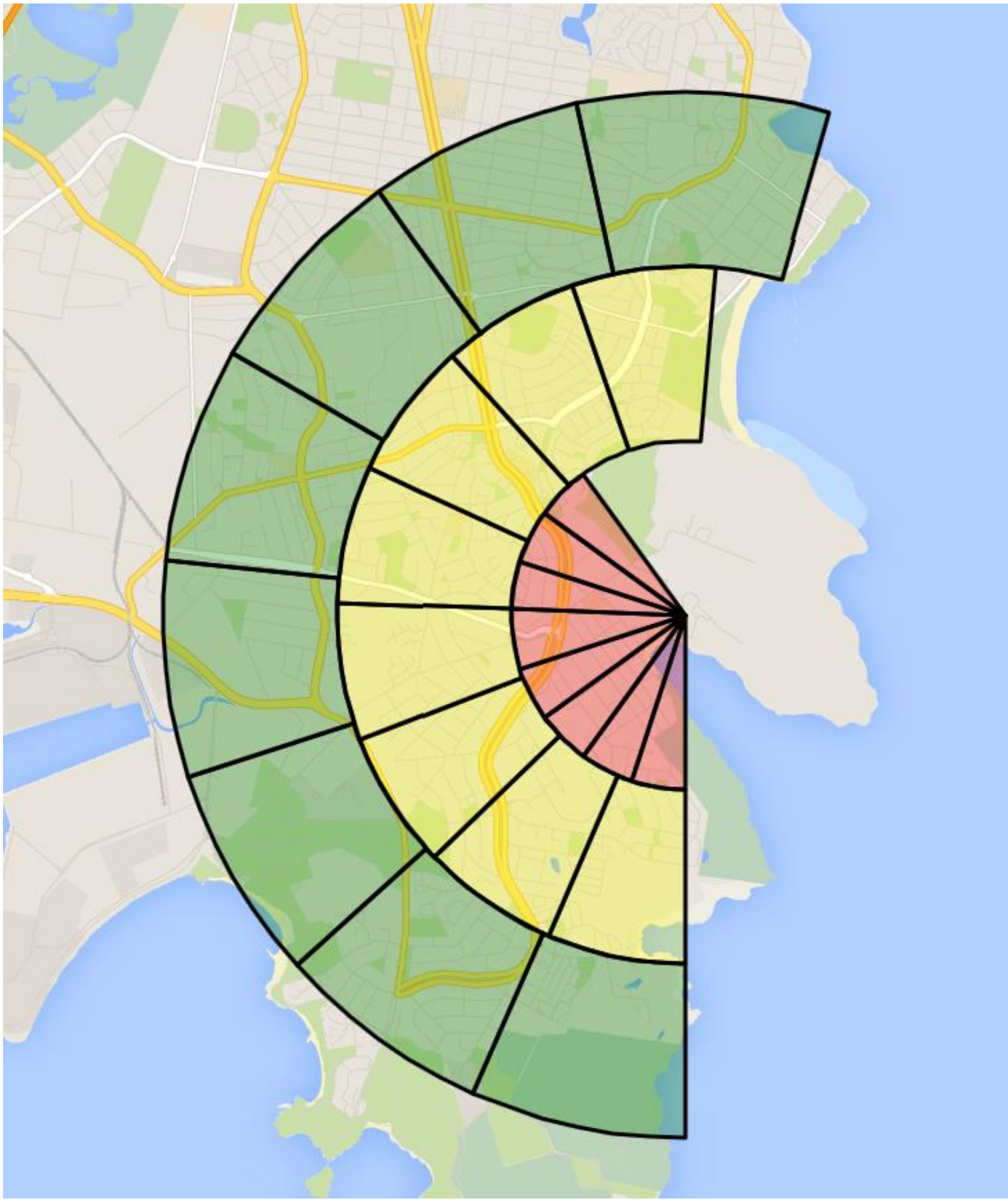
B

```
[[1], [1], [0], [1], [0], [0], [0], [0], [1], [0], [1], [0], [0], [0], [0],
[0], [0], [1], [0], [0], [0], [0], [0], [0], [1], [1], [1], [0], [0], [0],
[1], [0], [1], [0], [0], [0], [0], [0], [0], [0], [1], [0], [0], [0], [0],
[0], [0], [0], [0], [0], [0], [1], [0], [1], [1], [0], [1], [0], [0], [1],
[1], [1], [1], [0], [1], [1], [1], [0], [0], [1], [0], [1], [0], [0], [0],
[0], [0], [0], [0], [0], [1], [0], [1], [0], [0], [1], [0], [0], [1], [0],
[0], [1], [0]]
```

Figure 21. Programming for random distribution of surveys using Python language (Repl.IT compiler). Panels: (A) Example code for randomisation of dwellings surveyed and (B) Example code output (0 = dwelling not selected for survey, 1 = dwelling selected for survey)

All areas within the three kilometre survey zone were divided into three concentric rings (*i.e.* distances) defined by their distance from the WWTP (**Figure 22-23**). The closest ring was the area 0-1km from the WWTP, the second as 1-2 km range from the WWTP, and the furthest as 2-3km. These distances were each divided into eight equally sized zones within the area that was able to be surveyed. Areas within the sites unable to be surveyed such as ocean, national parks, and military installations were not included with these sections. To avoid confusion in statistical analysis, industrial and commercial places were excluded, with the sole sector of this survey being residential dwellings. The resulting 24 in total zones were each allotted 30 randomly distributed surveys and thus 720 surveys in total were delivered per site.

There were some error within both Google Maps and Land Zoning Tools with regards to address listings, apartment sizes, and in some instances, apartment numbering schemes (Moser *et al.* 1971). Occasionally, addresses were characterised as an unusual number, or there were more or less dwellings than those listed on a single block. Apartment numbers were occasionally challenging as they used unconventional list systems, such as stating floor numbers as opposed to the numerical number of the apartment. In addition, several addresses had been demolished, put up for sale, or otherwise rendered unable to be surveyed. In these instances, labels on the survey envelopes were amended to reflect the appropriate address, or the allocated survey was delivered to next appropriate address available. The main round of surveys was distributed either by post or by hand delivery in mid-2015.

3165 

3166 **Figure 22.** Site 4 survey distribution. The 0-1km range from the WWTP is indicated in red,
3167 the 1-2km range is indicated in yellow, and the 2-3km range in green.

3168

5.3.3.1 Site 5 Survey Distribution

The WWTP location at Site 5 necessitated altering the survey distribution plan (**Figure 23**). The inner 0-1km distance consisted purely of a new housing development with only 181 potential addresses. The close proximities of these houses made section divisions redundant and was so considered a single zone. In addition, the 1-2km range had a paucity of housing at the Eastern edges of the zone. To resolve this, the 1-2km range was instead divided into seven zones, with the seventh zone exhausted for potential survey recipients with 24 surveys distributed. Approximately 50% of the 2-3km zone was postal delivered due to the very large number of incorrect addresses requiring re-sending. An area North-East of Site 5 was considered for survey distribution given its residential status, but fell just outside the 3km range.

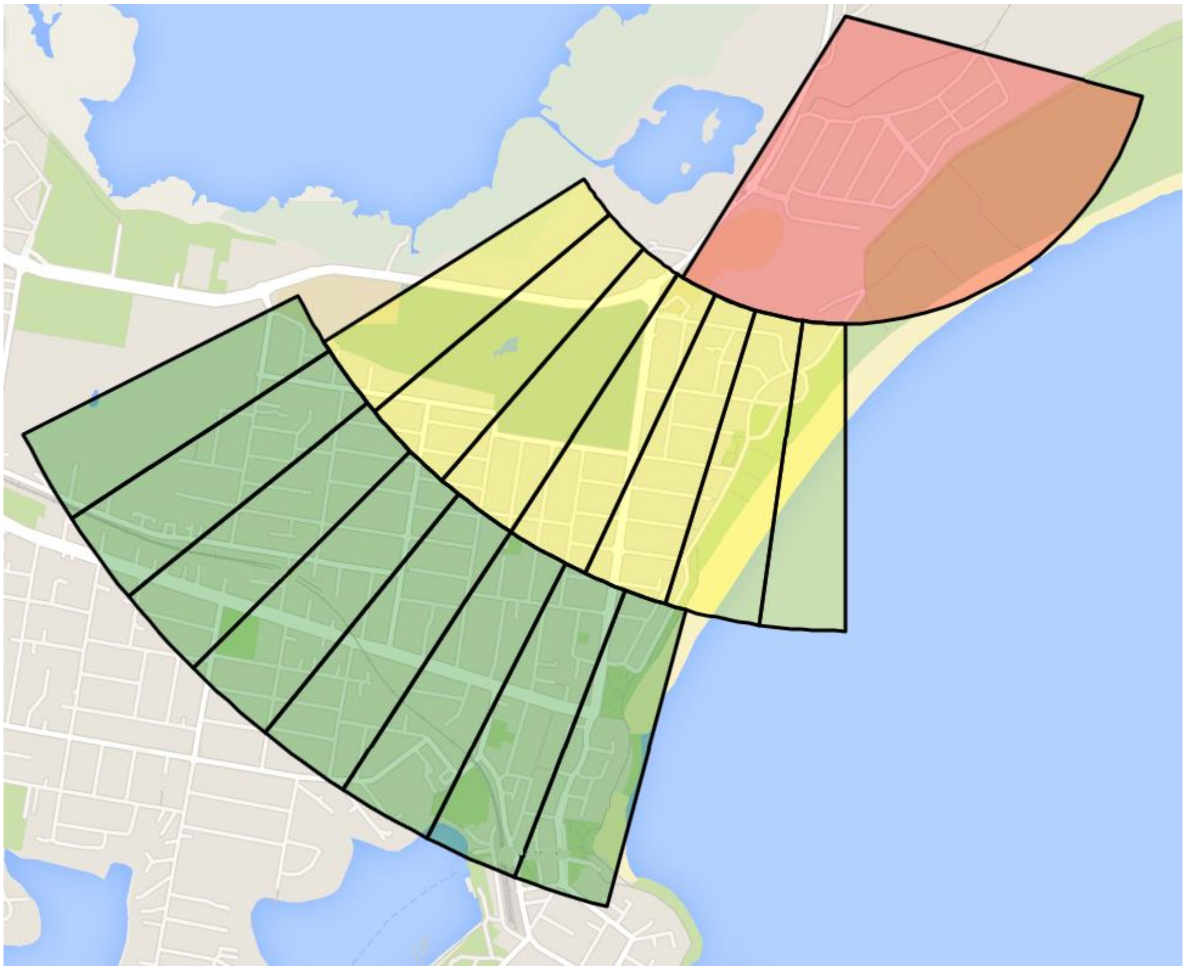


Figure 23. Site 5 survey distribution. The 0-1km range from the WWTP is indicated in red, the 1-2km range is indicated in yellow, and the 2-3km range in green.

5.3.3.2 Control Suburb survey distribution

The residential area in the Control Suburb was broadly distributed across the coast, meaning that there were many eligible dwellings in this survey zone (**Figure 24**). As there are no industry sites or WWTPs in the Control Suburb, a location in the centre of the coastline was selected for the focal point of distribution zones. The response rate for the control suburb was very poor, which indicated a lack of community interest in the survey. The majority of surveys in the Control Suburb were hand delivered.

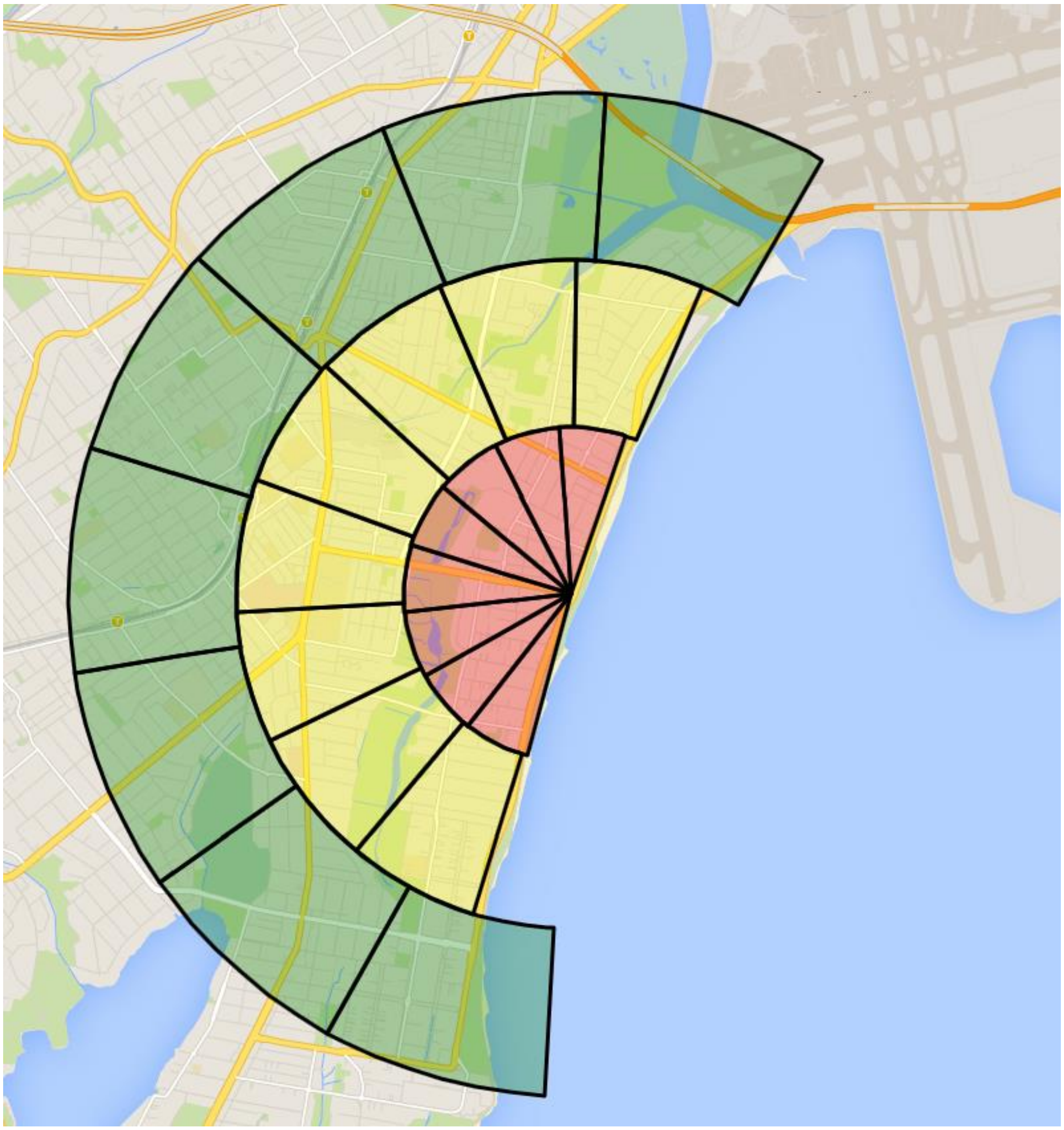


Figure 24. Control Suburb survey distribution. The 0-1km range from the centre of the coastline is indicated in red, the 1-2km range is indicated in yellow, and the 2-3km range in green.

5.3.4 Overall Survey Response Rate

Survey response rate varied between sites, as well as zones (**Table 11** **and 12**). Overall, return rates were fairly poor. The average response rate was 5.86%, which is not atypical for mail-delivered surveys or this kind of research (Moser *et al.* 1971, Marans 1987, Fox *et al.* 1988, Steinheider *et al.* 1993, de Vaus 2002). Both independent sites had a greater response rate in the 0-1 and 1-2 km distances (

Table 12). Comparatively, the control suburb had a comparatively lower response rate (3.61%). A possible explanation for this is that some residents in the Control Suburb considered this survey as a means by which to complain about nearby industrial sites.

Incentives and easier applications for Site 4 resulted in mild improvements to the return rate upon re-distribution of additional surveys. In **Table 11**, the original distribution is referred to as “Round 1”, whereas re-distribution (which included response incentivisation) is referred to as “Round 2”. The variance in response rate between sites and distances may be based on reporting bias (Neutra *et al.* 1991).

Table 11. Survey response rates by Sites and Rounds (Site 4 only)

Site	Number of Surveys	Response Rate (%)
Site 4 Round 1	720	6.52
Site 5	625	6.88
Control suburb	720	3.61
Site 4 Round 2	240	7.91
Total	2305	5.86

Table 12. Survey response rates by Distance (kilometres)

	Distance response rate (%)		
Site	**0-1 km**	**1-2 km**	**2-3 km**
4	7.5	7.5	5.6
5	7.7	7.8	6.25
Control	3.3	2.5	5.0

5.3.5 Incentivisation to Improve Response Rate at Site 4

The survey packages included several tools that improved response rates according to prior research. Firstly, participants were provided with a self-addressed return envelope to ease the rate of return (Moser *et al.* 1971). To assist with returns further, internet links provided the participants with a means by which to ignore posting entirely. Additionally, we indicated the purpose of the survey, and means by which for further information to be obtained; particulars that have been acknowledged to improve response rates (Moser *et al.* 1971).

The original survey distribution at Site 4 produced a response rate of 6.39% which was considered poor. To overcome this issue, further surveys for re-distribution included several changes. Firstly, the code number for the survey was stapled to the survey itself; this was in response to some calls that had difficulty finding the code slip within the envelope. Secondly, all further surveys included a “prize entry form” for 1 of 6 $50 Coles Myer gift cards to incentivise returns (Moser *et al.* 1971, Fox *et al.* 1988). The URL for the online version of the prize form was also provided on the entry form as well as the code form. The prize entry form required a code entry and contact details, thereby assuring survey completion to receive the prize.

5.3.5.1 Site 4 Re-distribution

To improve response rates from Site 4, an additional round of distribution included 10 additional surveys to be randomly delivered to each of the 24 zones (240 surveys in total, same zones as found in **Figure 22**). These supplementary surveys included prize entry forms as described in the previous section. With the exception of a small number of address alterations, all surveys in the first distribution round were delivered in mid-2015. The second round of distributions for Site 4 only occurred in January 2016.

5.4 Results

5.4.1 Sources of Environmental Malodour

Overall, the most odour observations to cause odour impact answered as part of Question 11 and 15 were attributed to the WWTPs; however, these odours were regarded as only average in annoyance when compared to other sources (**Figure 25 and Figure 26**). Other sources of complaints included passing trucks, sewers, and other industry.

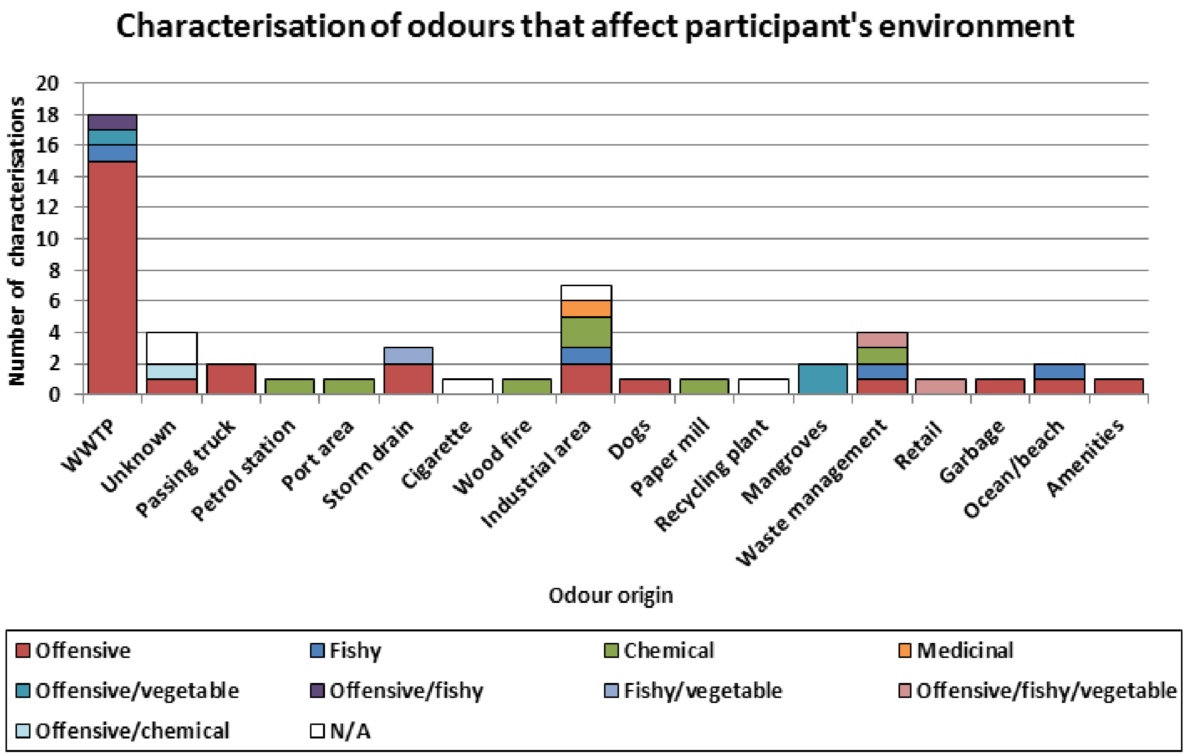


Figure 25. Characterisation of odours that affected participant's environment (answers to Question 11).

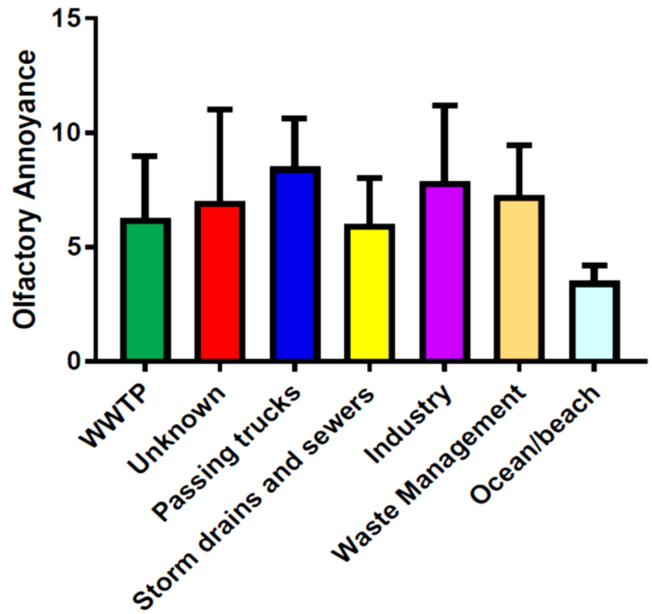


Figure 26. Average annoyance ratings of odours experienced by the community (answers to Question 11). Extraneous odour sources removed. Error bars represent Standard Deviation (SD).

The behaviours of the majority of WWTP odour impacted participants reported in answers from Question 13 varied between “most of the time” and “only when it smells” (**Figure 27 Panels A and B**). WWTP odour from all sites only impacted three participants to the degree that they changed behaviours the majority of the time. Comparatively, the modifications of behaviours for when the odours became apparent were very diverse.

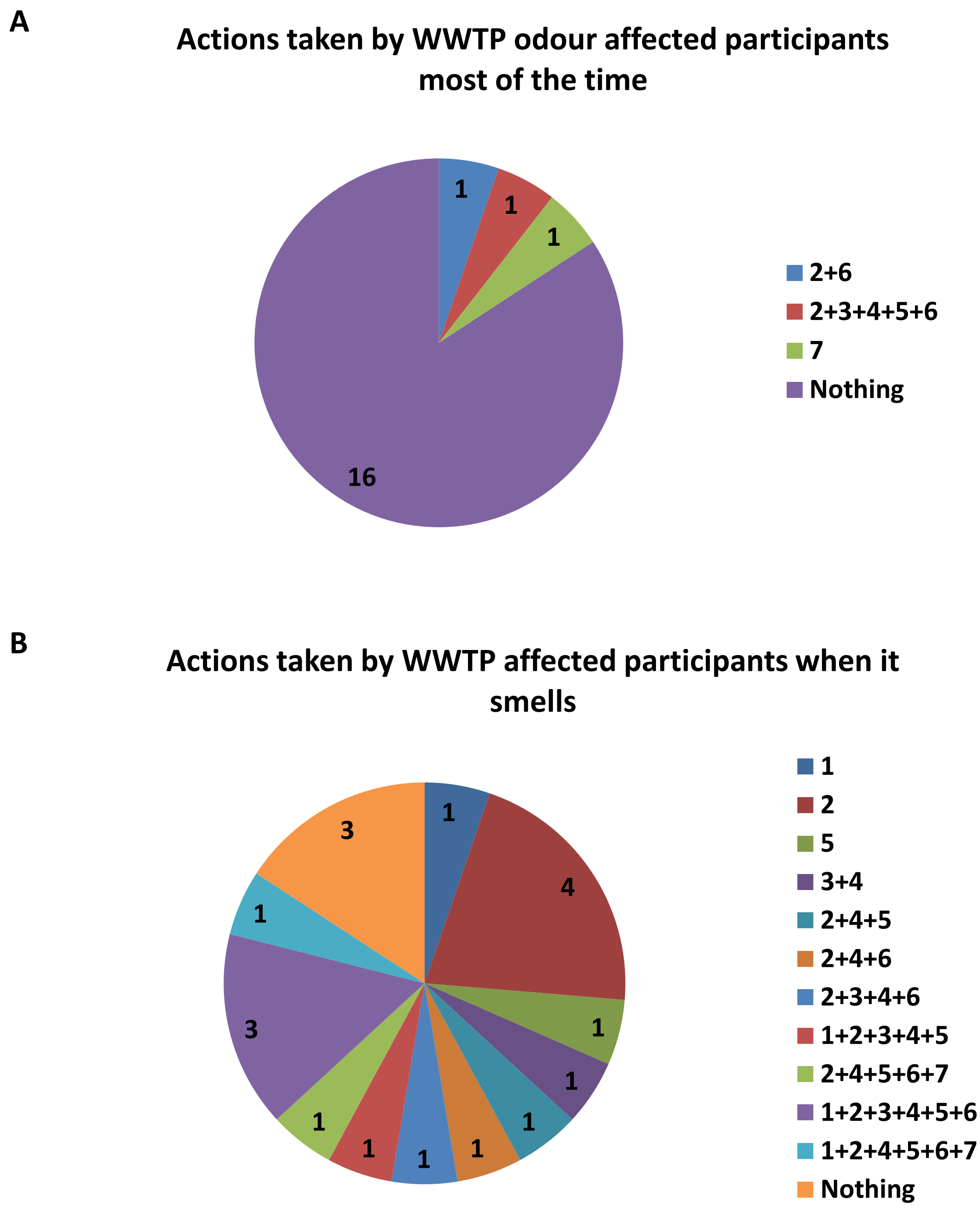


Figure 27. Actions taken by WWTP odour affected participants. Panel (A): "Most of the Time" answers for Question 13; Panel (B): "Only when it smells" answers for Question 13. Key for actions: 1= not letting children play outdoors, 2= closing windows, 3= stopping or not having barbecues or other social events, 4= stops me from walking around the neighbourhood, 5= stops me from hanging out laundry, 6= stops me from gardening, 7= other.

We did not find a significant difference in the number of complaints between the three survey areas [$\chi^2(2,N=140)= 4.430$, *p*= 0.109]. However, this was due partially to the effects of odour impact occurring only at the 0-1km distance for Site 4 and 5, with a weaker effect at the 1-2km and 2-3km for Site 4 (**Figure 28**, aspect of Question 11). When incorporating distances, a very significant relationship and effect with odour impact was discovered [$\chi^2(8,N=140)= 31.12$, *p*= <0.000, Cramer's *V*= 0.471].

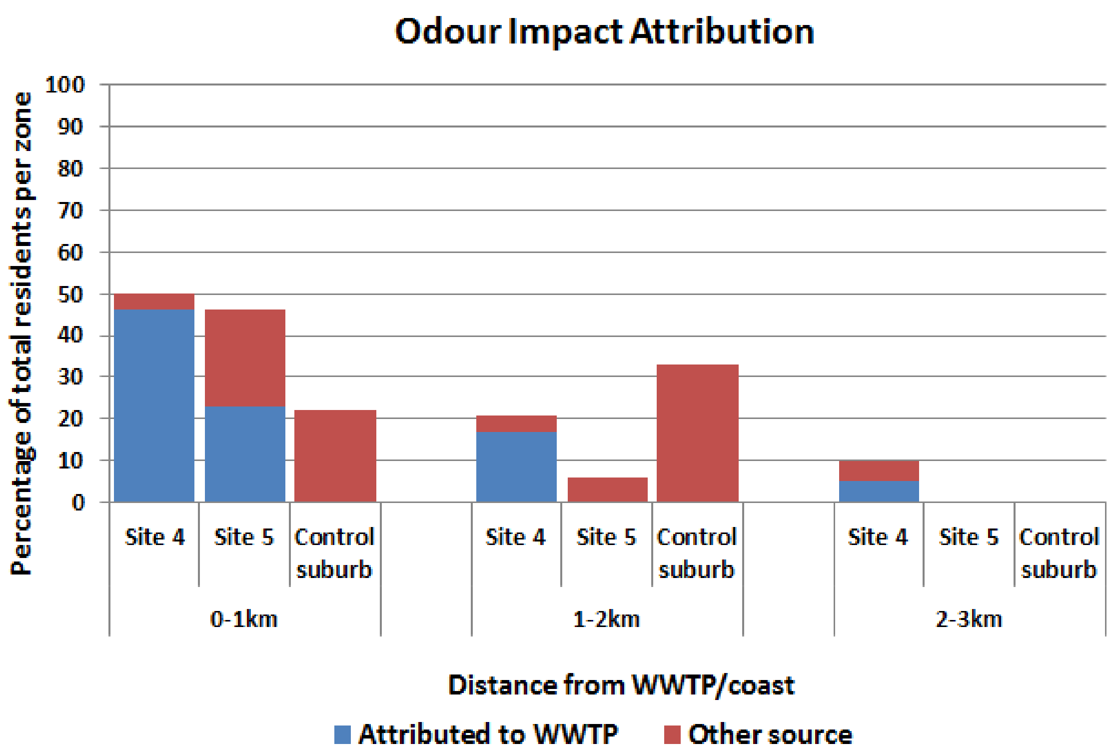


Figure 28. Proportion of Respondents Reporting an Odour Impact (answers to Question 11).

The number of complaints at Site 3 at 0-1km and 1-2km are proportionally high. However, the Control Suburb produced a low total response rate of *n*=26. As a result, we disregarded these odour events as indicative of endemic issues within the Control Suburb.

A series of Chi square tests were implemented in order to determine any relationships with reported odour impact. There were several factors that we found no relationship with odour impact (**Table 13**).

Table 13. Factors that have no relationship with odour impact

Factor	***df***	**N**	**Pearson' s Chi**	***P value***
Fitness	5	140	4.18	0.523
Wellbeing (coded)	10	140	7.26	0.701
Neighbourhood likes (coded)	8	140	10.97	0.204
Neighbourhood dislikes (coded)	12	140	16.89	0.154
Self-described olfactory sensitivity	1	140	0.346	0.556
Sense of belonging to community	1	140	0.829	0.363
Livestock odour annoyance	10	140	7.18	0.708
Manufacturing odour annoyance	10	140	9.67	0.470
Chemical processing odour annoyance	10	140	10.27	0.417
Construction odour annoyance	10	140	11.94	0.289
Waste management odour annoyance	10	140	10.98	0.359
Agriculture odour annoyance	10	140	14.45	0.153
Composting odour annoyance	10	140	15.81	0.105
Question: "I am satisfied with the procedures used to involve citizens in the local industrial site's *decision making*"*	6	131	8.51	0.203
Question: "Decisions about my local industry sites have been made in an *open way*"*	6	131	3.57	0.735

Table 13. Factors that have no relationship with odour impact *(continued)*

Factor	***df***	**N**	**Pearson’ s chi**	***P value***
Question: “I feel I am adequately informed about local industries and their risks”	7	131	4.24	0.751
Question: “Local industrial sites, including the one I am most close to, are being managed well”	7	131	11.73	0.110
Question: “The local industrial site is an important part of the community”*	7	131	3.69	0.815
Question: “The local industrial site is an important part of the region”*	6	131	11.49	0.074
Length of time spent in local area	4	137	1.87	0.759
Education level	7	140	11.38	0.123
Number of people in household	6	137	11.20	0.082
Household status	8	138	7.39	0.495
Gender	1	139	1.56	0.212

df = Degrees of Freedom; *Answered via a 7-point Likert scale

However, we did find significant relationships with other factors (**Table 14**, bold indicates $p<0.05$) and these were used to form the basis for a binary logistic regression analysis.

Table 14. Factors that relate to odour impact

Factor	*df*	N	Pearson' s chi	*P value*	Cramer's *V*
Wastewater odour annoyance	9	140	19.80	**0.019**	0.376
Question: "I am concerned by the local industrial site"*	6	131	13.68	**0.033**	0.323
Question: "I feel the local industrial site is causing a noticeable environmental impact"*	6	131	27.15	**0.000**	0.455
Question: "I feel the local industrial site is noticeably affecting my social life"*	6	131	23.64	**0.001**	0.425
Question: " I feel the industrial site is noticeably affecting my environment through its smell"*	6	131	40.96	**0.000**	0.559
Question: "I am, overall, comfortable with the nearby industrial site"*	6	131	14.51	**0.024**	0.333
Question: "I am worried about the nearby industrial site" *	6	131	14.01	**0.030**	0.327
Beliefs regarding local odour legislation	2	138	10.84	**0.004**	0.280
House ownership or lease	2	134	6.44	**0.040**	0.219

Bold indicates significance; *answered via a 7-point Likert scale

These responses provided intriguing avenues of investigation. Home ownership as opposed to renting predicted a significant increase in the likelihood to experience environmental odour impact. The remaining factors all showed that negative appraisals of WWTPs and the nearby industrial sites increased the likelihood that that participant experienced environmental odour impact.

5.4.2 Perceived control and depression

Answered as part of Questions 3 and 4, perceived control was found to be not significantly related to reports of odour impact, [$F(1,135)=1.67$, $p= 0.198$, $\eta_p^2=0.012$]. Similarly, the relationship between depression and odour impact was not significant either [$F(1,135)=1.08$ $p=0.3$, $\eta_p^2=0.008$]. In order to control for any potential variables with regards to perceived control and depression, we included the Holmes *et al.* social readjustment scale as a covariate pertaining to major life changes, such as the loss of a spouse (Holmes *et al.* 1967). With this covariate included, perceived control was still not significant [$F(1,134)=2.79$, $p= 0.097$, $\eta_p^2=0.02$]. Comparatively, depression with the Holmes *et al.* checklist neared significance [$F(1,134)=3.16$, $p= 0.078$, $\eta_p^2=0.023$].

5.4.3 Odour frequency and annoyance

We investigated the effect of odour frequency and annoyance on sub-items for Question 16: "How likely are you to take any of these actions in the future regarding these smells and odours?" with regards to WWTPs. We removed some odour items that would skew results as they are not issues that councils or companies could effectively approach. These odour items were "unknown", "cigarettes", "dogs", "mangroves", "garbage", and "ocean/beach". We found some significant relationships between frequency, annoyance, and the sub items (**Table 15**, bold indicates $p<0.05$).

Table 15. The effect of odour frequency and odour annoyance on Question 16 sub-items

Question 16 sub-item	Odour frequency	Odour annoyance
To sign a petition if presented with one	$F(4,17)=1.11$, $p= 0.380$, $\eta_p^2=0.21$	$F(4,17)=2.48$, $p= 0.083$, $\eta_p^2=0.37$
To contact your local council or other official	$F(4,16)=0.794$, $p= 0.570$, $\eta_p^2=0.17$	$F(4,16)=1.10$, $p= 0.390$, $\eta_p^2=0.22$
To complain to your council or other official	$F(4,16)=3.43$, **$p= 0.025$**, $\eta_p^2=0.48$	$F(4,16)=2.59$, $p= 0.077$, $\eta_p^2=0.39$
To complain to the company you feel is responsible	$F(4,23)=1.56$, $p= 0.220$, $\eta_p^2=0.21$	$F(4,19)=2.21$, $p= 0.107$, $\eta_p^2=0.32$
To help organise community action to tackle the issue	$F(4,19)=1.09$, $p= 0.391$, $\eta_p^2=0.19$	$F(4,17)=3.13$, **$p= 0.042$**, $\eta_p^2=0.42$

Bold indicates significance

5.4.4 Binary logistic regression

Binary logistic regression was used to establish whether any items of the survey were independently predictive of a community member experiencing odour impact (**Table 16**). In order to streamline the analysis, we excluded distance as a factor as it is easily measured and assessed; the overwhelming influence of distance would reduce the usefulness of the binary logistic regression as distance is a factor that is most often a fixed assessment. Additionally, the measurement of distance is fully able to be used as its own separate influence on the capacity to influence odour impact.

Through the elimination of weaker but significant items, we produced the best model that included the annoyance assessment of wastewater, as well as the items “I am concerned by the local industrial site”, “I feel that the local industrial site is causing a noticeable environmental impact”, and “I feel that the industrial site is noticeably affecting my environment through its smell”.

Table 16. Observed and predictive frequencies for assessing odour impact

Classification Table*

Observed			Predicted: Smell impact No	Predicted: Smell impact Yes	Predicted: Percentage Correct
Step 1	Smell impact	No	97	4	96.0
		Yes	13	17	56.7
	Overall Percentage				87.0

* The cut-off value is 0.500

5.5 Discussion

In this Chapter, we designed a community survey that encapsulated the three main branches of survey investigation into environmental malodour: health, odour characterisation, and odour as a mediation of reaction. This survey was used in order to establish what factors were likely to cause odour impact, as well as defining how the impact manifested. We found a small group of items that could determine the likelihood of odour impact occurring with 87% certainty. Additionally, we found that WWTPs caused the most odour impacts, however their annoyance was average when compared to other sources.

WWTPs unsurprisingly elicited the most reports of odour affecting the participant's environment. While the annoyance of WWTPs was considered average compared to other sources, the frequency for WWTPs being reported outweighs any annoyance "advantage". The ratings of annoyance are in agreement with the changes in behaviour recorded- most participants will alter their behaviour only when particularly bad odours occur as opposed to most of the time. The characterisation of WWTP odour is indicative of untrained participants as they considered the odour offensive without further elaboration (Doty 1997).

We did not find any significant variation between wellbeing and the zones, distances, or reports of odour impact. This is in stark contrast to multiple studies that have found health effects at odour sites; however, Cavalini *et al*. found similar results (Cavalini *et al.* 1991, Shusterman 1992, Dalton *et al.* 1997a, Elliott *et al.* 1999, Köster 2002, Luginaah *et al.* 2002, Lowman *et al.* 2013). The difference of our results to previous literature may be due to two major factors. Taking cue from Robinson *et al.*, as well as Neutra and colleagues, we did not place responses relating to health and illness within the context of environmental odour, and as such generated a "non-alerted" response (Neutra *et al.* 1991, Robinson *et al.* 2012). This was an attempt to separate a perceived health impact from odour as opposed to a real one. It is reasonable to assume that this supports research conducted by Elliott *et al*. that finds cognitive reappraisal plays an significant role in determining health impacts of industrial sites (Elliott *et al.* 1993, Elliott *et al.* 1997, Elliott *et al.* 1999, Luginaah *et al.* 2000, Luginaah *et al.* 2002). A second factor to consider is that the communities we investigated had reasonably high socio-economic assessments as opposed to some prior research investigating poor communities (Dalton *et al.* 1997a, Wing *et al.* 2008). It is feasible that variations in socio-economics may explain variation in health symptom reporting.

We did not find perceived control or depression to be an indicator of odour impact, even when controlling for other life stressors. The lack of an effect on perceived control is in agreement with Bullers *et al.* (Bullers 2005). However, the reasons behind this are not understood considering that environmental malodour possesses the hallmarks for an effect on perceived control (Rotton 1983, Alloy *et al.* 1993). Nevertheless, data presented in this Chapter suggests that even if environmental odour does have an effect on perceived control, its effect is slight. Similarly to health effects, it is possible that the discrepancy of socio-economic factors between prior research and this investigation may explain the lack of an effect on depression (Cutrona *et al.* 2006).

In agreement with previous literature, we found that odour frequency and annoyance had some significant influence on odour impacted members and the types of action the individual undertakes (Sucker *et al.* 2008a, Sucker *et al.* 2008b). When odour frequency increased, participants were more likely to complain to their Council regarding odours. When odour annoyance increased, participants were more likely to assist in community action. Annoyance also produced effects nearing significance on complaining to Council and signing a petition to combat odour incursions. In relation to complaint management,

Chapter 6 and **Chapter 3** research showed that odour complaints originating from local Councils are poorly logged and that the industry could not be considered a reliable source to record community concern. The results of the Community Survey presented here indicate that better odour reporting from Council is an important step to assess community complaints. These findings also highlight the importance of odour qualities to assess community dissatisfaction as higher annoyance from malodour will result in particularly aggressive community response (Seeber *et al.* 2002, Both *et al.* 2004, Sucker *et al.* 2008b).

By investigating using logistic regression, we have determined the specific factors that elicit complaints. The factors involved were centred on attitudes, with the exception of home ownership status. This indicates that the perception of malodours is the predominant factor in determining the cause of environmental odour complaints. In other words, if participants experience odours, they will have a negative appraisal of the industrial site and vice versa. This supports the commonly held theory that odours are excellent elicitors of emotions, and incite concern (Berglund *et al.* 1987, Berglund *et al.* 1992a, Press *et al.* 2000).

We removed distance from our binary logistic regression for two reasons. Firstly, distance is an exceptionally powerful predictor that would overshadow the contributions that other factors made. Secondly, distance is a self-evident factor when considering the sources of environmental malodours, hence Plant Managers in **Chapter 6** consistently desiring established buffer zones around their plants (Hobbs *et al.* 2000, Sironi *et al.* 2010, Capelli *et al.* 2013b). What this particular measure can indicate is that for the WWTPs experienced, a 1km buffer zone would remove practically all serious odour grievances.

There are some considerations for future implementation. Improving future survey return rates could be accomplished by shortening the survey further. The survey itself should be distributed to a wide variety of communities in order to better encapsulate the modifications of community and how they relate to odour perceptions. Some concepts that neared significance, such as perceived control, should be better understood by the community context in which they are placed (Alloy *et al.* 1993). The survey itself has some avenues for improvement. Of note, improving odour characterisation for community members should be considered an important goal, as most often the term "offensive" can act as a catch-all for annoying malodours. This research encouraged us to improve the ways in which communities were asked to identify odours, and an improved version was provided in **Chapter 7**'s research. Coding at times proved difficult as odour impacts were reported coming from cigarettes and other material that should not be considered a focus of the industry environmental malodour research area. This could be improved by including a list of industry and non-industry options for malodour sources.

5.6 Summary

The research presented in this Chapter supports the hypothesis that community dissatisfaction is heavily modulated by the perception of odours in that their attitudes of their odour source influence how they feel about the odours themselves (Shusterman 1999). It also supports the notion that odour frequency and hedonics play a significant role in determining the degree of action the community is likely to undertake. We found that several previously explored factors such as wellbeing, depression, multiple demographic statuses, as well as perceived control, did not seem to affect or predict any odour impact.

Chapter 6

Investigation of non-community stakeholders

Chapter 6. Investigation of Non-Community Stakeholders

6.1 Introduction

Previous Chapters have investigated the effects of environmental malodour within the community as well as the ways in which the water industry manages odour concerns. To bridge the gap between the investigation of community stakeholders and industry practices, this chapter is concerned with the evaluation of industry stakeholders. Non-community stakeholders modulate the environment and industry to which the community is exposed to, and as a result are important avenues of investigation in their own right (Covello *et al.* 1988, Sandman *et al.* 1993, Elliott *et al.* 1999, Lockie *et al.* 2008, Kobayashi *et al.* 2014). Of note, prior research as well as previous Chapters has suggested that communication in addressing environmental malodour represents extraordinary value, which requires that every part of the industry-community communication system be investigated (Chess *et al.* 1992, Syme *et al.* 2007, Sucker 2009).

With regards to investigating stakeholders, prior studies into the environmental malodour space have been almost entirely concerned with the assessment of community members. Non-community stakeholders, *i.e.* staff and regulators, when they are considered, are investigated within the context of communication with residents, data extraction, or decision making (Longhurst *et al.* 2004, Dorfman *et al.* 2010, Robinson *et al.* 2012). This represents a knowledge gap when considering an identified need for all stakeholder involvement and an onus on stakeholder communication (Kim *et al.* 2003, Longhurst *et al.* 2004, Robinson *et al.* 2012, De Gisi *et al.* 2015). Very little attention has been paid to beliefs, attitudes, and actions of other stakeholders, such as members of industry, when compared to members of communities. This Chapter aims to accommodate non-community stakeholders who interact with the environmental malodour field. This component of research endeavours to address the rigidity of research paths identified in the Literature Review by establishing new potential sources of information for malodour amelioration, as well as investigating communities indirectly via other stakeholders.

To date, non-community stakeholders are comparatively under researched, therefore the work presented in this Chapter is exploratory in nature. By using qualitative research methods, we have attempted to encapsulate as much information as possible regarding the interaction between these stakeholders and community (Creswell 1994, de Vaus 2002, Brown 2003, Schauberger *et al.* 2006, Doria Mde *et al.* 2009). This has included conducting semi-structured Plant Manager (PM) interviews of the six WWTPs in focus for this project; an online survey for members of the water industry; holding workshops for academics, as well as conducting informal interviews with a variety of biosolids land application stakeholders. The key findings in this Chapter include a lack of communicative structures for industry members which has led to an absence of standardised engagement methods; development of a set of recommendations for community engagement by research stakeholders, as well as further understanding the dynamic relationship structure that must be responded to in order to improve biosolids uptake.

This Chapter consists of four sections. Firstly, we conducted a series of interviews with the Plant Managers of the six WWTPs of investigation. Secondly, we designed an industry survey that was distributed to water industry personnel and some broader industry personnel. This industry survey focused on attitudes relating to their company and community engagement. Finally, we conducted a series of sub-studies on land application interviews, as well as odour tests on stakeholders (**Appendix 3**).

6.2 Plant Manager Interviews

6.2.1 Introduction

While it is reasonable to state that intense, persistent, and unpleasant odours garner the most negative reactions, there is still little understanding of why one community member may complain while a neighbour will not (Cavalini *et al.* 1991). In order to determine how communities and their members react to environmental malodour, multiple frameworks have been suggested. In particular, factors relating to environment interaction, as well as psychological response have been proposed as the most salient contributors by a variety of research groups and legislation (Zimmerman *et al.* 1988, Winneke *et al.* 1992, Shusterman 1999, Shusterman 2001, Sucker *et al.* 2001, Both *et al.* 2004, Cervinka *et al.* 2004). For either framework, the duty of PM is a crucial role that provides communication and problem solving components of the industry at a local level (Covello *et al.* 1988, Pagell *et al.* 2009). PMs are at the forefront of community engagement for their industry; however, this role is sophisticated owing to the variety of stakeholders, including the company itself, that the PM must consider (Kassinis *et al.* 2006, Pagell *et al.* 2009).

Successful community relationships with WWTPs can be difficult to define. Perhaps the most accessible measure is by defining the number and severity of complaints (Kaye *et al.* 2000). This is because complaint handling has legislative ramifications, therefore meeting complaint expectations is a sunk cost and complaint levels are also readily definable (Australia/Standards New Zealand Committee QR-015 Complaint Handling 2014). But should this be the only way community engagement should be considered a success? As previously discussed in **Chapter 3**, complaint levels are often poor measures of a Community's satisfaction (Robinson *et al.* 2012). Of concern, complaint minimisation is often seen as a goal within itself, as opposed to fixing the cause of complaints (Longhurst *et al.* 2004). Even if complaint reduction sits as the determinant factor for community engagement, a guide or appraisal of the various methods of complaint reduction strategies has not been established within the Australian context. Despite a lack of community engagement policies, PMs have had increasing expectations on their roles as industry diplomats, consequently their attempts at these roles require examination (Covello *et al.* 1988).

Increasingly, Industry PMs have an expectation not only for garnering revenue, but also to manage the sustainability and environmental impact of their plant, as well as addressing community issues (Covello *et al.* 1988, Gunningham *et al.* 2004, Kassinis *et al.* 2006). In relation to odour management, this trend is evident through several means including via the Community, local government, as well as the industry itself (Gunningham *et al.* 2004). PMs are often the first point of contact and almost always the first responders with regards to local community and government derived odour issues (Covello *et al.* 1988, Elliott *et al.* 1999). They also often represent the communicative link between the local plant and their company and industry as a whole. As decision makers, their choices on odour abatement practices around the WWTP, as well as their engagement strategies and knowledge regarding community, other sectors of the industry, and government have enormous influence on community-government-industry relationships (Covello *et al.* 1988). Despite this, understanding practices, knowledge, and attitudes of PMs remains under researched.

Research undertaken as part of this Chapter will identify and classify the methods currently undertaken by PMs, as well as the themes that influence them. Interviews of WWTP PMs, alongside the Water Industry Survey we have developed, provided an unique insight into the culture, attitudes, and behaviors of the water industry and how these traits influenced their relationship with the community. By understanding the methods used by plant managers, the ways in which academic understanding is produced can be undertaken. Over the course of these interviews, pertinent themes were identified using well-established research practices. We found that the group of PMs interviewed shared similarities as well as contrasts with each other, and that these variances indicated not only is there a poor communicative understanding between WWTP, but also that Best Practice has not yet been established. Overall, we found that the most pertinent issues surrounding PM practices were gaps in product knowledge, lack of WWTP to WWTP communication, and variability as to the quality of relationships with upper management.

6.2.2 Methods

This part of the research constituted a qualitative study of seven current WWTP PMs within the New South Wales area. The goals of this research were to:

- Establish the ways by which the respective WWTPs interact with their local community.
- Discern interaction styles that indicate more successful approaches.
- Assess the attitudes and beliefs of plant managers with regards to their community, industry, and government.

6.2.2.1 Interview Sample

PM interviews were conducted for the six plants as outlined in **Chapter 2** which represent broad variation of sites in relation to size, location, and complaint levels. Plant managers were designated as "PM" followed by their corresponding site number (*e.g.* PM1 is plant manager of WWTP1). Seven PM interviews were undertaken as PM4 had resigned during the course of the project and was subsequently replaced by PM7. All interviews were carried out onsite at a room of the PM's choosing- these all comprised of rooms typically used for group meetings.

6.2.2.2 Interview Approach

These interviews were semi-structured around six questions. Information regarding complaints and management were asked in order to establish PM behavior and attitudes and also to ascertain what measures were in place to manage complaints and reduce odour. This was due to the relative difficulty in establishing procedures through other means of information gathering.

<u>"How long have you worked in your current position?"</u>

This question was used to determine the PM's familiarity with their WWTP in order to determine whether the following questions were reasonable to ask the PM. We also investigated whether the length of current position employment dictated any attitudes towards the community or WWTP.

<u>"What have been your prior interactions with the community?"</u>

This question was used to establish the history of community engagement and the PM's attitudes and beliefs regarding the engagement.

"How are you made aware of complaints?"

Complaint information transmission is currently unknown within the water companies we investigated, and several sources are possible; upper management, local government, and the community itself. By considering the entirety of the complaint process, we endeavoured to investigate the underlying mechanisms and behaviour of the industry.

"Do you feel that community complaints are valid?"

This question was centered on PMs attitudes regarding their surrounding communities and whether this had any perceived effects on the relationship of the industry with the respective surrounding communities.

"What future projects are being undertaken regarding the community?"

This question investigated what current trends with community interaction are being undertaken.

"What is the quality of biosolids produced at this plant?"

Increased use of biosolids is a core focus of the CRC for Low Carbon Living and so we included it as a topic of inquiry. It appears, due in part to biosolids transport being handled by a third party, that knowledge of the biosolids product by PMs is low. We decided to investigate this further as biosolids processing and application represents a large odour risk (Crites 2000, McFarland 2001, Murthy *et al.* 2006).

A case study methodology was established using standard resources which involved exploring topics of investigation until information of the topic was exhausted (Mays *et al.* 1974, Williamson *et al.* 1982, Tellis 1997, Babbie 2001, Braun *et al.* 2006). Any topics and themes brought up by these questions would be inquired until sufficient information had been established (Williamson *et al.* 1982, Meyer 2001). Coding text was similarly standard, and provided a framework for which to establish themes (Babbie 2001, Meyer 2001, Braun *et al.* 2006).

6.2.2.3 Establishing themes and categories

Malodour amelioration processes were organised into seven categories: communication; engagement; exposure reduction; odour control; odour monitoring; management and other. Communication was defined as one-way communication with local community or government. This category includes practices such as newsletters, flyers, or advertisements. Engagement represented two-way communication with local Community or government, which could allow for some kind of feedback process; examples include community meetings or odour reports. Exposure reduction represented any action that limited odour exposure to the community that did not contain or process odours such as biosolids transport at non-peak times. This is contrast to odour control that involved any attempt to scrub or contains odours. Odour monitoring was defined as any practice that measured odour levels. The management category was regarded as any “in-house” design that improved community relationships through actions such as personnel training. Finally, the other category involved anything not covered by the previous categories.

Using standard qualitative review procedures, we identified themes regarding community engagement and grouped them into overarching articles (Babbie 2001, Bazeley 2009). These themes were then discussed not only through information obtained through the PM interviews, but also in the context of information obtained throughout the project.

6.2.3 Results

We found a plurality of exercises carried out by PMs and the WWTPs overall (**Table 17**).

Table 17. Actions undertaken by WWTP sites to reduce odour complaints and improve community relations.

Site	Number of complaints 2004-2014	Type of action	Action
1	26	Engagement	Frequent meetings with local council
			Host community and volunteer groups
		Exposure reduction	Communicated concern regarding buffer zone reduction
		Odour control	3 biofilters and chemical scrubbers
2	22	Communication	Host open days
		Engagement	Customer log books
			Establish “complaint cycle” for community and customers
		Exposure reduction	Dedicated truck route
		Odour Control	Sludge hoppers
			Contained building for outloading to odour scrubber
			Cover up sedimentation tanks (future)
3	56	Engagement	Communication with public “let us know”
		Exposure reduction	Fortnightly biosolids truck model for low storage levels
			Dedicated truck routes
		Odour Control	Deodourisers on trucks (scrapped)
			Sludge hoppers for direct truck outloading
4	258	Engagement	Community meetings every three months
			Meeting improvements
			Council meetings
		Exposure Reduction	Dedicated truck route
		Odour Control	Upgraded stacks for higher dispersion velocity
			Re-designed odour ventilation system
			Contained sludge conveyors
			Air duct and media repair/replacement
			Sludge hoppers for direct truck outloading
			Biofilter bypass to wet chemical scrubber
		Odour Monitoring	Ventilation for screening
			Walk outs
			Fugitive emission analysis

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Table 17. Actions undertaken by WWTP sites to reduce odour complaints and improve community relations *(continued)*

Site	Number of complaints 2004-2014	Type of action	Action
5	4	Engagement	Letter drop for local community outlining future plant projects and hosting open day
		Management	Improvement of internal management systems
		Odour control	Installed chemical scrubber
		Other	Plant well hidden
6	126	Engagement	3 month engagement
			Sydney Water-run survey and audit
			Council forums
		Engagement/management	Separate complaint handling procedure
		Exposure reduction	Dedicated truck route and times (7:30-10:30 outloading, weekdays)
		Odour control	2nd gas burner installed
			Upgrade of central odour scrubber
			Resealing for buildings
		Odour monitoring	Walk outs with observation checklist
			H_2S monitoring
			Wind surveys

6.2.3.1 Themes

We established several themes that were repeatedly discussed with PMs (**Figure 29**). These themes could be described in three overall categories: community behaviour, inter-industry behaviour, and product knowledge.

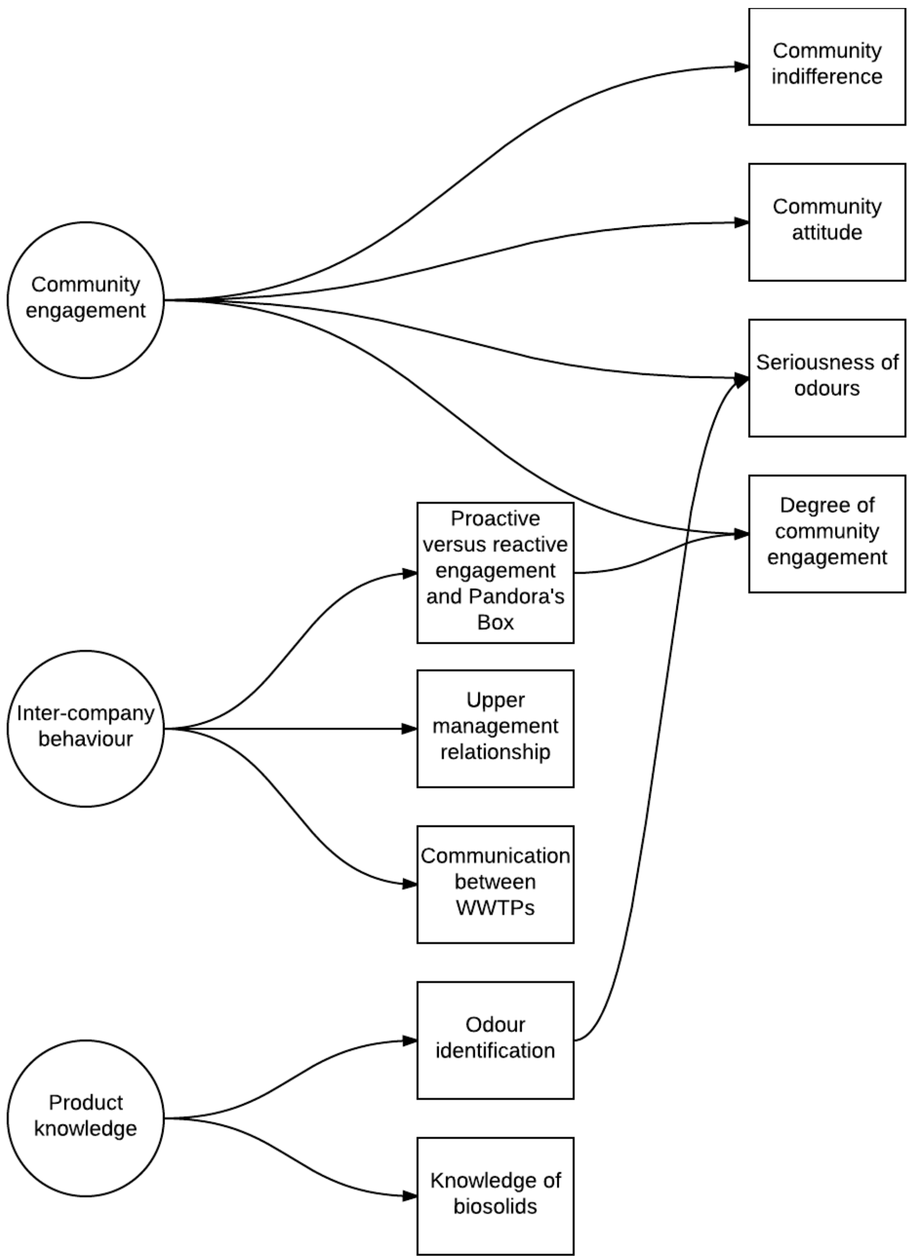


Figure 29. Themes and categories of PM interviews and their relationship with each other

6.3.1.1 Community Interaction

The most outstanding theme was community interaction. PMs differed widely with regards to how they perceived their Community's intentions and interactions. This variability was not wholly explained by the variance of complaint levels. The two sites with the most complaints, WWTPs 4 and 6, had PMs with very different perspective with how to interact with the community. PM7 favoured meeting engagement strategies while PM 6 was predominantly concerned with complaint filtration. There was similar degree of variability with regards to community engagement methods between sites; this appeared to be mediated by community proximity to the WWTP.

6.3.1.2 Degree of community engagement

The level to which WWTPs engaged with their community was influenced by the WWTP's relationship with upper management, and the level of complaints experienced. While all WWTPs have some methods of exposure reduction, practices became more numerous and engaged depending in sites with higher levels of complaint. For some PMs, this was believed to be an outcome of Sydney Water's "reactive" methodology. Smaller WWTPs 3 and 5, with fewer complaints, adopt a feedback approach where they encouraged odour reporting from nearby Community members. Primarily, this was due to the low risk of an alerted community as a result of the reduced number of complaints, as well as the need for reports caused the WWTPs not operating on a constant basis (Robinson *et al.* 2012). WWTP5 with a previously distant community had used an isolation policy which then transformed into an engagement approach with the advent of a new housing estate close to the WWTP. The transition from PM4 to PM7 at WWTP4 was marked by far greater emphasis on direct community engagement including meetings every three months, open days, and active complaint management.

6.3.1.3 Community Attitudes

PMs identified that there was variance between communities in their attitudes towards WWTPs. In addressing the question, “Do you feel that community complaints are valid?”, PMs to some degree explained their appreciation of the community’s attitudes. The attitudes of the community were considered in instances where sites experienced high complaints. To that end, both PM4 and PM6 cited several community members producing “frivolous” complaints. It was understood by several PMs that different areas produced varying levels of complaint *i.e.* different communities produced varying degrees of outrage. It appeared that PMs possessed a degree of defensiveness regarding their respective WWTPs, and that this was pressured dependent on the levels of complaint experienced by the plant:

> I: …so do you feel (.) the complaints you received are valid…”
>
> PM6:-well I mean it’s easy to get defensive about these things [sure] and I think initially we were quite defensive the concept was they were um complaining for (.) complaint’s sake I it it wasn’t helped by the fact that um we’d how-do-I-put-this-in-a-diplomatic-way we’ve got a lot of history

> with some of our complainants our complainants have a particular agenda…
>
> (PM6, Line 166-177)

PMs of higher complaint WWTPs felt that community members used malodours as an excuse to complain about the WWTPs in general. WWTP2 and WWTP3, both with fewer complaints, used a more discussion based style with communities in order to inform them of the processes involved with odour reduction and complaint management; both PMs of this plant believed that this resulted in community satisfaction.

6.3.1.4 Seriousness of Odours

There was significant variance between PMs in how they perceived the importance of the odours they produced. The most significant modulating factor did not appear to be the odours produced themselves, rather the relative proximity of other industry with the plant:

> we are in an industrial area so that means our residential impact is is is minimal [sure] and also we uh are adjacent to a race course [yeah[… … so uh probably our odour threshold is a bit higher than normal…
>
> (PM1, Line 77-84)

This sentiment was shared by PM2, and to a degree PM5, as WWTP5 was for a time located far away from residential areas. Odour sensors for all plants was limited to H_2S monitoring, however odour scrubbers were also cited to control for H_2S as well as ammonia. PMs with higher complaint levels varied from denying considerable impact in the case of PM4, while PM7 maintaining a perspective of information gathering. PM6's attitudes on the seriousness of odours was somewhat in between PM4 and PM7, identifying a need to logged odour complaints, but also carrying out a separate odour complaint procedure in order to remove frivolous complaints (Australia/Standards New Zealand Committee QR-015 Complaint Handling 2014).

6.3.1.5 Community Indifference

A curious facet of community interaction experienced by most of the PMs was the way in which the community expressed their indifference to the WWTP. This manifested in several ways. Firstly, it was noted for all cases that the vast proportion of local community did not register complaints. This was in agreement with our own complaint data analysis which discovered that approximately fifty percent of all complaints were made by 1-4 individuals. While difficult to ascertain via complaint data, plant managers felt that most community members who did register a complaint were satisfied with the complaint's outcomes.

Another manifestation of community indifference involved the lack of community support with regards to WWTP interaction. Two PMs (PM2 and PM7) cited that open days at the

WWTP were very poorly frequented, and WWTP4's new PM was in the process of using reach out programs to "re-energise" community meetings as only a handful of the same community members were attending.

6.3.1.6 Inter-Company Behaviour

Very little research has been paid to the ways in which companies can improve organisationally to address Community issues, much less how malodour complaints can be successfully addressed (Chess *et al.* 1992). The lack of communication between WWTPs and upper management translated into PMs adopting separate methodologies for improving community attitudes, and best practice measures have yet to be understood.

6.3.1.7 Relationship with Upper Management

The relationship between the WWTPs and upper management is mixed. With regards to community engagement, PMs receive a moderate degree of autonomy, save for certain scenarios that involve powerful stakeholders, such as inquiries made by the Mayor of the Council surrounding WWTP1. Upper management will also undertake engagement practices, including surveys, but these are often fixed within investigating the attitudes of Sydney Water as a whole, as opposed to local WWTPs or odour concerns. Communication regarding complaints was most often distributed through CMS.

In the instance of WWTP6, current Sydney Water complaint management is considered insufficient to establish odour complaints; as a result, Site 6 has established a separate

CMS. The highly active nature of its Community has resulted in a number of “frivolous” complaints, which in turn has resulted in a complaint process independent of the Sydney Water system.

6.3.1.8 Proactive versus Reactive Engagement and “Pandora’s Box”

Some PMs felt that the company’s strategy was primarily reactionary, and was insufficient to address specific community issues. PM5, PM6, and PM4 all made mention of the potential risk involved with regards to interacting with communities more directly. This is indicative of concern for an “activated” community, who is more sensitive and aware of their environment (Robinson *et al.* 2012).

PM5, while concerned with community engagement, cited that it was necessary in the context of the new housing development established approximately 400m from Site 5. However, PM5 felt that upper management took a “reactive” approach dependent on complaint generation in order to elicit a response for communities.

6.3.1.9 Communication between WWTPs

Communication between WWTPs is informal and infrequent. There is some discussion between PM3 and PM2 thanks in part to their close proximity, but at no time was it suggested that strategies had been adopted based on other WWTPs using them, or whether certain strategies were not attempted due to previous experiences. This meant that many practices were individually explored by PMs.

6.3.1.10 Product Knowledge

Within the academic spectrum, an understanding has emerged regarding the need to assess not only sulfur but also VOCs, as well as appreciate variations in odour qualities. It is currently under researched whether this understanding has translated into any practices at a community-industry level. Sydney Water hires contractors for transport and application of its biosolids product. As a result, PMs rarely had any knowledge regarding their biosolids product, or how to effectively approach odour control.

6.3.1.11 Odour Identification

Anecdotally, PMs and site operators are said to often identify problems at unit processes dependent on variations in odour. PMs had very little understanding of odour characteristics beyond air dispersion and the need to control H_2S and ammonia emissions. A habit undertaken by PMs 4, 6, and 3 was to arrive at the location where an odour complaint was reported so that they could undertake their own assessment. This practice seemed to mostly be an indication of their willingness to respond to community concerns, as opposed to any real investigation- regardless of whether an odour was detected or not did not seem to have any influence in future decision making.

There were some small attempts to improve odour identification and reporting. PM7 instituted a worksheet checklist for the WWTP, which included a small section to notice any unusual odours. However, this checklist's history was inspected and was almost never used by the site operators.

6.3.1.12 Knowledge of Biosolids

An additional question posed to PMs was “What is the quality of biosolids produced at the plant?” which elaborated on their knowledge of the biosolids stream and process. Most admitted a lack of knowledge as to the class or final destination of the biosolids product, rather this information was related as being under the purview of one of two companies who managed the transportation of the biosolids product. One PM (PM4) stated that, thanks to new upgrades, whatever biosolids that was being produced was of the highest possible quality, even though the plant in question was only capable of producing Class B. Similarly, with the exception of PM7, no PMs understood the final location of their biosolids or what it was being used for.

Variation in biosolids quality between plants was noticed anecdotally for PM3, who heard that WWTP3s product was less odourous and “sticky” compared to others.

6.2.4 Discussion of PM Interviews

The research presented in this component of **Chapter 6** provides a new avenue of investigation for environmental malodour and the water industry. In it, we have discovered variations in engagement strategies, attitudes, and beliefs for PMs. While we have looked at variations of community engagement, establishing current best practice is not simply taking the adopted policies of the WWTP with the least number of complaints. Proximity to residential and industrial locations is understood to provide a good explanation for number of complaints from prior research as well as the community survey

(Brennan 1993, McIntyre 2000, Sironi *et al.* 2010). However, the biosolids product also seems to play a role. For example, WWTP3 is very close to its local community and has few odour controls; yet it has low complaints.

It could be suggested that the odour potential of its product is sufficiently weaker compared to other WWTPs which has been suggested independently by PM3 as well as our own investigations with GC-MS/O application. This shows, once again, that odour measurement techniques are still a necessary requirement for effective plant management (Muñoz *et al.* 2010). Nevertheless, the attitudes and actions of PMs in how that odour is addressed has enormous influence (Covello *et al.* 1988, Robinson *et al.* 2012).

There are some recommendations that can be derived from this research. For our own research purposes, PM interviews have revealed some intriguing facets that lend themselves to developing future methodologies. Firstly, it is interesting to note that the issues regarding odour and communities for these plants is related to a small group within the community as a whole (Robinson *et al.* 2012). Comparatively, as we have seen in company attitudes relating to community survey work, there is a concern that discussing odour issues with the community is opening Pandora's box; "alerting" individuals to odours will increase their sensitivity to them (Robinson *et al.* 2012). Whether or not this is the case is a matter for debate, however what it does suggest is that targeted community engagement practices will satisfy both the community as well as the company, and comes with the added benefit that those practices are likely to be inexpensive compared to all-encompassing community engagement techniques. If we look at the mechanisms by which communities engage industry, we can see that “complaint figureheads” behave as community spokespersons (Brown 1992).

The effective dispersion of knowledge is crucial to improve productivity, and the lack of inter-industry communication expressed by these PMs indicates that a communicative platform is sorely lacking (Covello *et al.* 1988, Dyer *et al.* 2000). Other areas of improvement include the general knowledge of their products; some PMs were not able to correctly answer either quality or application sites for their plant’s biosolids. As seen in the industry survey, these knowledge gaps suggest that an integrated understanding of odour, as well as biosolids is necessary for improved production outcomes (Jakeman *et al.* 2007).

6.5 Industry Survey

6.5.1. Introduction

Very little attention has been paid to understanding attitudes of industry members and employees with regards to community engagement despite their presence as stakeholders (Harvey *et al.* 2005, Lockie *et al.* 2008). Within the context of wastewater treatment, there is virtually zero investigation into member and operator attitudes despite a lack of engagement methods or ways to improve community-industry relationships and the two-way nature of community-industry communication (Syme *et al.* 2007). Jakeman *et al*.

identifies, in the related water industry, the need to appreciate all stakeholder attitudes and preferences, and how research investigates these factors within the context of integrated assessment which is a requirement for today's industry (Cervinka *et al.* 2004, Jakeman *et al.* 2007).

The Industry Survey presented in this Chapter is an investigation into Industry members attitudes and beliefs regarding their companies, communities, and associated factors. Overall, this survey assists in understanding if particular pre-existing engagement policies are effective, as well as discovering potential engagement practices from individuals within the water industry. In agreement with our assessment of PMs, we found that inter-industry communication is often lacking and poorly implemented. Additionally, the water industry identified odours as the chief risk with regards to community-industry relationships, and provided insight for operator knowledge and attitudes about their companies.

6.5.2 Methods

The Industry Survey (found in its entirety in **Appendix 4**) investigated three issues. Firstly, the participant's appraisal of the water industry, as well as their company's place within that industry. Secondly, we investigated the participant's belief in the validity of community complaints regarding social-environmental impacts. Finally, we investigated participant's demographics within the context of their employment status and company.

This questionnaire was designed with input from members of the CRC-Low Carbon Living. Standard question practices were followed to improve results and survey completion (Roberson *et al.* 1990, de Vaus 2002). This Survey was approved by the UNSW Human Research Ethics Committee (approval number HC3261).

The Water Industry Survey was conducted online through Survey Monkey (URL: https://www.surveymonkey.com/r/waterindustrysurvey). The industry survey was distributed to the six WWTPs via emails of PMs interviewed, as well as advertised at the 2014 AWA Biosolids and Source Management conference (further discussed in **Section 6.4**). Further distribution occurred through the Survey's distribution on two Water Services Association of Australia newsletters in February and March 2016.

In addition to the Water Industry Survey, we be applied a Standard Industry version (url: https://www.surveymonkey.com/r/industryodoursurvey), which was distributed to conference members at the 2015 CRC Poultry Ideas Exchange (23-25th September 2014, QLD, Australia). This allowed us to make comparisons between personnel of varying industries and place biosolids production within that context.

6.5.2.1 Questions 1 to 8: Demographic and Location

In order to investigate variations between company and occupation, multiple questions were required to appropriately characterise participants. These questions were discussed at length with CRC members as to their relevancy and similarity with their own in-house survey designs. These questions had alternatives in the standard industry version of the survey.

Question 1: What company do you work for/ are most involved with? *OR*

S*tandard industry version:* What company do you work for/ are most involved with? (This can include being a member of a university if you do not have close industry affiliations)

This question was posed via text box to allow for all potential entries and summarily coded.

Question 2: What sector of the water industry are you most involved in? *OR*

Standard industry version: What sector of industry are you most involved in?

The Water Industry Survey version offered several options: sewer networks; drinking water; wastewater treatment plant operation; administration; other (with option to specify).

The Standard Industry Survey was broader in scope, pertaining to types of industry as opposed to the sector of that industry: intensive livestock farming; wastewater treatment; manufacturing; chemical processing; construction; agriculture; waste management; composting; other (with option to specify)

Question 3: What job best defines your role?

These job descriptions were defined in the Water Industry Survey with assistance from CRC industry partners: engineer; operator; manager; administration; transport; customer relations; inspector; finance and corporate services; information technology; other. In addition to these choices, the Standard Industry version included “researcher” as an option.

<u>Question 4: How long have you worked?</u>

This question defined working periods within “in your industry”, “with your current company” and “in your current position” with the following options for each: less than 6 months; 6 months to a year; 1 year to 5 years; 5 years to 10 years; 10 years to 20 years or over 20 years.

<u>Question 5: Please indicate your age group.</u>

Age groupings were determined by discussion with CRC Industry members and could be selected as: under 20; 20-30; 31-40; 41-40; 51-60 or over 60.

<u>Question 6: What general areas (for example suburb or site name) are you based at or do you visit regularly as a part of your work?</u>

In order to define varying workers but remain comprehensive to their selections, this question allowed up to four separate entries within text boxes.

Question 7: Do you live close (within 10km) to one or more of the treatment processing sites you work at?

This question was centered around the understanding that proximity to industry has the potential to affect perception regarding that industry (Heath *et al.* 1998). The responses to this question formed groups that were compared between each other based on responses to Question 17.

Question 8: Are you a member of any local community organisation(s)?

Community membership is a concept that was explored within the community survey, which has been suggested to affect attitudes regarding industries (Robinson *et al.* 2012). This question was followed by Question 9: "If you answered "yes" to the previous question, which organisation(s) are you affiliated with?" with an option to include up to four entries. Similar to Question 7, the responses to this question formed groups that were compared between each other based on responses to Question 17.

6.5.2.3 Questions 10 To 18: Company and Community Attitudes and Knowledge

Similar to the Community survey, these questions were designed for as little prompting as possible regarding odour and community interactions. While this produced a non-elicited response, it made some question structures complicated. Another important facet was to determine the level of complaint involvement members of industry experienced so as to control for guessing (de Vaus 2002).

<u>Question 10: How often do you hear of complaints about your company or site?</u>

This question posed the participant with a variety of complaint sources with frequency options of “several times a day”; “at least once a day”; “at least once a week”; “at least once a month”; “once in a while”, as well as a no response option. The complaint sources were identified as: members of the community directly; notifications from head office; second hand sources but originally the community. These results were compared between the Water Industry and General Industry responses.

<u>Question 11: Except for billing, listed below are some of the main types of complaints that customers and community make about industries. In your experience or based on what you have heard, which of these causes the most complaints?</u>

This question used an ordinal system that ranked up to four complaint reasons that an industrial site would most likely experience. The complaint reasons were: environmental (e.g. spillage); property maintenance issues (e.g. branches overhanging onto customer property, grass too long); Noise from industrial site; Odour from industrial site; Noise from trucks/vehicles entering/leaving the site; or odour from trucks/vehicles transporting materials.

<u>Question 12: Are there any other complaints that customers and the community make about your industrial sites or company that you are aware of? Please describe those types of complaints in the space below</u>

This was an opportunity for participants to describe any additional complaints in a text box.

<u>Question 13: Which of the following best describes how much you are involved in the management of complaints? Please choose only one.</u>

This question was used to determine the degree of complaint exposure by industry members, with options including:

- I am directly involved in complaints management; it is a part of my job
- I have been directly involved in complaints management in the past
- I am not directly involved in complaints management but I am well informed about the sort of complaints we deal with through various means
- I am not directly involved in complaints management but I hear about the sort of complaints we deal with from others within our company
- I am not directly involved in complaints management and have little knowledge of the sort of complaints we deal with

<u>Question 14: Which of the following statements applies to each of the following complaints for your industry? Please tick all that apply for each statement or “none of these” if you do you not think the statement is relevant to any types of complaint</u>

This question was displayed as a tick box “grid” which allowed for multiple entries for several complaint types (**Figure 30**). These complaint types and options were established with the assistance of CRC members, and assessed the attitudes of the participants regarding them. The complaint types were the same as used in Question 11 and had the following options as to their characteristics:

- Is a legitimate environmental impact
- Could restrict my treatment processing site's operations through legislation of environmental impacts
- Could tarnish my treatment processing site's reputation
- Is a social-environmental barrier for my industry
- Is a social concern that probably affects a large group, such as a suburb
- Is a social concern of a small number of community members who are overly sensitive
- Could be causing a social-environmental barrier but is not considered a branding issue for my company
- Is a particularly difficult issue to deal with
- None of these

14. Which of the following statements applies to each of the following complaints for your industry? Please tick all that apply for each statement or "none of these" if you do not think the statement is relevant to any of the types of complaint

	General environmental impacts	Property maintenance	Site noise	Site odour	Truck/vehicle noise	Truck/vehicle odour	None of these
Is a legitimate environmental impact	☐	☐	☐	☐	☐	☐	☐
Could restrict my treatment processing site's operations through legislation of environmental impacts	☐	☐	☐	☐	☐	☐	☐
Could tarnish my treatement processing site's reputation	☐	☐	☐	☐	☐	☐	☐
Is a social-environmental barrier for my industry	☐	☐	☐	☐	☐	☐	☐
Is a social concern that probably affects a large group, such as a suburb	☐	☐	☐	☐	☐	☐	☐
Is a social concern of a small number of community members who are overly sensitive	☐	☐	☐	☐	☐	☐	☐
Could be causing a social-environmental barrier but is not considered a branding issue for my company	☐	☐	☐	☐	☐	☐	☐
Is a particularly difficult issue to deal with	☐	☐	☐	☐	☐	☐	☐
None of these	☐	☐	☐	☐	☐	☐	☐

Figure 30. Grid design for answers to Question 14. Note that complaint types could receive multiple characteristics.

<u>Question 15 (A): Do you know if your company or industrial site independently implements a community engagement system?</u>

This Question was used in order to determine the sort of community engagements used by industry companies, and whether participants are aware of it. This question had several options: my company does; my industrial site does; both; neither; don't know.

Question 15 (B): If "my company does" "my industrial site does" or "both" was selected for the previous question, what sort of strategies do they use?

This part of question 15 includes several options to elaborate on participant's response: surveys; focus groups; open forums (*e.g.* discussion sessions); information nights; interview; responding to complaints; site tours; website for the public; other (please specify). This question allowed participants to select whether their company or site are operating these actions.

Question 16 (A): Do you know if your company or industrial site independently implements an environmental impact assessment for odours?

Similar to Question 15, these questions is designed to investigate participant's knowledge and current company actions regarding environmental impact assessment. This had similar response options to Question 15.

Question 16 (B): If "my company does" "my industrial site does" or "both" was selected for the previous question, what sort of strategies do they use?

Similar to Question 15, this question had several options available to be defined as either a company-wide or site-specific action:

- Field testing
- Spectral analysis (such as gas chromatography)
- Panellist testing for odour units (OU)
- Testing for suprathreshold values (such as using an odour wheel)
- Other (please specify)

<u>Question 17: Please evaluate the following statements…</u>

This Question was used to evaluate participant's attitudes regarding community and their company. These questions were assessed using a five point Likert scale ranging from Strongly Disagree to Strongly Agree. These responses were compared between local community organisation (Question 8), proximity to site (Question 9), and company affiliation (Question 1). The sub-items were:

- Overall, my treatment processing site handles complaints well
- My company is in general well organised
- The complaints I hear about my company are typically important
- Addressing complaints from the community is something my company does effectively
- The systems in place to deal with complaints to my company are effective

- The systems in place within my treatment processing site to engage with the community are effective

<u>Question 18: Do you have any suggestions about how your company could improve the way in manages complaints? Please tell us in the space below.</u>

This Question was presented as a text box.

<u>Question 19: Do you believe there are complaints about environmental impacts or social-environmental barriers that your company receives that need to be dealt with better? If so what are they and how do you believe they should be dealt with?</u>

Similar to Question 18, this Question was presented as a text box.

6.5.3 Results

6.3.4.1 Survey demographics

The survey of Water Industry personnel was filled out by 63 participants. The mean age range of the participants was 31-40 with a standard deviation (SD) of 1.87. **Table 18** outlines the means and SD for participant's employment history.

Table 18. Means and standard deviations (SD) for participant's employment history.

Employment within	**Mean**	**SD**
Water industry	4.83 (5 years to 10 years)	1.12
Current company	4.31	1.24
Current position	3.55 (1 year to 5 years)	1.19

7.5% of water industry participants reported that they were not directly involved in complaints management and had little knowledge of the complaints. The four other categories which identified at least a degree of complaint awareness were equally proportioned. The occupations of participants from the Water Industry Survey are provided in **Figure 31**.

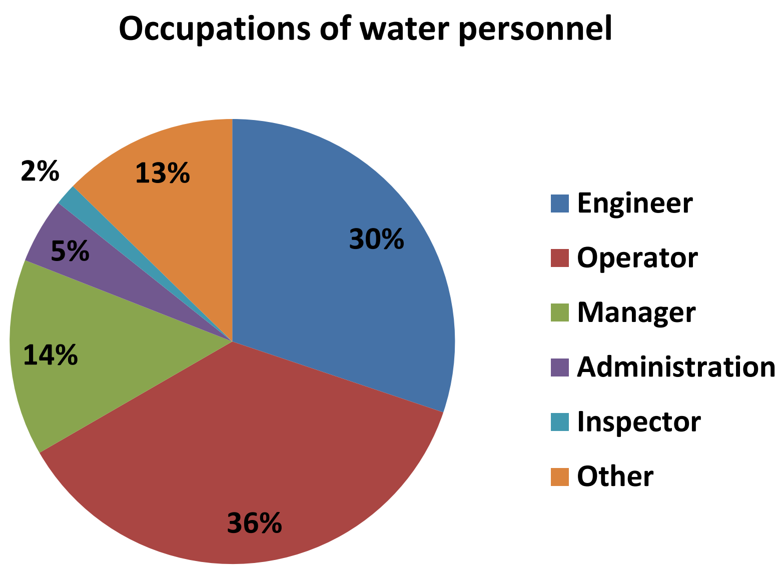


Figure 31. Occupations of water personnel reported in Water Industry Survey

Companies of participants in the Water Industry Survey were varied. 24 responses were derived from Sydney Water, 15 from Hunter Water, 9 from SA Water, and 2 responses from South East Water. The remainder consisted of 11 participants sourced from private companies, as well as 2 Council participants.

The survey of Industry personnel was completed by 17 participants (**Figure 32**); however, there was a significant degree of missing data, in addition to 33% of respondents reporting no complaint exposure when answering Question 13. As a result, any information drawn from this survey was minimal and only in comparison to Water Industry personnel.

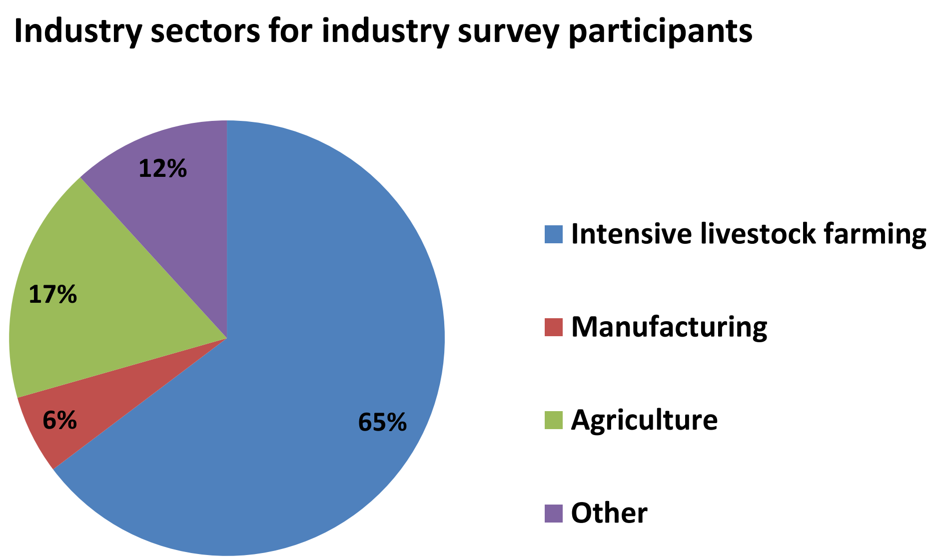


Figure 32. Occupations of industry personnel reported in General Industry Survey.

6.3.4.2 Water Industry Participant's Attitudes and Beliefs

Water Industry Survey participants answering Question 10 responded that they were made aware of complaints by members of the Community, head office notifications, and second hand sources to the same degree in regards to both number and frequency [$F(2,175)=0.04$, $p=0.96$, $\eta_p^2=0.00$].

Question 11 indicated that 59% of Water Industry participants felt that “odours from industrial sites” was the category that produced the most complaints. Overall, odour related complaints accounted for 43% of all complaints experienced. Comparatively, the survey of Industry personnel participants did not answer this question sufficiently to draw meaningful conclusions regarding the most complaint producing factor, but odour-related complaint factors accounted for 19% of all complaints experienced.

Results from Question 14 regarding the participant’s attitudes towards specific statements are shown in **Figure 33 (Panels A-I)**. Strikingly, Site and Truck/vehicle odour stand out as large concerns in all categories.

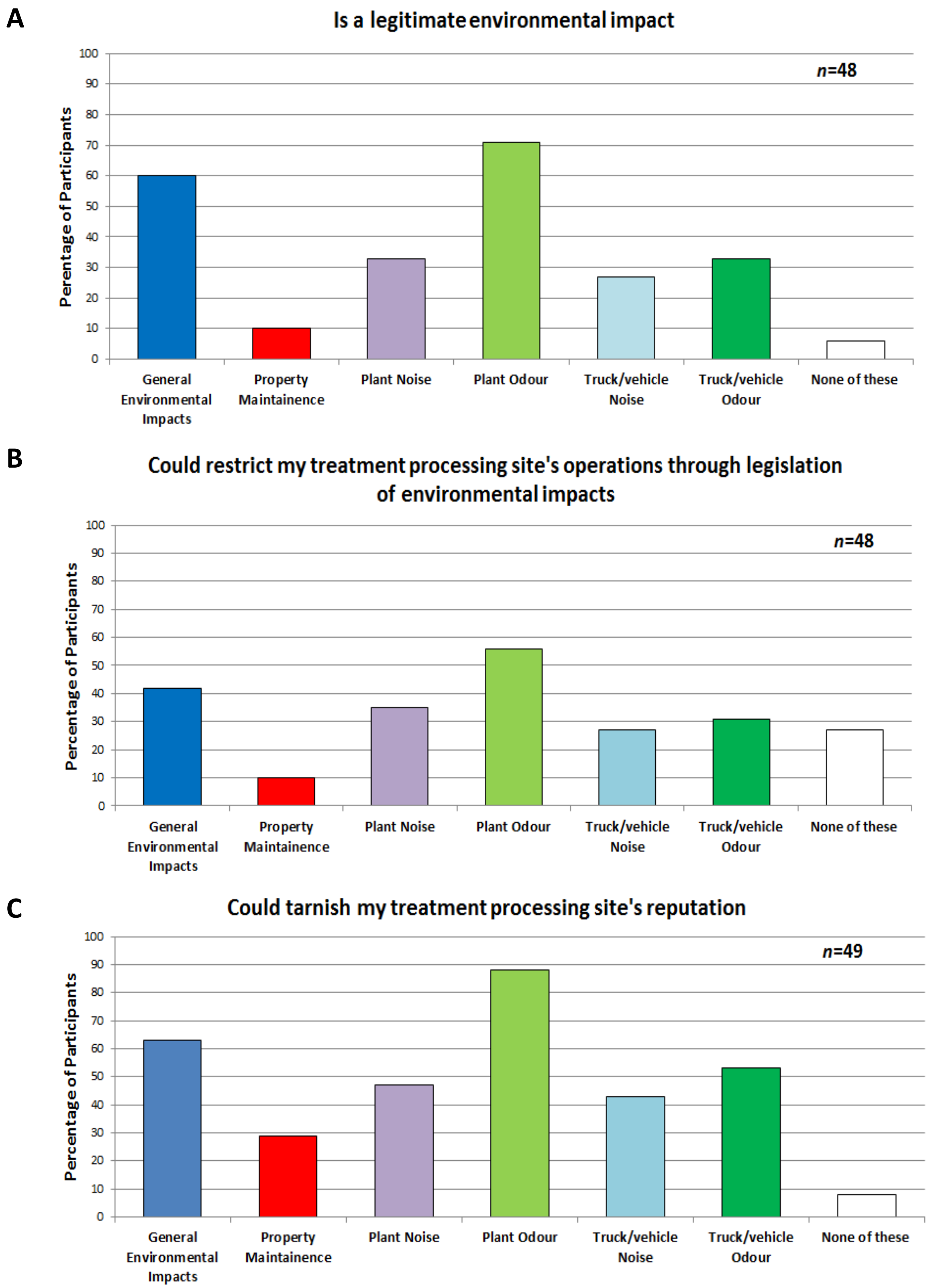
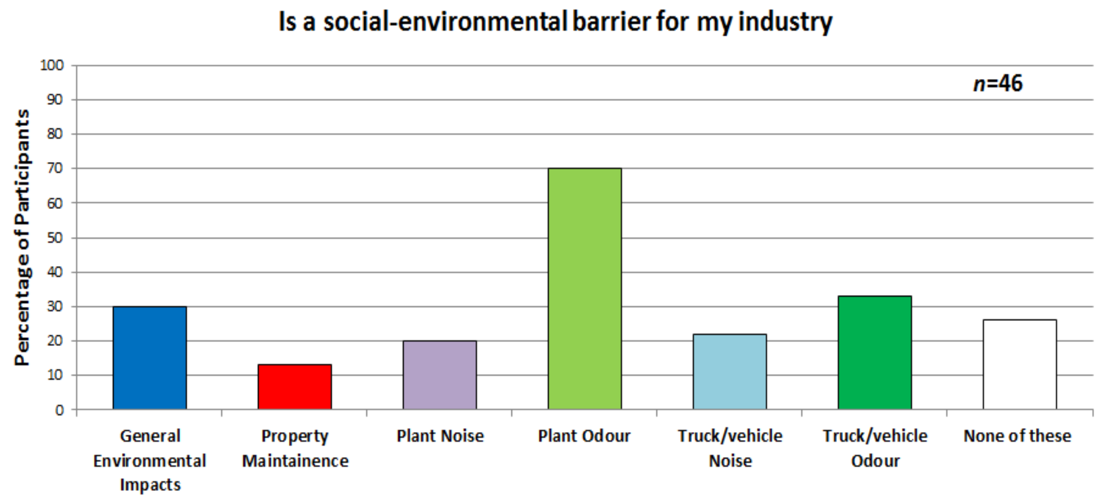


Figure 33 (Panels A-I). Water industry responses to sub-items of Question 14

D



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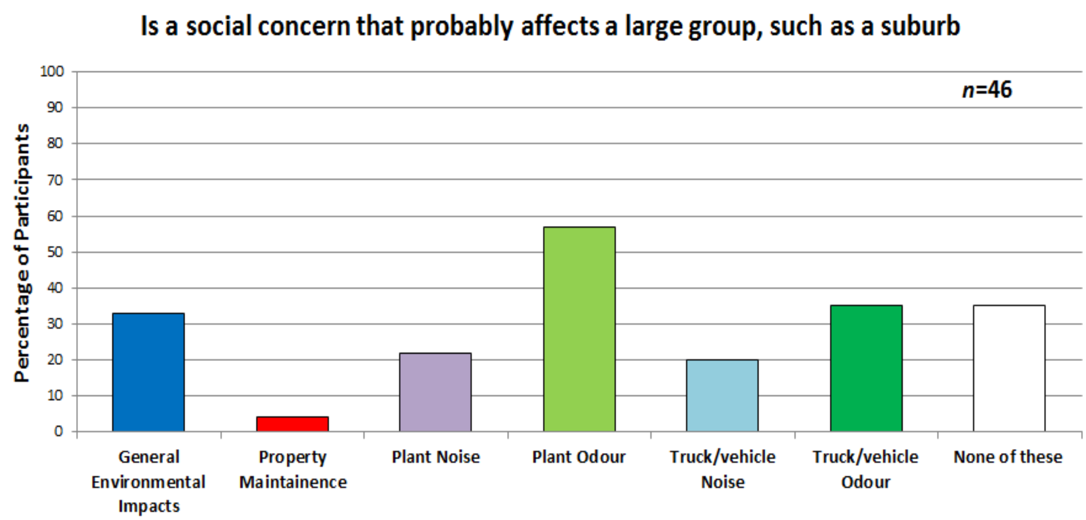

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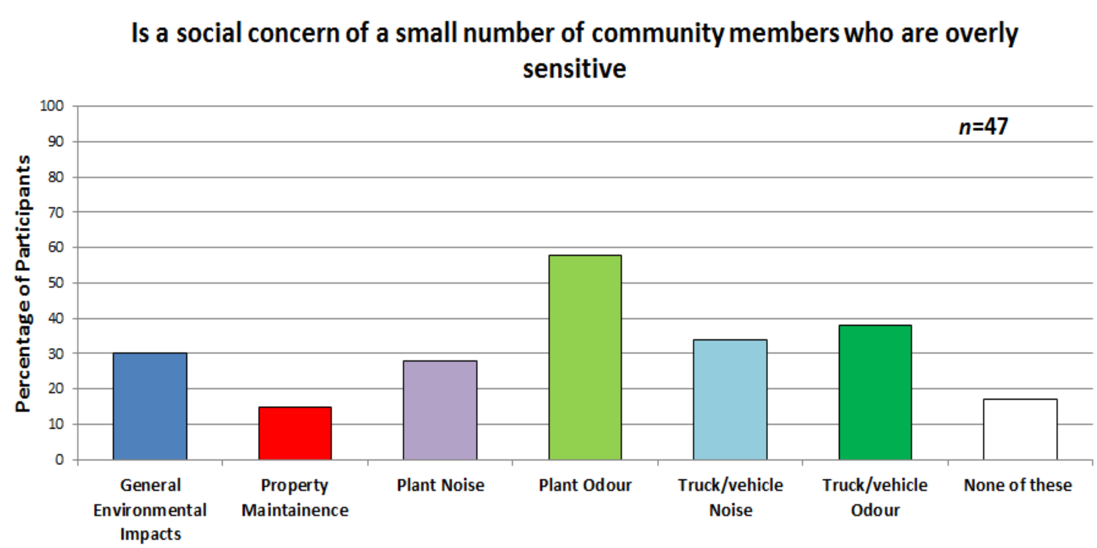

Figure 32 (Panels A-I). Water industry responses to sub-items of Question 14 *(continued)*

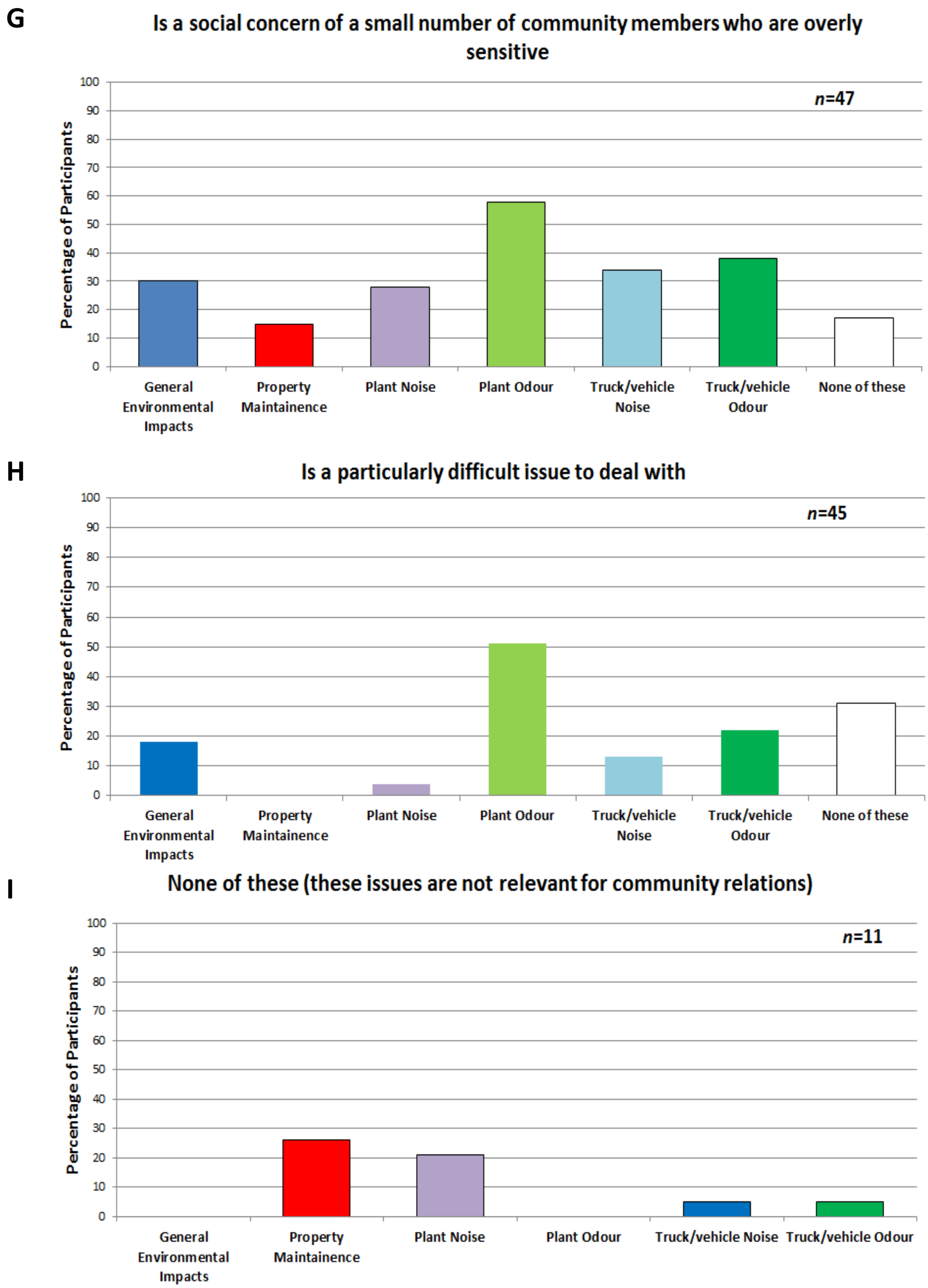

Figure 32 (Panels A-I). Water industry responses to sub-items of Question 14 *(continued)*

6.3.4.3 Attitudes of Water Industry Personnel Regarding Community Engagement

Question 15 was answered by 53 participants and indicated that, overall, water companies were believed to use community engagement strategies by 55% of Water Industry panellists, compared to 4% for Industrial sites or 23% for both. 19% of responders were not aware of any community engagement techniques. Of those not aware of community engagement techniques, 5 participants were from Sydney Water (three managers, an engineer, and an administrator), 3 from Hunter Water (two managers and an engineer), a manager from a private company, as well as a manager from SA Water. 43 participants defined the community engagement techniques used (**Figure 34**).

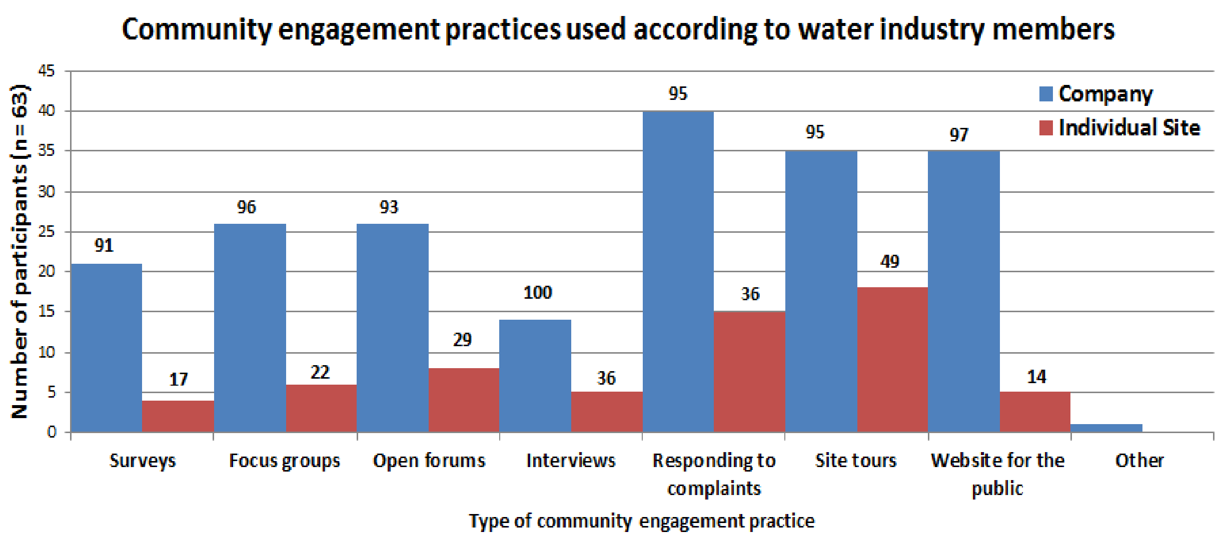

Figure 34. Community engagement strategies according to Water Industry members. Numbers over each column indicate the percentage of participants who attempted the question that confirmed either the company or individual site's involvement.

6.3.4.4 Attitudes of Water Industry Personnel Regarding Environmental Impact Assessments

Question 16 was answered by 52 participants in the Water Industry Survey. 46% stated that their company was involved in environmental impact assessments, while 13% stated their industrial site was involved, and 21% for both. 19% of participants did not know of any odour assessment tools. The participants who did not know of any odour assessment techniques included 5 from Sydney Water (one engineer, two administrators, and two operators), 3 from Hunter water (2 engineers and one unspecified), one engineer from a private company, and 3 operators from SA Water. 39 participants characterised the odour assessment techniques used (**Figure 35**).

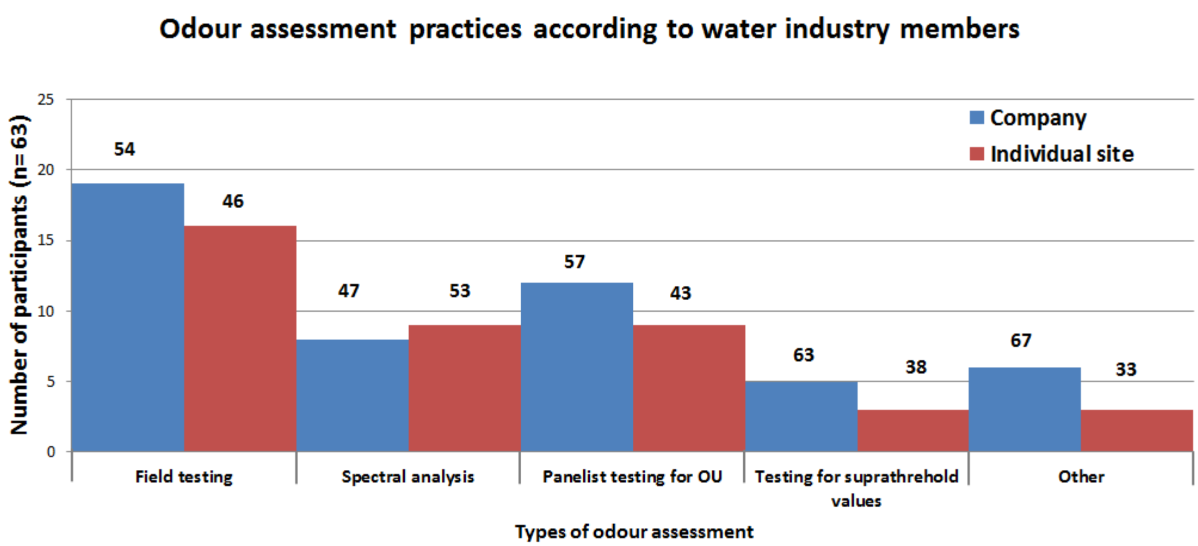

Figure 35. Odour assessment techniques used as responses from Water Industry personnel. The “other” category was unanimously defined as odour monitoring. Values (above each column) indicate the percentage of participants who attempted the question that confirmed either the company or individual site’s involvement.

6.3.4.5 Comparisons between Water Industry Personnel Groups

Responses to sub-items in Question 17 were used to compare responses between local and non-local workers (Question 7), local community membership status (Question 8), and between companies (Question 1) (**Table 19**). We found no significant relationships between any sub-items and worker locality. In regards to members of local communities, we found that local community membership predicted less favourable attitudes towards the sub-item “my company in general is well organised” [$F(4,47)=2.91$, $p=0.03$, $\eta_p^2= 0.2$]. We also compared Question 17’s sub-items between Sydney Water, SA Water, South East Water, Hunter Water, and Other categories, and found no significant variance between these companies for any sub-items. Overall sub-item responses from Water Industry personnel to Question 17 are shown in **Figure 36**.

Table 19. Responses to Question 17 dependant on Group Type

Question	Community membership	Live locally (within 10km)	Company
Overall, my treatment processing site handles complaints well	F(3,48)=0.43,*p*=0.73, η_p^2=0.03	F(3,48)=1.16,*p*=0.33, η_p^2=0.07	F(3,48)=0.53,*p*=0.66, η_p^2=0.032
My company in general, is well organised	F(4,47)=2.91,***p*=0.03**, η_p^2=0.20	F(4,47)=0.80,*p*=0.53, η_p^2=0.64	F(4,47)=1.59,*p*=0.19, η_p^2=0.12
The complaints I heard about my company are typically important	F(4,47)=0.27,*p*=0.89, η_p^2=0.023	F(4,47)=0.80,*p*=0.53, η_p^2=0.06	F(4,47)=0.34,*p*=0.85, η_p^2=0.03
Addressing complaints from the community is something my company does effectively	F(3,48)=1.37,*p*=0.26, η_p^2=0.08	F(3,48)=1.29,*p*=0.29, η_p^2=0.08	F(3,48)=0.97,*p*=0.41, η_p^2=0.06
The systems in place to deal with complaints to my company are effective	F(4,47)=0.62,*p*=0,65, η_p^2=0.50	F(4,47)=0.76,*p*=0.56, η_p^2=0.061	F(4,47)=1.27,*p*=0.30, η_p^2=0.10
The systems in place within my company to engage with the community are effective	F(4,46)=0.61,*p*=0.66, η_p^2=0.51	F(4,46)=0.54,*p*=0.71, η_p^2=0.045	F(4,46)=1.95,*p*=0.12, η_p^2=0.15
The systems in place within my treatment processing site to engage with the community are effective	F(4,46)=0.76,*p*=0.56, η_p^2=0.06	F(4,46)=0.71.,*p*=0.59, η_p^2=0.06	F(4,46)=2.22,*p*=0.081, η_p^2=0.16

Bold indicates significance (*p*<0.05)

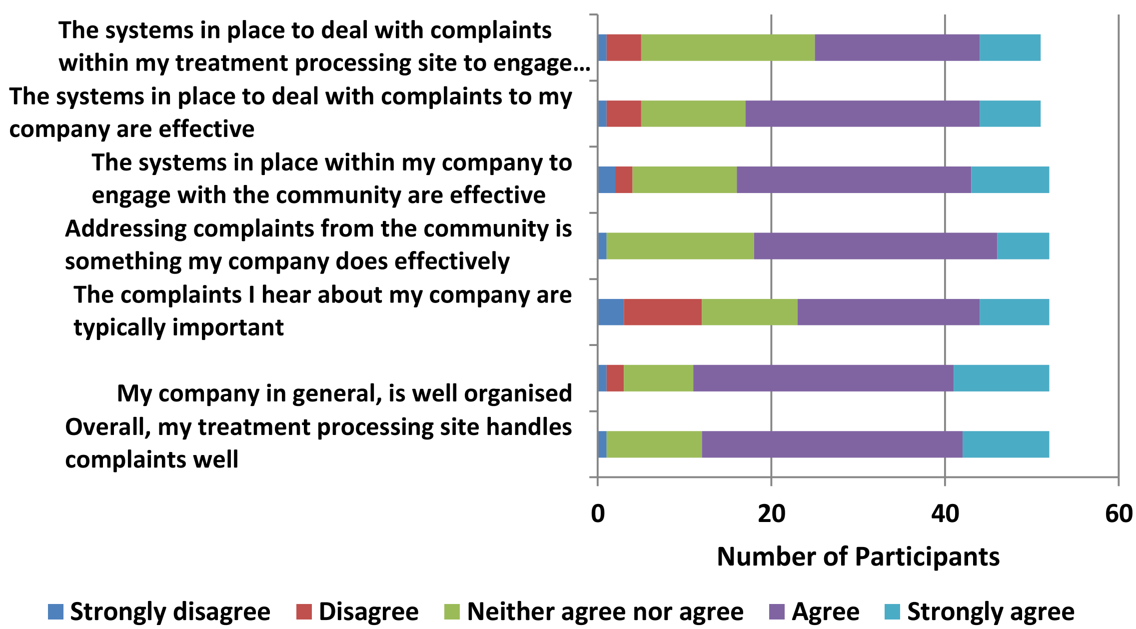

Figure 36. Response to Question 17 sub-items (*n*=51-52)

6.3.4.6 Additional Comments from Water Industry Personnel

We received 17 responses to Question 18 and 19 in our Water Industry Survey. With regards to Question 18, 2 participants indicated a need to resist the reduction of buffer zones. Three participants stated that better complaint data was required. Two participants indicated a transparent and proactive approach, one felt that biosolids reuse sites required more focus, one cited an inclination to finish the complaint handling procedure as quickly as possible, and finally one participant wanted improved inflow into WWTPs in order to improve treatment quality.

Question 19 was concerned with determining if there was any complaint sources derived from environmental impacts or social-environmental barriers previously unexplored. One participant cited that the investigation of complaints frequently led to more complaints being uncovered, and that this produced problems as it increased complaint numbers which they believed “skewed” numbers. Another participant considered collating data for environmental impact monitoring as currently suboptimal. Finally, another participant was concerned at the lack of a pro-active approach with regards to odour monitoring.

6.5.4 Discussion on the Water and General Industry Surveys

We conducted a survey of Water Industry personnel that included employees from several Australian water companies, both public and private. This Water Industry survey included questions that determined participant’s attitudes towards their company, the community, as well as the challenges of their industry.

Question 10 illustrated that the relationship between head office and WWTPs is not the dominant complaint stream, rather all streams contribute equally. This poses several risks to the water industry. The variation of complaint sources suggests that complaint logs are under-representative of community's dissatisfaction (this was indicated again in a Question 18 response). This under-reporting of complaints is capable of hiding the true community dissatisfaction that may necessitate more expensive remedies (Brown 1992, Lees- Haley *et al.* 1992). This variation also likely results in disparate methods to categorise and qualify the complaint, heavily influencing the capability of the complaint system to produce meaningful information (Verein Deutscher Ingenieure 1993, Sucker *et al.* 2004, Feliubadaló *et al.* 2009).

Comparatively, for Question 10, the General Industry survey identified a relative lack of complaints, but received the majority of these complaints directly from community members. This indicates that wastewater treatment must deal with idiosyncratic risks and community expectations compared to other industry types (Henry *et al.* 1980, Muñoz *et al.* 2010).

Question 14 revealed that odour is an issue that Water Industry members are well aware of, and appreciate that its impact is perceived at all levels of community (Flesh *et al.* 1974, Dalton *et al.* 1997a, Cesca *et al.* 2007). Plant odour, and to a lesser extent truck odour, represented the biggest risk in all sub-items for the water industry and was highly divergent from results obtained from the General Industry survey. It should be noted that while WWTP odour was the highest scored issue for the sub-item “could be causing a social-environmental barrier but is not considered a branding issue for my company”, overall, participants predominantly chose the “none of these” option for this sub-item. This suggests that participants felt that none of these issues, including odour, were considered inherent problems within their companies. Considering the high recognition of odour as a problem for other sub-items, it suggests that Water Industry participants believed companies are not taking the odour issue seriously.

The absence of a unified odour or community engagement policy was further illustrated through the responses to Questions 15 and 16. Questions 15 and 16 revealed that an understanding or knowledge of community engagement as well as odour measurement tools is far from universal. Troublingly, this lack of awareness transcends various employment roles; including operators and PMs who are expected to implement these measures. Of those who are aware of particular community engagement and odour management practices, it seems that water companies tend to deal with community engagement practices predominantly centrally with individual WWTPs occasionally providing additional engagement measures. Comparatively, specific odour management practices are either adopted by the company or the individual site but hardly ever both. It should be noted that these results could be based on a lack of knowledge by the participants. One explanation for the variation between adoption strategies between community engagement and odour monitoring is the specialisations required to perform them.

Despite suggestions to the contrary in prior work (Heath *et al.* 1998), WWTP site proximity did not seem to affect attitudes towards the water industry by its employees, as demonstrated in Question 17. The same could not be said for community membership, which decreases the belief that the employee's water company is managed well (Question 8).

While it was expected that there would be some variance between different companies owing to their discrepant sizes, status, and locations, we were surprised to find that there was no significant variance between them for any sub-items in Question 17. All participants leant towards either ambivalence or mild approval at both their company and WWTP site's ability to engage and deal with complaints, and also agreed that complaints experienced are valid. This contrasts the responses from Question 14 that suggested Water Industry participants did not think companies consider complaints as branding issues. The contrast can be explained as participants believing that companies do not perceive these particular complaints as a risk, but also those participants perceiving current complaint levels as a low risk also, while acknowledging the various risk potentials.

Questions 18 and 19 provided insight into further reasons why complaint numbers are insufficient to assess community satisfaction. Firstly, a participant noted that complaint investigation could uncover further complaints; by doing the “right thing” in resolving grievances can result in a perceived poorer performance based on current standards. Similarly, another participant cited that the burden of a speedy resolution can lead to poor complaint satisfaction. Considering the lack of oversight and definition of what “resolved” entails within complaint management as discussed in Chapter 3, as well as a policy towards isolation (sometimes termed “defensiveness”) with the community as seen with plant manager interviews, we have discovered a fault in community engagement for these companies that demands clarification and adjustment (Fornell *et al.* 1988). In other industries, this sort of complaint disassociation has produced detrimental or catastrophic effects (Schoefer *et al.* 2005, Harris *et al.* 2009, Desai 2010).

There are several recommendations for water companies that can be applied based upon these findings from the Water Industry Survey. Perhaps most importantly, complaint numbers should not be considered the only measure of community engagement success. One way in which community engagement is indirectly addressed by the industry is the use of odour measurement and dispersion tools to determine an “odour footprint” (Yang *et al.* 2000, Stuetz *et al.* 2001b, Sarkar *et al.* 2003a, Hayes *et al.* 2006, Schmidt *et al.* 2010, Sironi *et al.* 2010, Capelli *et al.* 2013b). Previously identified, however, is that at a fundamental level, there is already a clear understanding that the variations of the size of site, community activity, demographics, perception of risk, as well as other variables contribute to fluctuations in complaint levels (Baxter 1997, Dalton *et al.* 1997a, Kasperson *et al.* 1999, Kolarova 1999, Winneke 2004, Kemp *et al.* 2012, Robinson *et al.* 2012). These variables make comparisons between plants practically impossible and reduce the efficacy of odour measurement tools.

Community engagement assessment beyond complaint numbers has been previously researched. An extreme example, not necessarily centred on odour, was provided by Baird *et al*. who produced a method by which health reporting could provide an early warning system of community-wide endemics (Baird *et al.* 1990). Considering the significant influence of community members around WWTP4 without accompanying health effects as determined in our community survey, this method of assessment would be far too delayed to provide any meaningful feedback within a high complaint site. Other research has explored other measurement strategies, such as the amount of use of facilities to assess odour impacts (Afful *et al.* 2015). No particular measurement technique appears to fulfil the needs of the Australian water industry or community. As a more effective alternative, it is recommended that a pro-active approach will produce the desired outcomes.

The prioritisation of complaints levels has detracted from investing in “social capital”- a necessary requirement of any modern industrial works (Syme *et al.* 2007, Dare *et al.* 2014, Kobayashi *et al.* 2014). As discussed in **Chapter 3**, overseas guidelines have focused on dialogue procedures between industry and community in a variety of settings (Winneke 2004, Lockie *et al.* 2008, Rae *et al.* 2009, Sucker 2009). Of note, multiple research groups have noted the need to provide formalised discussion platforms, as well as integrative meetings that may have cultural or communicative significance for the communities (Sandman *et al.* 1993, Lockie *et al.* 2008, McDevitt *et al.* 2013, O'Faircheallaigh 2013). Engagement practices such as these are most often concerned with addressing perceptions of risk for which odour is a primary influence (Covello *et al.* 1988, Heath *et al.* 1998, Galetzka 1999, Kolarova 1999, Dalton 2002, Scorgie *et al.* 2007, Sakawi *et al.* 2011, Robinson *et al.* 2012).

Our PM interviews, as well as prior research, has suggested that some parts of industry may be adverse to such procedures due to the risk of “activating” the community which results in further complaints (Sandman *et al.* 1993, Robinson *et al.* 2012). Nevertheless, the necessity of communicative structures has been identified by the interviewed PMs who have all explored ways in which communities can be engaged beyond complaint management. Adopting these procedures has two perceived weaknesses. These engagement policies require expenditure and effort, as well as having no explicit relation to complaint reduction. However, multiple benefits outweigh these concerns. To begin with, engagement tools are able to halt emerging or on-going risk perception before communities log complaints or produce further barriers (McGuire 1961, Kemp *et al.* 2012, Dobbie *et al.* 2014). Additionally, the dissolution of risk perception provides health and wellbeing benefits to the community (Lazarus *et al.* 1978, Evans *et al.* 1987a, Steinheider *et al.* 1993, Bullers 2005, Cutrona *et al.* 2006). Finally, as indicated in this survey too, a public forum can offer ideas and concerns previously unconsidered (Irwin *et al.* 1999, Longhurst *et al.* 2004, Lockie *et al.* 2008).

Effective complaint management, as previously discussed in **Chapter 3**, requires a set of standards that this Survey reveals does not occur. A reason for informal complaint streams may be complaint avoidance. In order to capture these complaints effectively, the recommendations made regarding training for complaint receivers should extend to site operators and other roles that make informal communication with communities. Industry members have the potential for ambassadors, as well as figureheads, when engaging with surrounding communities (Lockie *et al.* 2008). The training demands for complaint management and community engagement for informal communication should be simple for improved adoption rates. This could include informing employees of how to register complaints (or where complainants should register them), explaining standard policies of their local site, or providing members of the community with resources in order to communicate with the industry.

Future application of this Water Industry Survey should include more comprehensive distribution strategies. This Survey could then expand to compare between site, employment status, and between industries effectively. In order to encapsulate desired participants, a screening process at the beginning of the survey could eliminate participants who are not needed such as those with no complaint experiences, or particular occupations that could skew results. This Survey offers the opportunity to investigate the attitudes and beliefs of industry employees, and with sufficient distribution and analysis could establish best practice for a variety of community related circumstances.

6.6 Summary and discussion

This Chapter was centred on four sub-studies: the Water Industry survey, PM interviews, Conference workshops and community odour testing (Australian Water Association Annual Conference), as well as biosolids land application interviews at Grenfell.

The Water Industry survey indicated that water industry workers are well aware of the threat of environmental malodour within their industry, and that odour is a specific risk for their industry compared to others. Despite this understanding, the lack of knowledge regarding odour evaluation tools or community engagement techniques means that more integration of these methods should be adopted by the water industry. Additionally, findings in this research support **Chapter 2** in that current complaint management is poor. The dis-incentivisation to properly address complaints poses an enormous risk for the water industry; however, this can be amended by reducing the emphasis on complaint reduction, and focusing on a more comprehensive community engagement strategy.

PM interviews showed that there is a wide spectrum of techniques, attitudes, and beliefs between plant managers. In agreement with our Industry survey findings, PMs who adopted more community engagement strategies appeared to have improved relationships with the community that could have otherwise proved costly to overcome. Of particular importance for the water industry, the lack of communication between WWTPs has resulted in multiple strategies that have meant that a best practice has not been established. Improved, formal communication between WWTPs is a strong recommendation in order to reduce expense and waste.

The Conference workshops and odour testing of the community group (found in **Appendix 3**) provided some pilot testing for odours found in wastewater treatment. In this way, it represents a connection between the findings in **Chapter 4** and recommended engagement policies in **Chapter 7**. Additionally, suggestions brought up by industry stakeholders broadly support the findings of the Industry survey.

The Biosolids land application interviews with local farmers in Grenfell provide insight into the challenges facing biosolids acceptance (found in **Appendix 3**). The typical reactions and attitudes regarding environmental malodour experienced by all affected communities are discussed. Additionally, biosolids impact the farmer's social dynamics to a degree that adoption has been slow despite producing better outcomes for crops. Solving these social dynamics is a difficult task that may be best addressed by allowing biosolids to become steadily more acceptable over time.

Chapter 7

Online Engagement for Community Attitudes

Chapter 7. Online Engagement for Community Attitudes

7.1 Introduction

PM interviews and Water Industry surveys discussed in **Chapter 6** illustrated a need for inter-industry communication. This communication is required both as a way to discuss and share community engagement practices, as well as integrate knowledge regarding community engagement and odour measurement within standard operations.

Chapters 3 and **6**, in agreement with previous literature, identified that multiple complainants represent the biggest risk for community outrage, and that current complaint management is substandard with regards to recording odour events (Sandman *et al.* 1993, Robinson *et al.* 2012). Relating to the difficulty of recording odour events, **Chapters 4** and **5** illustrated the need to accommodate for variations of olfactory sensitivity within the community, and that to establish varying OIs for untrained detectors a simplified system is required. Finally, **Chapter 5** showed that odour frequency and annoyance are factors crucial to understanding community disposition, and that the *perception* of industry determines odour impact and vice versa.

To address these core findings, we have developed and implemented the Online Dynamic Engagement system for Communities (ODEC). ODEC represents a communicative platform not only for odour observations, but as a tool for engagement between community and industry, as well as inter-industry communication. ODEC provides this platform as well as an opportunity for extending research and community interaction investigations.

The interaction between industry and community regarding environmental malodour has been investigated through both research and community interaction paradigms. From a research perspective, the effects of malodour on wellbeing, and how odour models correlate with community satisfaction have been primary focal points (Neutra *et al.* 1991, McIntyre 2000, Sucker 2009). Comparatively, community interaction has looked at the ways in which community desires are expressed, and the effectiveness of meeting these desires; in some cases this could be classified as environmental justice (Čapek 1993, Wing *et al.* 2008). While these archetypes have had separate goals, recently there is an increasing overlap of needs, as well as an improved ability to facilitate the kinds of methodologies required to address these needs; something which was identified by plant managers in **Chapter 6**. Therefore, we propose the use of the ODEC, which is a modern approach to improve both research and community interaction outcomes.

Historically, research and community interaction models have emerged from contrasting demands. From a community interaction perspective, there has been an increasing focus on the role and communication platforms of communities, as well as their interaction with their environment. This increasing emphasis has been driven by the growing demands of the public, which has transformed public acceptance of industrial works into a critical objective at every level of community-industry communication (Covello *et al.* 1988, Chess *et al.* 1992, Sandman *et al.* 1993, Verein Deutscher Ingenieure 1993, Donham *et al.* 2007, Brown 2009, Pagell *et al.* 2009, Rae *et al.* 2009, Kalbar *et al.* 2012). An additional driver of the community interaction paradigm has been environmental justice, which is broadly characterised as the right to access fair and accurate information regarding environmental issues, increased representation for all stakeholders, compensation for wronged parties, as well as communication structures that allow for stakeholder interaction and resolution (Čapek 1993, Cutter 1995). As discussed in **Chapter 3**, there are also legislative guidelines and ramifications in order for industrial companies to appropriately address the needs of local Communities. Legislative guidelines have often focused on responding to community grievances through complaint management (Australia/Standards New Zealand Committee QR-015 Complaint Handling 2014). However, PMs interviewed as part of **Chapter 6** have shown that wastewater treatment odour management may be moving towards a "collective action" approach has been adopted by other industry-community relationships due to increasing public demands (Chess *et al.* 1992, Longhurst *et al.* 2004, Donham *et al.* 2007, McDevitt *et al.* 2013, Dobbie *et al.* 2014, Kobayashi *et al.* 2014).

Summarily, in order to minimise complaints, which is now a fundamental requirement of industry, answering the needs of the community with regards to environmental malodour is required beyond recording and monitoring complaints (Čapek 1993, Donham *et al.* 2007, Brown 2009, Sucker 2009). Typically, these needs are addressed through complaint systems and community engagement meetings (Verein Deutscher Ingenieure 1993, Freeman *et al.* 2002, Sucker 2009, Australia/Standards New Zealand Committee QR-015 Complaint Handling 2014, Brancher *et al.* 2014). The research paradigm has informed the community interaction paradigm of how useful these tools and platforms are. As previously stated, complaint systems, while regulated, are not very effective as complaint mitigation tools due to being poorly implemented or unrepresentative of actual complaint levels (Cavalini 1994, Blumberg *et al.* 2001, Cervinka *et al.* 2004, Keil *et al.* 2011).

Other communicative structures, both industry-community, as well as community-specific have been somewhat under researched; however, some investigations have investigated their influence. Industry-community communication methods regarding odours ranges from round tables to advertisement, with some methods even possessing guidelines to assist users in the process (Longhurst *et al.* 2004, Scorgie *et al.* 2007, Sucker 2009). Longhurst *et al.* concluded that there is a clear requirement for clear communication platforms; however, industry-community communication effectiveness can be seriously undermined by community-centric counterparts (Brown 1992, Baxter 1997, Longhurst *et al.* 2004). The first issue to consider is that community-derived communication and knowledge acts very differently to a “professional” approach (Brown 1992, Brown 2003, Brown 2009). Community-derived communication seems to instil distrust of industry-community media, promoting community outrage (Sandman *et al.* 1993). As a result, scientific or indeed factual appreciation of a particular issue is rendered irrelevant within an emotionally driven community setting (Brown 1992, Sandman *et al.* 1993, Kemp *et al.* 2012). The relative strength of community-specific communication structures should not be underestimated. Kemp and colleagues investigated the ways in which the public could be "inoculated" against scare campaigns regarding recycled water. These authors found that community-derived communications were sufficiently powerful to resist countermeasures produced by industry (Kemp *et al.* 2012). Similarly, Robinson *et al.* found profound differences between communities regarding the acceptability of biosolids; this difference was dictated by how "active" the respective communities were (Robinson *et al.* 2012). In summary, community-derived communication is a powerful factor in determining the effectiveness of community engagement. Regarding environmental odours, the research paradigm has considered further factors, as well as methods of community investigation, that continue to illustrate the complex requirements for successful community engagement.

Research has also investigated the ways by which a community can be used as research tools. The use of Observers within the community as odour reporters has included comparisons to air dispersion data, using community members as field investigators, as well as observers able to capture odour samples (Cavalini 1994, Blumberg *et al.* 2001, Sarkar *et al.* 2003b, Schauberger *et al.* 2006). This research has provided ways in which human variance of olfaction is understood, as well as ways in which communities can be engaged that are not derived from the community interaction archetype. In particular, prior research has shown that establishing correlations with community reaction is complicated and often unsuccessful. This includes attempting to produce a dose-response relationship between annoyance and odour concentration, using complaints as predictors of odour exposure, or even establishing predictable individual reactions to increasing odorant concentrations (Cavalini 1994, Miedema *et al.* 2000, Blumberg *et al.* 2001, Cervinka *et al.* 2004). Sarkar *et al*. identified that better results could be produced by increasing panellist selectivity, accepting variation in sensitivity, as well as producing larger pools of data for averaging; by tightening community variance and expanding data, incongruences can be lessened or nullified (Sarkar *et al.* 2003b).

Engaging communities for the purposes of malodour research is well established when investigating factors such as effects on health, annoyance, and the comparisons between reported complaints and projected odour models. Health and wellbeing complaints in the presence of environmental malodours has been rigorously examined and has informed the community interaction archetype when characterising environmental justice (Winneke 2004, Donham *et al.* 2007, Lowman *et al.* 2013). While an explanation has not been forthright, there is a clear link between a decrease in health and wellbeing due to exposure to environmental malodours (Neutra *et al.* 1991, Schiffman *et al.* 1995, Dalton *et al.* 1997a, Schiffman 1998, Schiffman *et al.* 2000, Sucker *et al.* 2001, Cervinka *et al.* 2004, Yang *et al.* 2010, Afful *et al.* 2015). The variables that modulate the relationship between wellbeing and malodour have also been investigated, and it has been suggested that personality, coping mechanisms, psychosocial factors, as well as perceived health may all play a role that has additional effects over the qualities of the malodours experienced (Steinheider *et al.* 1993, Schiffman *et al.* 1995, Winneke *et al.* 1996, Luginaah *et al.* 2000, Schiffman *et al.* 2000, Wakefield *et al.* 2000, Luginaah *et al.* 2002). This is despite no clear dose-response relationship between health effects and odorant exposure identified in the literature (Neutra *et al.* 1991, O'Connor *et al.* 2010, Sommer-Quabach *et al.* 2014, Piringer *et al.* 2015). Considering the influence of community-derived communication, and the current knowledge gap of explanatory models for declines in wellbeing, industries have a disadvantage regarding community engagement when considering environmental malodour. Reducing these disadvantages would provide industry with the ability to engage communities effectively.

Based on the research previously conducted, we have constructed a combined online and in-person community engagement policy. Throughout this research, we have noticed several implementation gaps with regards to community engagement practices, as well as sub-standard methods that could be improved for better community engagement. Our research has identified a clear need for standardised and straightforward communication platforms, which is what ODEC intends to provide (Keil *et al.* 2011). In addition, the way in which this tool is designed and administered means that it can be used as both an industry-community and a community-centric platform. This is accomplished by targeting identified active community members for engagement, which taps into community-derived communication, as well as offsetting community outrage. Additionally, ODEC endeavours to provide a crucial research component. Observation and wind data are provided as tools that are easy to understand for both industry and community users, and the constantly accumulative information provides research structures that can identify trends and provide platforms for air dispersion overlays.

7.2 Training workshops

7.2.1 Community Odour Wheel

Odour wheels provide a way in which to communicate the olfactory qualities of a particular type of odour source. As a way to improve biosolids management, another goal of GC-MS/O research at UNSW was to create an Odour Wheel for biosolids processing which was assisted with the research conducted in **Chapter 4**. This provided a way for trained panellists to identify particular biosolids odours. However, the relative depth of the Biosolids Odour Wheel was considered too complex for community distribution as it requires a moderate degree of training. This reduced the degree to which community and industry could discuss environmental malodours. As a result, a new Odour Wheel was designed in order to provide a common language platform between community and industry.

In order to establish a common language approach, we created a "Community Odour Wheel" derived from the previously designed biosolids odour wheel and modified after responses regarding odour identification in the community survey, as well as descriptors from the conference and community group odour testing (**Figure 37**) (Vandegrift 1988). This Community Odour Wheel fulfilled several goals with regards to addressing the issue of providing a common language approach. Firstly, the Community Odour Wheel provided sufficient descriptors to include not only odours commonly associated with WWTPs, but also odours that could be experienced within a typical community. In this way, any misattributed odours or odours causing concern but without a WWTP origin can be correctly classified. The Community Odour Wheel, owing to its simplicity, is able to adopted with a minimal degree of training. Finally, the Community Odour Wheel was readily translatable into the online platform, albeit without its “wheel” component; this allowed for site operators and community contributors to use the same language to assess odour incursions. Recording responses made by the community and industry regarding certain odours revealed particular odorant’s qualities for future analysis as well as provide an easy visual analysis (termed “olfactory signature”) for adoption by site operators.

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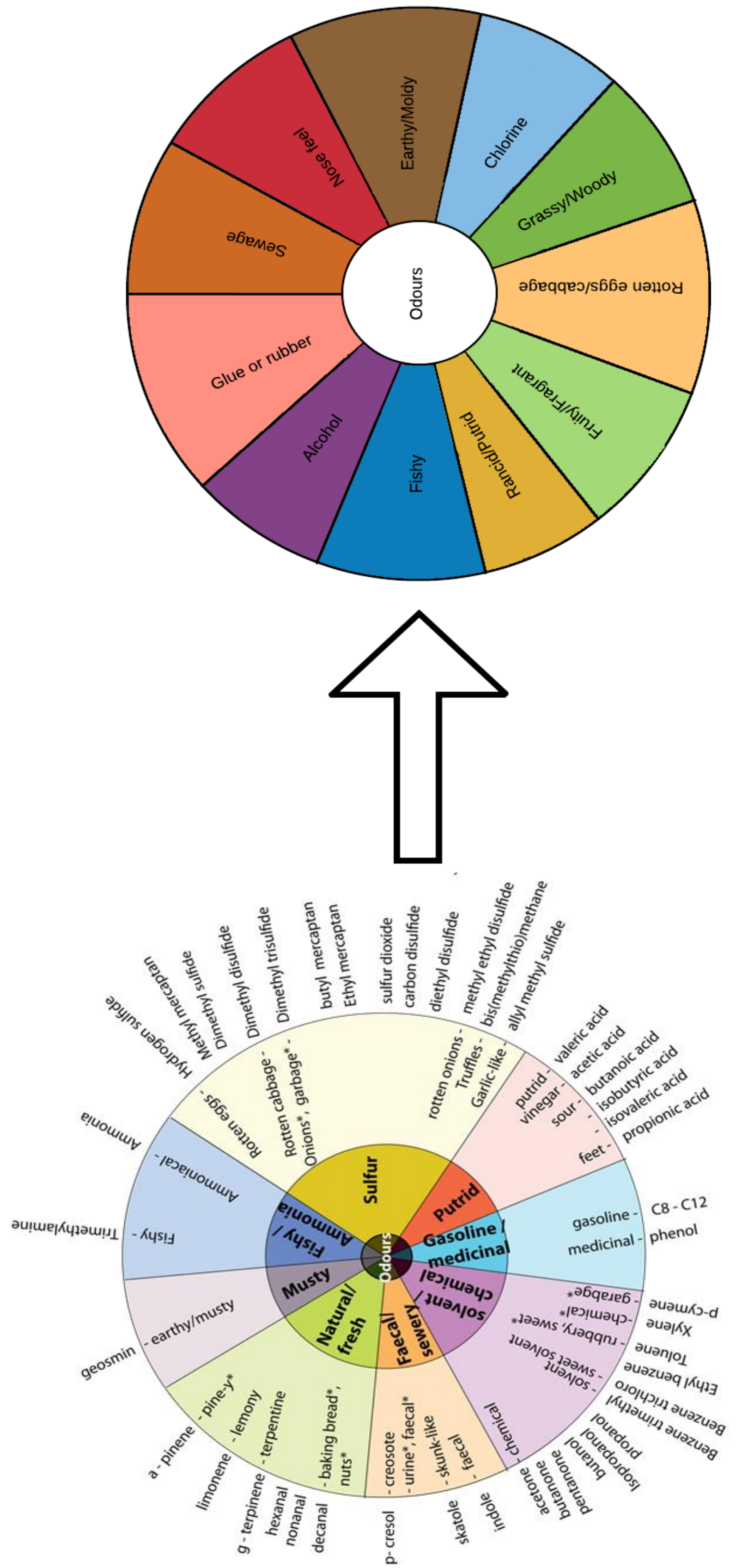


Figure 37. Transition from WWTP odour wheel to Community Odour Wheel.

7.2.2 Site operator training and community interaction

Site operator workshops were designed to familiarise site operators to community odour wheel and subsequent identification, as well as the online component of ODEC. The Community Odour Wheel was implemented to site operators via a workshop (WWTP5 only, August 2015). Operators were supplied with a worksheet which consisted of a Community Odour Wheel as well as space to make further descriptions of odorants encountered. This workshop was designed not only to familiarise site operators with the Community Odour Wheel, but also to encourage and show the online component when malodours were experienced at the WWTP. A further requirement was to make the workshop as succinct and easy to implement as possible; reducing the demands of the workshop would encourage future uptake and implementation. Site operators were trained in a relaxed setting due to no requirements for experimental rigour; these minimised settings further improved future uptake.

Several trials of the workshop were conducted. This involved presenting diluted odorants in sniff bottles (odorant concentrations found in **Table 20**). Site operators were instructed to sniff the odorants in any way that they found effective, including puffing or sniffing the cap. Site operators were encouraged not to discuss amongst themselves what qualities the odorant were, or what it reminded them of, until everyone had reported their results. For each odorant, site operators were instructed to write the number of the odorant in the part of the community odour wheel that they felt it corresponded to most. Site operators could include multiple Odour Wheels segments if desired. Additionally for each odorant, there was space on the worksheet for site operators to further define what they smelt, what it resembled, or what origin they believed the odorant to originate from. Community workshops were considered for communities where dissatisfaction and action were high. These highly dissatisfied communities could be arranged to have workshops within community centres. However, the relative disinterest of community members at WWTP5 meant that future Community workshops of this nature were unfeasible.

Pilot testing was used to determine which odours to use and at what concentrations. Odorants were selected for their ability to cause annoyance as well as their likelihood for exposure within a WWTP setting. Additional odorants were added to include contrast to WWTP odorants, as well as to further familiarise site operators with olfactory identification. Originally this test was included four odorants: dimethyl trisulphide, ethyl mercaptan, valeric acid, and limonene. After trial runs we found that dimethyl trisulphide, ethyl mercaptan, and valeric acid (*i.e.* malodours) were often described as being very similar to each other, often labelled as “putrid” or “disgusting”. We determined that by reducing odorant concentrations as well as introducing other, varied odorants in between malodours both expanded the use of the odour wheel, as well as provide a better olfactory perspective between the malodours (**Table 20**). As a result, we included rose and eucalyptus for their dissimilarity with other odours tested, as well as their ease of acquisition.

Table 20. Odorants and their concentrations for site operator workshops

Odorant	Pilot testing concentration	Testing concentration
Dimethyl trisulphide	1:40000	1:80000
Ethyl mercaptan	1:40000	1:80000
Valeric acid	1:40000	1:80000
Limonene	1:5	1:20
Rose	-	1:10
Eucalyptus	-	1:20

7.2.3 Site information distribution

PM5 supplied information regarding the workshops via email to WWTP operators who booked in specific times. Operators were made aware of the URL to the online component through A3 posters placed at workstations around WWTP5.

Information about the site and the ODEC was distributed to the community in several methods. As a part of the previous survey research, participants were provided with contact information for future research opportunities. This did not garner any responses for the ODEC area. Secondly, a new round of surveys were distributed at the request of WWTP5 management which also included contact information for researchers as well as the direct link to the online application. Unfortunately, this also produced very few responses. Subsequently, WWTP5 provided the contact information for several community members that complained about WWTP5. We contacted these community members who were informed and agreed to use ODEC for future odour observations. In this way, what could be considered pre-cursors to multiple complainants were functionalised into odour observers (Robinson *et al.* 2012). It was also anticipated that the industry interaction and opportunity to communicate on a new platform would improve community relations (Lockie *et al.* 2008, O'Faircheallaigh 2013). Finally, WWTP5 distributed flyers including the website information to the surrounding community.

7.3 Online platform

7.3.1 Online implementation

Online training for WWTP employees consisted of discussing and providing examples of operations available for the site operators as outlined in **Section 7.2.2**. Sydney Water was provided with a standard operating procedure manual for the ODEC system. We encouraged feedback from site operators in regards to ways to improve the design of the online component.

The Odourmap™ platform (Olfasense, Germany) provides several modular functions for use, which were customised based on the requests of Sydney Water as well as integration within the ODEC system.

Weather data was difficult to obtain from WWTP5 despite a weather station situated on the roof of the building. Concerns were raised by Sydney Water for data to be transmitted in real time onto a foreign server, and after several discussions this data source was abandoned. A substitute was provided by the Bureau of Meteorology which operates a weather station in near real time located approximately five kilometres north-east of WWTP5.

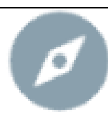
Several features were implemented at the request of Sydney Water. These included:

- No map icons indicating the location of WWTP5 or other industries. Sydney Water wanted to minimise the amount of visibility for WWTP5, as a result all icons indicating the location of industries were removed.
- Environment observations also included an ability to report noise and other observations. This was facilitated to reduce a community-perceived onus on malodours.
- All observational data restricted to system administrators. Concerns were raised that by showing the number of odour observations that this could "activate" the community. As a result, observational data was restricted to WWTP5 management, researchers, and Odourmap™ personnel.

7.3.2 Functions for registered online ODEC users

Registered ODEC users are provided with several functions in order to make informed observations as well as be provided with information from WWTP5. Several tools are restricted for registered ODEC users. Registered users are not able to view any other observations made by other users or themselves. Several tools are also unavailable for registered users but are implemented by system administrators. All of these functions were available through the use of labelled icons (**Table 21**).

Table 21. Registered observer functions and their icons

Function	**Image**	**Description**
Sign in/out		This gives an individual the option to login or sign up to the system. Originally this was an option if individuals were interested in follow-up contact; however concern was raised that it could result in frivolous complaints. Subsequently, users have to register to ODEC in order to make online observations.
Your profile		This provides the user with information on their profile as well as the opportunity to edit corresponding email address and password.
News		The news tab provides registered users information from system administrators regarding environmental or community based issues. For example, this tool could inform users that the WWTP is planning site maintenance that could inadvertently spread malodours. This tool currently provides an introductory screen to the ODEC platform, which includes links to assist with usability.
Select another language		The application has multiple alternative languages including German, French, Spanish, and Portuguese.
List of meteorological data		This provides a menu of the latest meteorological data from the nearby weather station. If desired, this information can be exported by the user.
Windrose		This activates the small windrose of the Kurnell weather station at the bottom right hand corner if the windrose has been switched off. The windrose is on by default. This tab provides a more detailed windrose that can be manipulated by use of the “time bar” at the bottom of the screen.
Statistical windrose		This tab provides a more detailed windrose that can be manipulated by use of the “time bar” at the bottom of the screen.
Register an observation		This allows the user to register an odour, noise, or “other” observation.

7.3.2.1 Register an observation

Registering an observation is likely to be the most used feature of the application. This involves several steps to log an odour observation within Site 5 WWTP (**Figure 38**).

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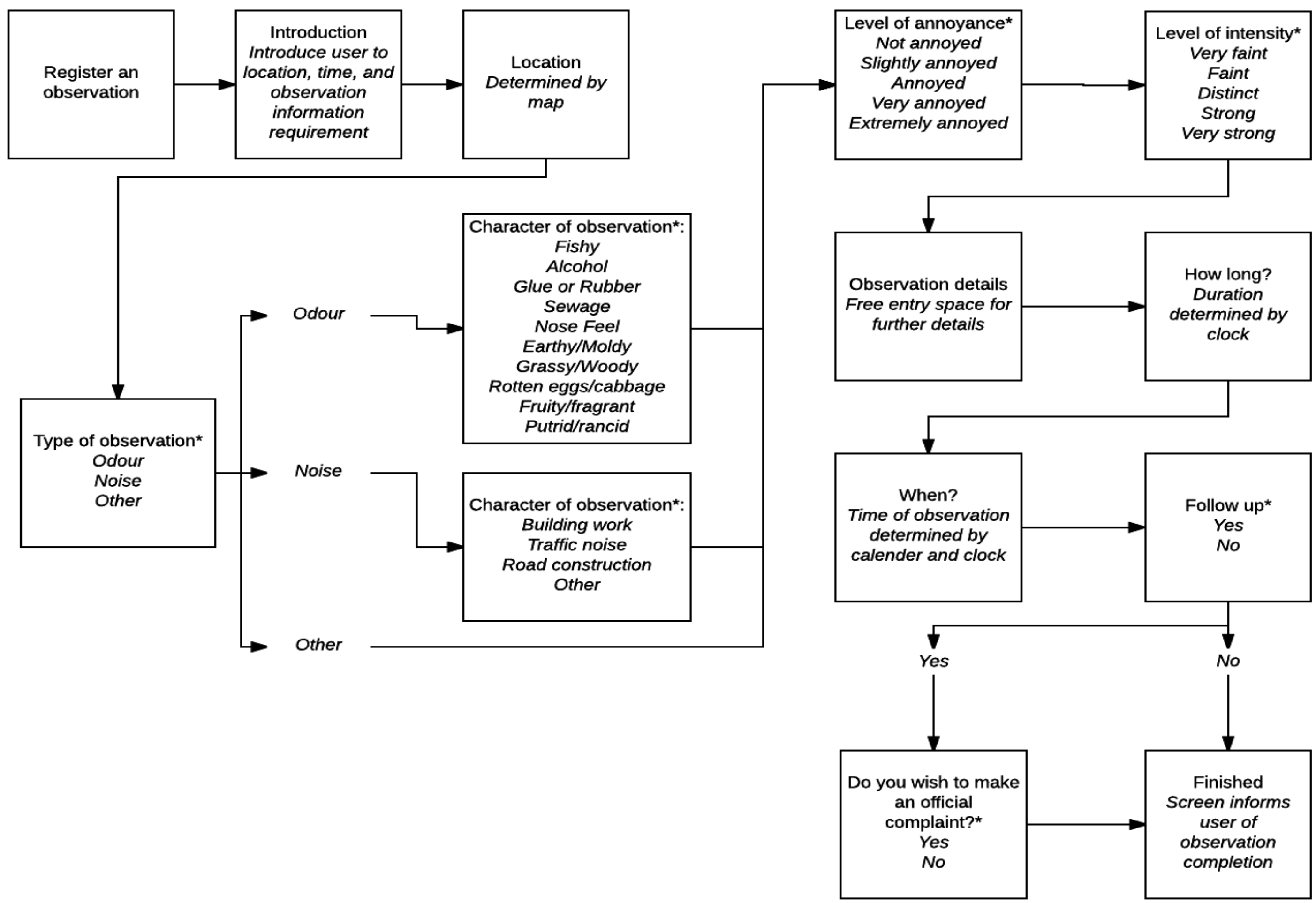

Figure 38. Flowchart of how to register an observation using ODEC.
Text in *italics* provides a description of the screen. Note: an * in a screen denotes that text in italics are user options.

Introduction

This is the first page of making an observation that informs the user of the process, which involves specifying location, observation, and temporal variables.

Location

This brings up a Google Map plan of the local area with a crosshair icon. Clicking and dragging can adjust the crosshair icon, and mouse scrolling determines the zoom. The participant must target where the observation event occurred.

Type of observation

Observations are divided into odour, noise, and other. Noise and other observation types were included as a request from Sydney Water so as to de-emphasise the importance of odour observations.

Character of observation

This option relates to defining the observation type previously confirmed, each of which have specific definitions. The odour observation type can be defined as a section of the community odour wheel, as well as an “other” option. Noise observations are defined as building works, traffic noise, road construction, or other. The Other observation type is not definable; as a result, it is describable within the “Observation details” screen.

<u>Level of annoyance</u>

This is a five item Likert scale ranging from not annoyed to extremely annoyed. Alongside the "level of intensity" measure, the "level of annoyance" is useful when identifying the degree of community dissatisfaction.

<u>Level of intensity</u>

This is a five item Likert scale ranging from very faint to very strong.

<u>Observation details</u>

This is a section where the user can add additional details. These could include situations surrounding the observation, as well as adding more odour qualities, or any information the user feels is pertinent.

<u>When?</u>

This option brings up a calendar and clock for the user to record at what time the observation event occurred.

<u>How long?</u>

This option allows the user to choose for how long the observation occurred.

<u>Follow up</u>

This option relates to whether the user would like further information from WWTP5, and whether they would like to register the observation as an official complaint. This section ends the odour observation component.

7.3.3 Functions for system administrators

By using the current setup, system administrators can obtain information pertaining to odour observations and inter-industry communication. Information regarding odour observations can be accessed by using the system itself, or by exporting data to an appropriate program such as Microsoft Excel (**Figure 39**). Visualisation of the complaint information is assisted in the morphology of the time bar and map. Both the time bar and map can be extended or shrunk to virtually any range required. This ability allows system administrators to identify specific observations at specific times, or to visualise observations as a part of a trend.

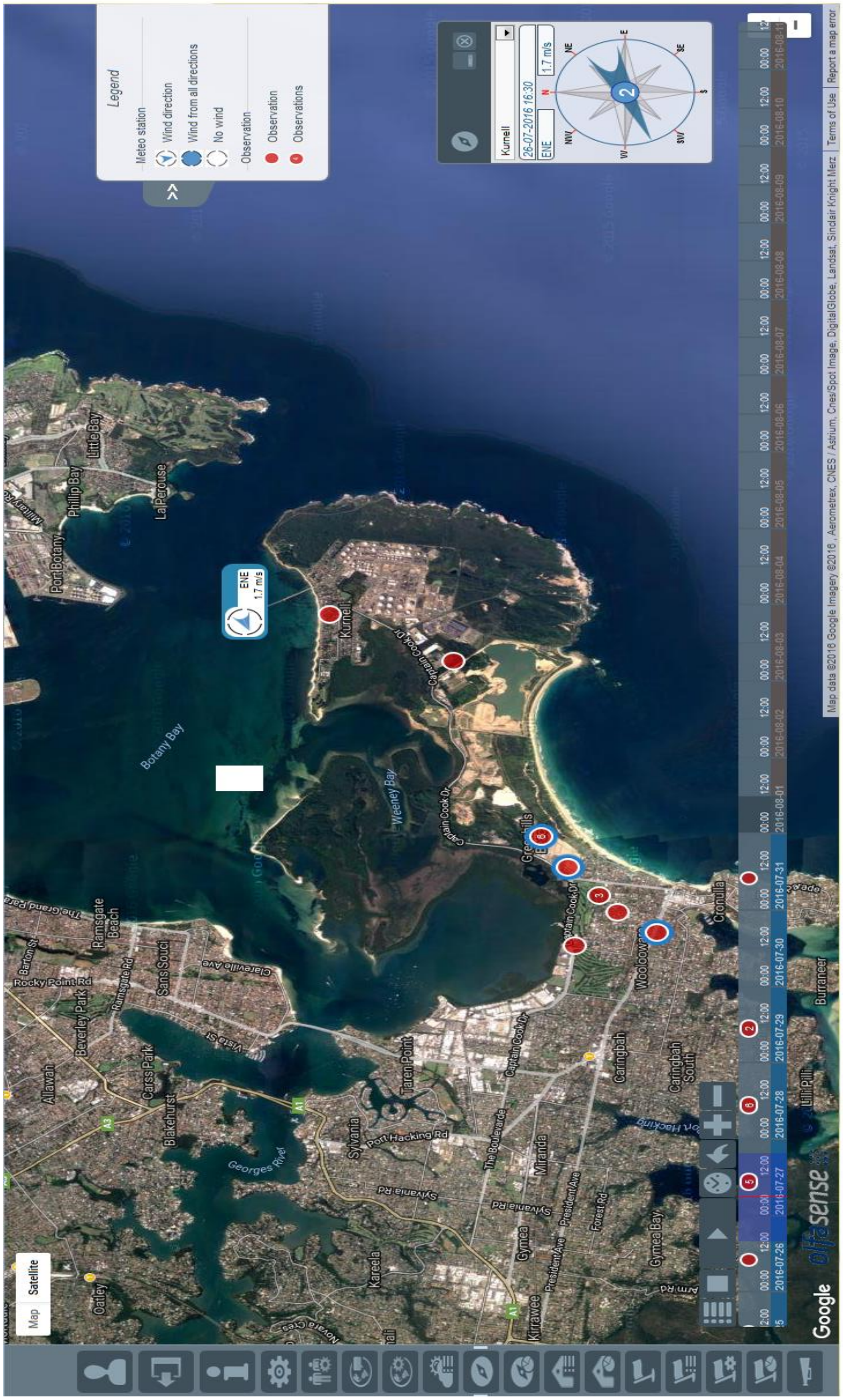

Figure 39. Example of ODEC screen. Red dots on the map and time bar represent odour observations. Those observations highlighted in blue are currently selected, and the weather information provided by the bottom right windrose adjusts to provide weather information at the time of the observation. Clicking on any red dot provides the system administrator with the specific time, observation description, intensity, and additional comments.

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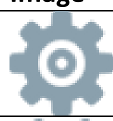
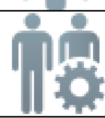
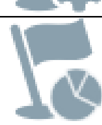
System administrators have additional functions and tools available to them in addition to those provided to registered ODEC users (**Table 22**). These additional functions and tools are mostly relating to data analysis of environment observations as well as being able to create news bulletins.

Table 22. Additional system administrator functions and corresponding icons

Function	Image	Description
System configuration		System configuration controls which modules of the site are active, and who has access to them.
User list		This function lists users and can also create new user names and passwords.
Store current map		Sets the map location for initial opening of the site for all users
Facilities		The facilities function is to map various facilities within a given map. This function is not used as Sydney Water did not want to draw unnecessary attention towards its WWTPs.
Facility summary		Facility summary provides a dropdown list of labelled facilities.
Manage observations		Manage observations provides a drop down menu containing logged observation history. This data can also be exported. This information is privy to system administrators only.
Management observation types		This function allows for observation types (such as odour and noise) to be modified as required.
Observation statistics		Observation statistics interacts with the time bar to provide characteristics of observations within a given time period. This includes pie charts to determine the proportions of observation characteristics (such as fishy odour), and the comparative annoyance and intensity estimates of each characteristic respectively.
Manage articles		This tool allows system administrators to design and publish articles which are then visible to registered users.
Time Bar		The time bar runs along the base of the screen and is used in monitoring when observations are recorded. The time bar can accommodate for virtually any duration of time.

7.3.4 Smartphone application

The online component of ODEC is also available as a smartphone application for iPhone and Android. The smartphone application behaves similarly to the “sign up” and “register an observation” components, except that the observation registration also has the ability to identify a user’s current location using their smartphones location services.

7.4 Results

7.4.1 Workshop results

Using site operators, we established the olfactory signature of six odorants using the Community Odour Wheel, establishing the relative proportion of odour qualities (**Figure 40, Panels A-F**). We found that the different descriptors used by the Odour Wheel produced effective olfactory signatures that differentiated odorants from each other, and that each section of the odour wheel was represented. We also investigated the terms and qualities used by site operators to describe these odorants (**Figure 41, Panels A-F**). We found that, unlike other stakeholders related to wastewater treatment, site operators were capable of accurately associating malodours to processes within the WWTP, albeit with varying degrees of success dependent upon the odorant. The variation with the descriptors, as well as the odour wheels, was expected thanks to the olfactory variability of participants tested (Doty 1991b, Doty *et al.* 2001).

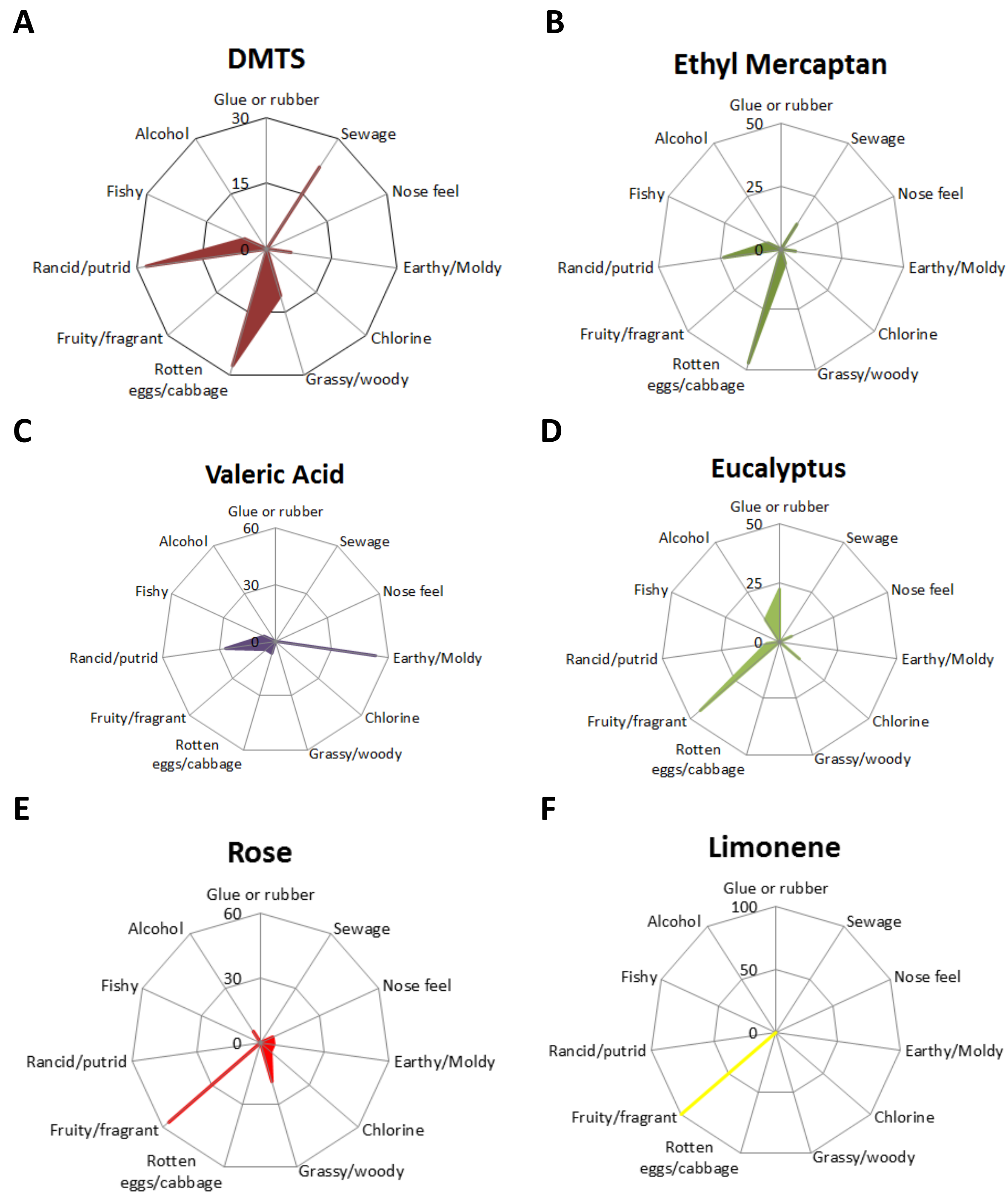


Figure 40 (Panels A-F). Olfactory signature of several Odorants using site operators and community odour wheel. Panels (A): Olfactory signature of DMTS; (B): Olfactory signature of ethyl mercaptan; (C): Olfactory signature of valeric acid; (D): Olfactory signature of eucalyptus; (E): Olfactory signature of rose; (F): Olfactory signature of limonene.

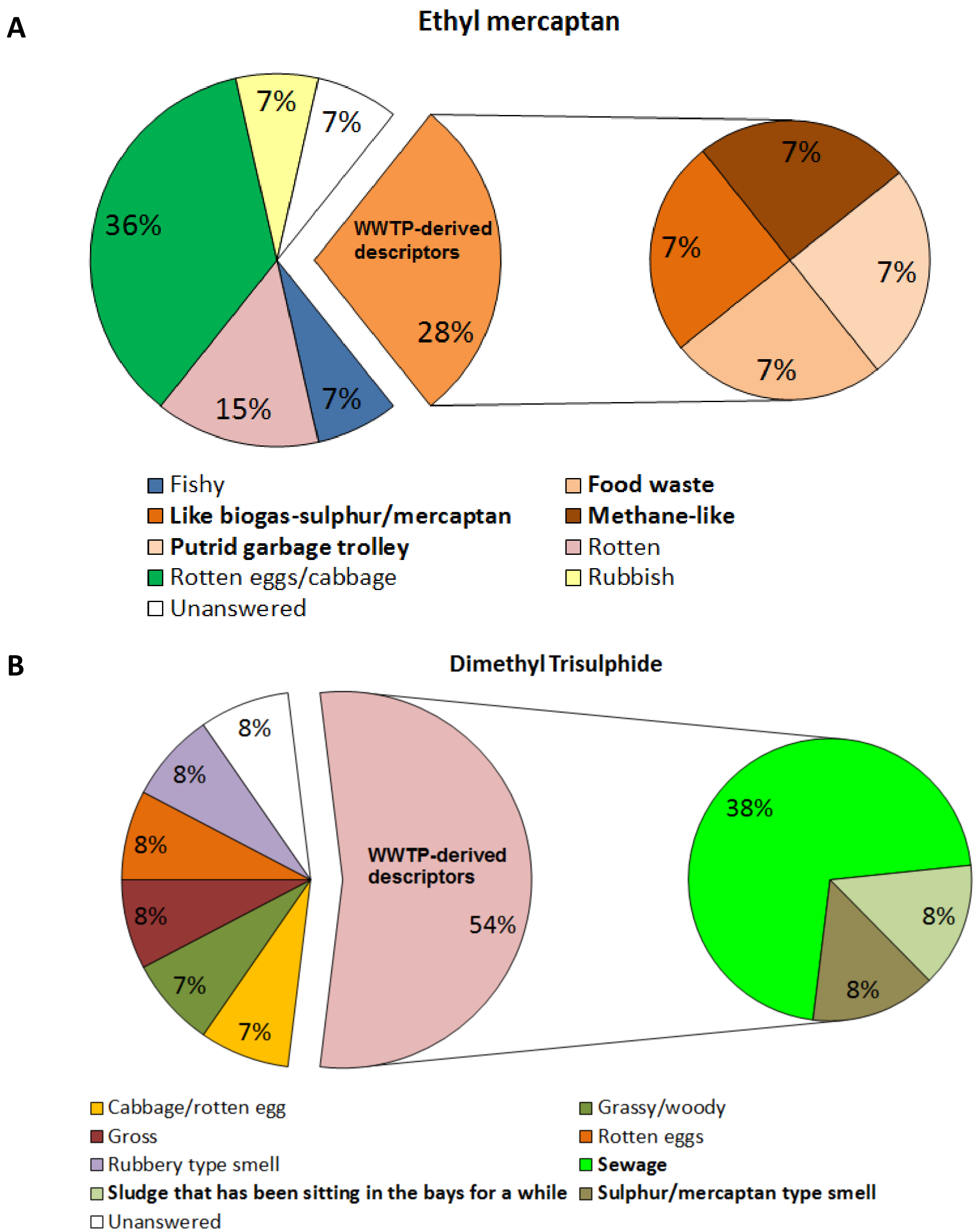
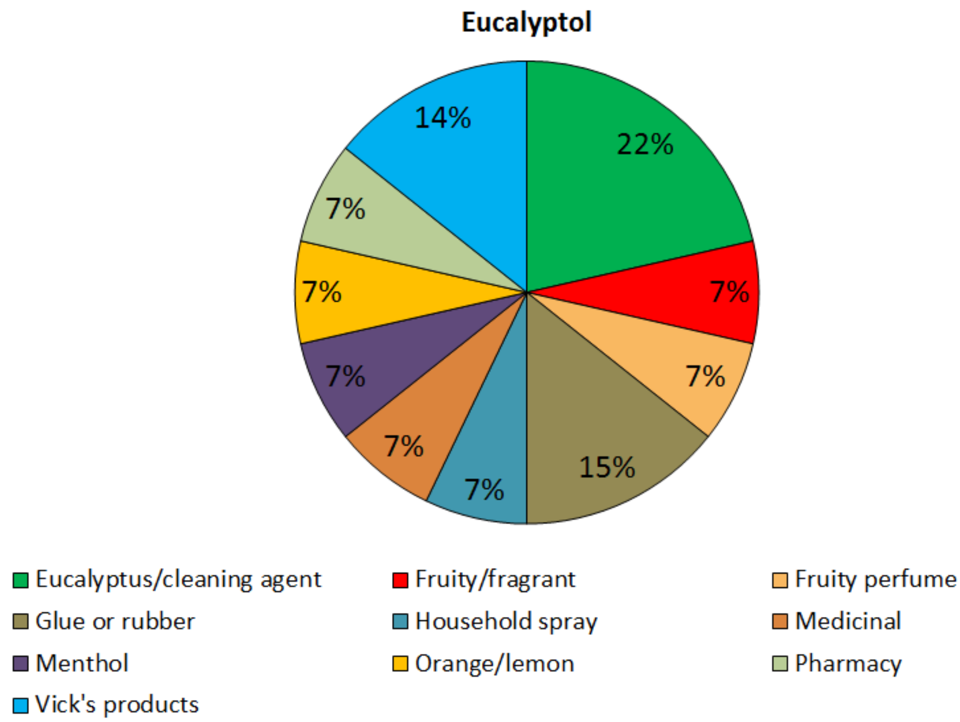


Figure 41. Odorants and their descriptors and prevalence for Round 2 workshops. Odours listed in **bold** are those associated specifically with wastewater treatment processing.



D

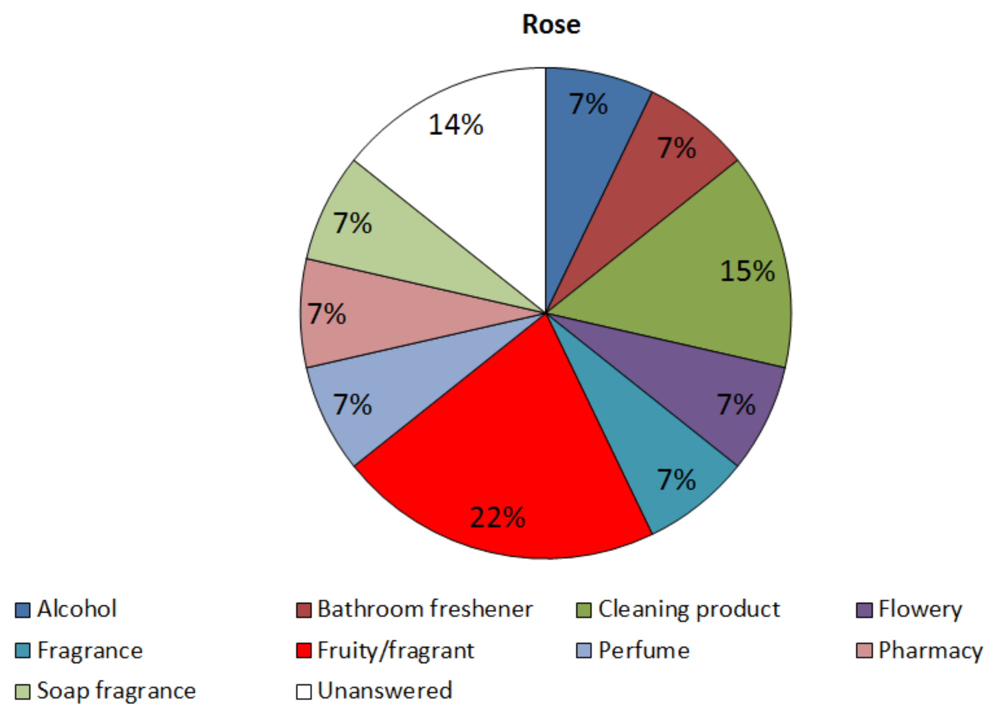
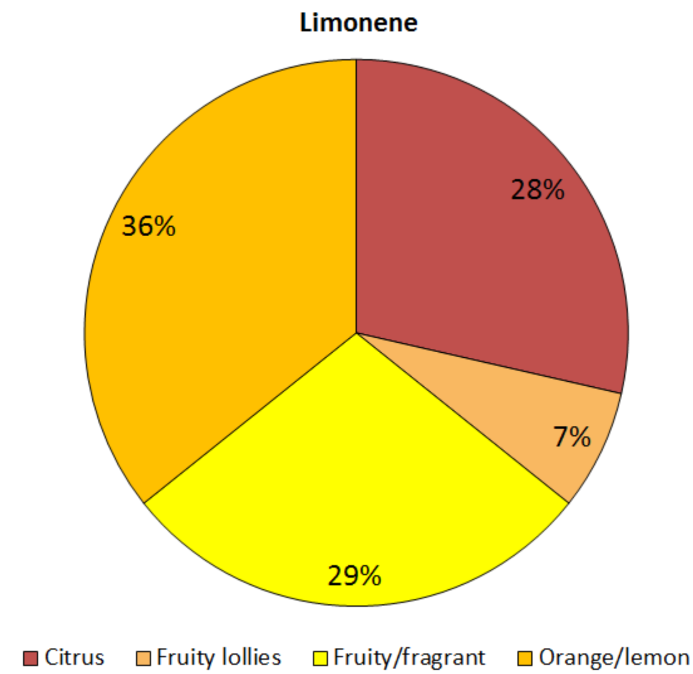


Figure 45. Odorants and their descriptors and prevalence for Round 2 workshops *(continued)*. Odours listed in **bold** are those associated specifically with wastewater treatment processing.

E



F

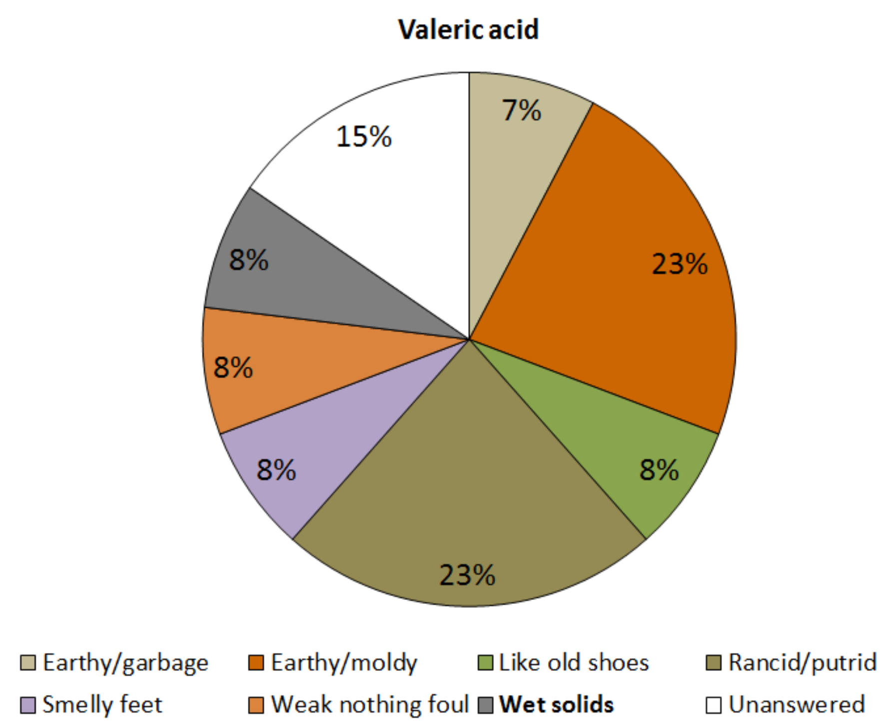


Figure 45. Odorants and their descriptors and prevalence for Round 2 workshops *(continued).* Odours listed in **bold** are those associated specifically with wastewater treatment processing.

7.4.2 ODEC reports

The ODEC system, when properly implemented, can produce accessible information with regards to complaints, their location, weather information, and relative odour qualities. We found that there was variation in the adoption of the ODEC system between site operators and members of the community, with very few community members using the system, with only two observations (one of which was noise based). However, a small number of complaints made by the community suggests that this outcome is to be expected, and with a similar reduction of odour observations from site operators, proposes that the WWTP is operating sufficiently as to not cause complaints (**Figure 42**). An additional factor to consider is that WWTP5's plant manager was personally contactable by community members as this sort of person to person engagement likely reduced the desire to use ODEC.

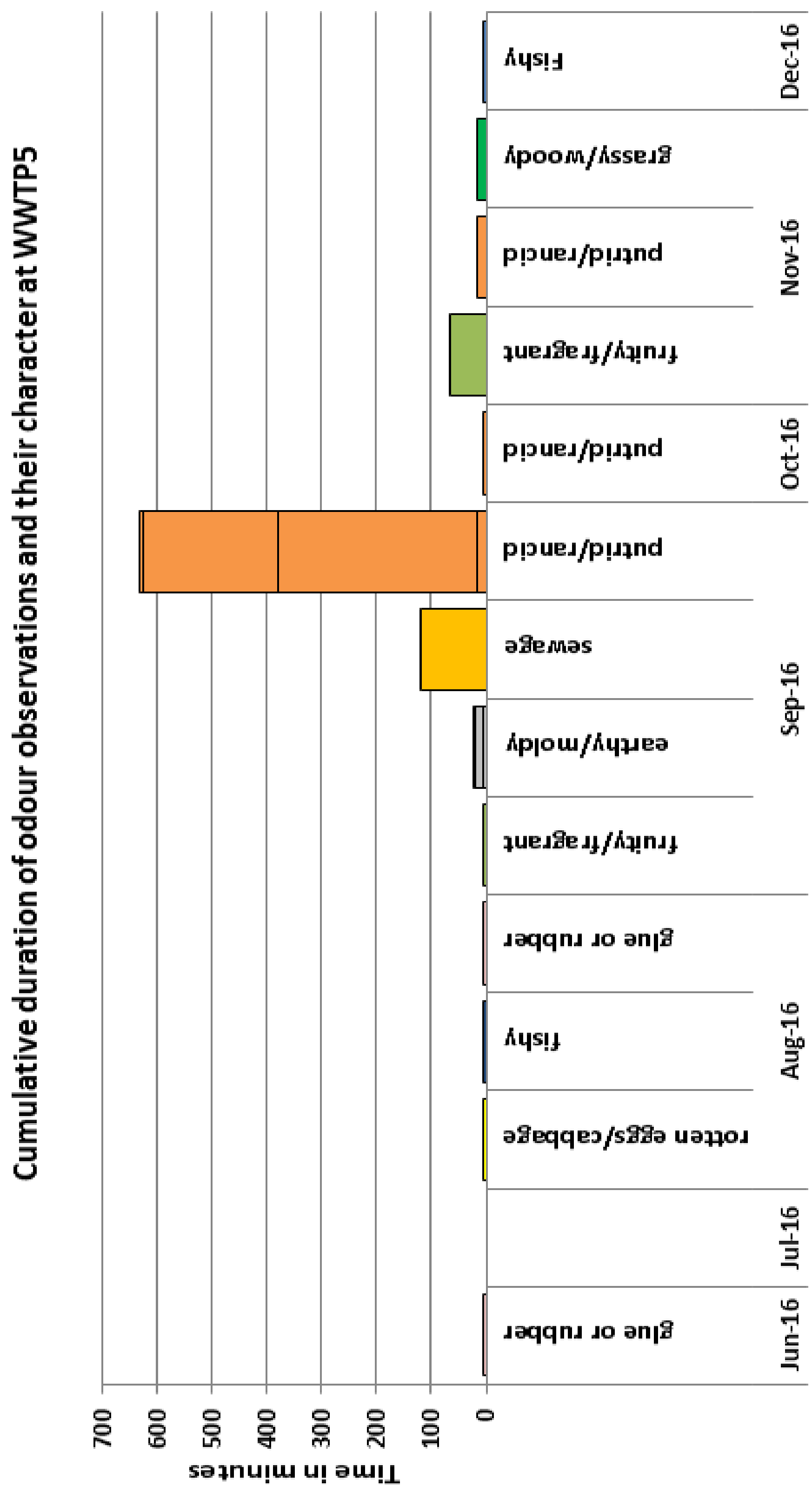


Figure 42. Cumulative duration of odour observations and their character gathered from ODEC for WWTP5 between June-December 2016

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Obtaining data from the online platform, we charted the cumulative odour observations at WWTP5 based on their characterisation (**Figure 42**). We found that September 2016 produced highest number of observations, as well as observations that were experienced for the longest duration. The two longest odour experiences were characterised as putrid/rancid in September 2016. Revealingly, the log for these complaints reported that these complaints were made by contractors, and not full time site operators. These observations could therefore be explained by variations in odour habituation (Kobayashi *et al.* 2008). ODEC logs also provided information with regards to annoyance and intensity for each odour observation. However, while annoyance and intensity were significantly related [$F(4,14)= 8.15$, $p=0.001$, $\eta_p^2=0.70$], further observations would be preferable in establishing a relationship between odour character, annoyance, and intensity to make better associations between this sort of data collection and what was accomplished in the **Chapter 5** Community survey. Again, the relative low amount of odour observations is congruous with a historically very low complaint rate as well as a small, effectively working WWTP.

Compared to members of the community, site operators have adopted the ODEC system to report foul odour reports for themselves as well as contractors. Descriptions were representative of workshop output (**Table 23**). Between June and December 2016, 19 odour and one noise observations were logged by site operators. These observations were universally experienced within the WWTP itself, and encouragingly, 15 of the odour observations attributed specific unit processes as origins of the observed malodour. There were no user suggestions recorded on how to improve the ODEC program.

Table 23. Example of ODEC report

Character	Time	Duration	Annoyance	Intensity	Comment
Putrid/rancid	2016-11-03 07:00	00:15	Very annoyed	Strong	Food waste smell has grown stronger as tank has sat idle without receiving a fresh load.

7.5 Discussion

In this Chapter, we designed and implemented the ODEC system. This tool is based on identified key factors from previous Chapters as well as other environmental malodour studies. In particular, ODEC emphasises the creation of a common language between community and industry, inter-industry communication, as well as a platform that harnesses community action to develop augmented engagement practices.

Community engagement is pursued predominantly by either research or community interaction paradigms, each of which have differing but related goals. By identifying knowledge gaps and avenues of exploration from other and previous Chapters, we have designed and implemented the ODEC system as a method by which to improve both community interaction and research outcomes. Of note, we have established a common language approach to addressing environmental odours, engaged in community-based communication, increased community-industry transparency, as well as created a new, easy to interpret avenue of research that can lend itself to other, more established methodologies.

We found that, unlike other industry stakeholders we investigated in **Chapter 6**, site operators were capable of identifying odorants in relation to their unit process origins, even if habituation appears to influence odour reports. Recording odour reports from site operators formalises what has been anecdotally adopted as a way of identifying the status of unit processes by some site operators and plant managers as discussed in **Chapter 6**. Characterising odours in this way is a marked improvement over other formal systems that simply investigate the presence of an odour. Additionally, this system provides management with real-time and readily interpretable information.

The ease of which this odour information is understood means that it is more likely to be acted upon. Information obtained in every odour observation fulfils the requirements to log an odour event with meaningful information (Sucker *et al.* 2008a, Sucker *et al.* 2008b). The Odourmap™ design facilitates easy interpretation as to the location, identity, and severity of odour complaints. **Figure 42** provides a very simple example of how exported data from Odourmap™ can be translated into other forms of presentation. This odour reporting can be readily compared with sensor systems or WWTP site changes in order to establish trends and future expected reactions from site operators and the local community.

The olfactory signatures created from site operator descriptions displayed a good deal of diversity, as expected with olfactory variance of a standard population (Doty 1991b). This indicates that the community odour wheel is capable of defining a diverse range of odours experienced within a community. While most odorants were characterised distinctly, DMTS and ethyl mercaptan shared somewhat similar olfactory signatures. This could be due to the olfactory qualities of these odorants being somewhat similar, or that they are experienced in the same environments (Zarra *et al.* 2008). The use of these olfactory signatures could include establishing observations of an unknown odour, and comparing those observation patterns to odorant's olfactory signature (and updating the signature if need be) in order to determine what odour and concentration is causing a nuisance. It should be noted that these olfactory signatures are effective only at moderate intensities; gross odour incursions will likely be described in simpler terms. For example, a gross odour incursion of DMTS will likely be defined more readily as putrid/rancid as more subtle characteristics are obscured. However, defining a mystery odorant at a gross level would be a relatively easy task thanks to plant sensors and monitoring the prevailing health of the various WWTP unit processes.

WWTP5 provides an intriguing investigation into what community engagement establishes within a non-active community. It has been suggested that the implementation of devices such as ODEC improve community relationships simply by being used, and that this is supported by the relationship we identified in **Chapter 5** between an individual's attitudes of the industry and whether odour impacts them. It is expected that the "olive branch" provided by the local WWTP will improve the disposition of the local community (Chess *et al.* 1992, Syme *et al.* 2007, O'Faircheallaigh 2013). The comparative lack of odour observations being reported from communities by either the Sydney Water complaint database or the ODEC system seems to support this notion; however, the trend is unclear considering WWTP5 receives very low numbers of odour complaints. A promising future direction would be to apply ODEC to a more active community in order to establish more rigorous training procedures, as well as enhance the characterisation of olfactory signatures.

Future implementation of ODEC should involve the investigation of more community-active areas in order to better understand ODEC's supposed complaint-supressing effect, as well as its ability to inform WWTP design and direction. Additional directions for ODEC could include the integration of other data sources, such as sensor arrays, onto the Odourmap™ platform. Additionally, air dispersion monitoring could be easily overlaid onto existing ODEC odour observations, providing synergistic information that can establish a holistic odour monitoring program for the water industry.

7.6 Summary

Within this doctoral Thesis, we have established core factors required for successful and efficacious community engagement. This has been through a review of the research space, as well as novel research throughout the prior chapters. As discussed in this Chapter, the ODEC system is a design that addresses these unmet needs. In particular, ODEC provides a communicative platform and a common language that makes odour observations both pertinent and easily adopted by minimally trained site operators and members of the community. Additionally, this platform forms the basis to encompass other forms of odour observation, and provides a forum for PMs and stakeholders to discuss effective community engagement techniques.

Chapter 8

Conclusions and recommendations

8. Conclusions and Recommendations

Odour complaints are increasing in frequency and severity despite increasingly sophisticated techniques to reduce odour impact and improve community engagement. To investigate the interactions between the Australian water industry and the local community, we focused on six WWTPs that offered variable community-industry relationships for a multiple research technique approach.

This doctoral Thesis has incorporated a multi-faceted approach that has implemented research milestones, each of which produced independent novel findings, as well as provided information to improve subsequent research goals. In **Chapter 2**, we produced a Literature Review of the current assessment techniques for the effect of malodour on communities. We found that current assessment techniques can be broadly separated into analytical, odour assessment, and community assessment methodologies. Additionally, approaches that combined variations of these methodologies produced the most meaningful results to address community assessment.

Accordingly, we adopted multiple methodologies which progressively contributed information and concepts to further research goals. The research methodologies presented here have included an analysis of current complaint management techniques in Australia. We found that complaint management techniques are currently insufficient for appropriate information for which odour mitigation tools can be implemented, and that higher complaint WWTPs appear to indicate “active” communities with numerous multiple complainants. Additionally, complaint resolution appeared under-utilised, which was confirmed in PM interviews (**Chapter 6**).

In investigating GC-MS/O techniques within the Literature Review (**Chapter 2**), we discovered that the environmental malodour research space was restricted to priority odorant selections. As an alternative, we designed and implemented an experiment to investigate the variations of odour description and detection between individuals of average and high olfactory acuity across several odour samples of unit processes within three WWTPs (**Chapter 4**). We discovered that the variations were significant for both factors, and that this had implications when applying GC-MS/O findings to community odour impacts. The descriptors of odorants were subsequently used in designing an Odour Wheel (Fisher *et al.* 2017).

Another research goal was the creation, distribution, and analysis of a community survey across suburbs of high complaints, low complaints, and a suburb without odour causing industry (**Chapter 5**). We found that odour frequency and annoyance were significantly related to community action. Additionally, we performed binary logistic regression to establish five questions regarding community attitudes of industry that determined odour impact with 87% certainty. An additional survey was carried out with members of the water industry (**Chapter 6**). The Water Industry Survey revealed that there was a lack of understanding regarding community engagement and odour assessment tools. The

Industry survey complimented interviews conducted with plant managers of the six WWTPs. These two investigations established that community engagement is dissimilar between WWTPs, and that a lack of communication and knowledge within the industry has meant that best practice has not yet been established to the cost of the business. In addition to these two non-community stakeholder investigations, we conducted two sub-studies (**Chapter 6**). This included interviews of farmers who used biosolids, and other farmers for whom biosolids elicited a variety of attitudes. Additionally, we conducted odour workshops at academic conferences (**Chapter 6**) and discovered that researchers in the environmental malodour field supported notions investigated in the industry survey, and that odours originating from WWTP practices were suitable for future workshops.

By incorporating facets of methods from previously published literature, as well as the knowledge obtained from the research goals outlined in this Thesis, we designed and implemented the Online Dynamic Engagement for Communities (ODEC) in **Chapter 7**. This tool is based on minimal training and an online platform to produce effective community engagement strategies, reduce the risk of “multiple complainants”, and allow for inter-industry communication and further tool integration. We found during implementation that site operators used ODEC as a way by which to report on substandard performance of unit processes, and that site operator odour reports created easily understandable results that were a result of effective workshop training.

The four major contributions of this thesis have been the investigation of an enormous knowledge gap within inter-industry communication, the implementation of a comprehensive community survey, the expansion of GC-MS/O practices, and a tool that contributes to both research and community engagement paradigms. As deliverable outcomes of this Thesis, there are essential recommendations that can be made regarding complaint management, GC-MS/O methodology, community engagement, industry communication, and future ODEC implementation.

8.1 Recommendations regarding complaint management

Complaint management, as previously discussed, is sub-par for odour regulations in the water industry companies we investigated. To begin with, we recommend that complaint receivers log entries pertaining to the time, location, duration, intensity, and quality of every odour event that is reported. As a way by which to improve complaint resolution, the resolutions themselves should involve explaining how the complaint was resolved. Not only will this establish best practice procedures, but also create accountability and thereby improve community (and customer) satisfaction. Finally, the complaint recording system should be centralised before complaint dispersal throughout the SCADA systems; this will remove risks of double entries and ensure complaint logging integrity.

8.2 Broadening practices for GC-MS/O

The environmental malodour research space has used GC-MS/O as a way by which to identify priority odorants in odour mixtures. While this research is certainly effective at this goal, there are alternatives that can produce more ecological valid results and elucidate other research aims. The investigation of participants with higher olfactory sensitivity is a useful approach as it includes members of the community that would otherwise be unrepresented. As a result, their inclusion is a way by which odour impact for communities can be more comprehensively assessed.

8.3 Recommendations for community engagement practices around WWTPs and land application of biosolids

The Community Survey presented in **Chapter 5** revealed several fascinating findings. Of particular note; however, is that odour annoyance and frequency are strong factors that require attention. Additionally, attempts made to improve the image of facilities and/or industry, if effective, are capable of reducing odour complaints. The ways by which to improve this image are varied, however past investigations as well as our investigation with ODEC suggests that pro-activity and transparency are among the most likely to succeed. For future implementation of the survey tools used, it is recommended that communities of varying SEIFA levels be investigated; it is anticipated that lower SEIFA suburbs are likely to experience effects of perceived control and depression, and how that contributes to overall odour impact is worthy of investigation within the context of a non-elicited response.

8.4 Recommendations for industry communication

Inter-industry communication is a simple way to establish best practice for a host of operations, not the least of which community engagement and odour monitoring and mitigation. Similar to complaint data resolution requirements, and what ODEC provides, is that this communication should be formalised either through company organisations or communicative platforms. PMs should be able to discuss the relative issues facing their plants. Similarly, as the expectancy of water industry personnel to be ambassadors towards the community increases, they should experience integrated knowledge regarding community engagement practices and odour monitoring.

8.5 Future implications for ODEC

ODEC was implemented at a site that experiences very low levels of complaints. However, within a short amount of time even the small number of complaints were reduced to zero complaints. Nevertheless, it would have been preferable if ODEC was implemented in an area where there were measurable trends of odour complaints. In this way, odour patterns could be inexpensively identified and community engagement policies more effectively addressed. In particularly, the conversion of multiple complainants into odour observers would transform a community risk into a measurable observation. While it is reasonable to expect a degree of abuse from particularly vitriolic community members, the nature of ODEC means that there is a degree of accountability in all odour reports. If one community member reports an observation while his neighbours do not- has an odour event occurred? ODEC, at the very least, will contribute actual data to this discussion and a platform by which these issues can be meted out.

ODEC is a valuable tool as it represents both a research and community engagement outcome, as discussed in **Chapter 5**. From a research perspective, it provides a steady stream of weather data and odour observations that encapsulates community attitudes greater than current methods; subsequently, these communities can be sampled and understood with enhanced precision. From a community engagement perspective, the utilities using ODEC have a common language and easily interpretable information readily accessible. This means that utilities can enjoy independence from upper management interference up to the point that it is required, whereupon the steady stream of ODEC data will provide excellent context.

In regards to future endeavours, a system like ODEC has the potential to be company-wide and encompassing of all community and industry relationship data, much like the SCADA system currently in place. In a cloud format and with appropriate modifications, such as the addition of discussion forums, plant managers can discuss particular issues they experience, or comment on the support network of Standard Operation Procedures supplied in the ODEC design. Information sources from H_2S sensors, or air dispersion modelling could be added synergistically to further improve the information output of the system. Whole industry designs such as this can be controlled by user limitations, as indicated in **Chapter 7**, and this should provide sufficiently designed streams of data reaching intended targets such as residents, operators, and managers. Further still, additions such as real time video cameras and odour grabbers could be placed to provide further research (and potentially legislative) opportunities.

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Appendices

Appendices found on the CD component of this Thesis include:

- **Appendix 1:** Project ethics approval
- **Appendix 2:** Community survey
- **Appendix 3:** Conference and community odour testing & Biosolids Land Application Interviews
- **Appendix 4:** Water Industry Survey