AIR QUALITY IMPACT AND ODOUR ASSESSMENT FOR SHONGWENI LANDFILL

FINAL REPORT

NOVEMBER 16, 2017

CONFIDENTIAL

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FINAL REPORT

UPPER HIGHWAY AIR NON-PROFIT ORGANISATION

CONFIDENTIAL

PROJECT NO.: 48455 / 41100333-001
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This Air and Odour Assessment (Report) has been prepared by WSP Environmental Proprietary Limited (WSP) on behalf and at the request of Upper Highway Air (Client), to provide the Client an understanding of the Relevant Documents.

Unless otherwise agreed by us in writing, we do not accept responsibility or legal liability to any person other than the Client for the contents of, or any omissions from, this Report.

To prepare this Report, we have reviewed only the documents and information provided to us by the Client or any third parties directed to provide information and documents to us by the Client. We have not reviewed any other documents in relation to this Report and except where otherwise indicated in the Report.

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EXECUTIVE SUMMARY

Upper Highway Air (UHA) is a non-profit organisation (NPO) established in 2016 in response to the increase in frequency and intensity of odour nuisance and health impacts experienced by the communities of the Outer West region of Durban, KwaZulu-Natal. The NPO ascribes the source of complaints to emissions from the EnviroServ (Pty) Ltd (EnviroServ) Shongweni Landfill. The volunteer-run body relies on community and donor funding to provide the public with information and a complaints platform, as well as legal representation for registered interested and affected parties (I&APs). UHA appointed WSP Environmental (Pty) Ltd (WSP) to undertake an independent air quality assessment to:

- Determine possible exposure pathways through a comprehensive review of meteorological scenarios under which odour episodes are likely to be experienced at sensitive receptors;
- Evaluate the extent of odour exposure through a geospatial analysis of the community complaints database and sensorial monitoring conducted for UHA by e-Nose Africa cc;
- Identify the odorous compound/s in the air experienced by the community as an odour nuisance using appropriate monitoring techniques;
- Undertake predictive modelling to determine the dispersion potential of odorous emissions from the Shongweni Landfill;
- Qualitatively and quantitatively evaluate the impacts of this odour on the Upper Highway area; and
- Conduct peer review of air quality related studies conducted by EnviroServ's experts.

The UHA community complaints database revealed that 85% of complaints reported the odour in residential areas within a 5 km radius of the Shongweni Landfill, including but not limited to, Hillcrest, Winston Park, Gillitts and Assagay. 73.7% of odour events coincided with southerly wind trajectories (i.e. south-westerly – south-easterly) while 7.2% of events were experienced during calm conditions. The majority of odour events occurred between 06h00 and 09h00 and 19h00 and 02h00. The odour was described as 'refinery' (43%) 'chemical' (40%) or 'sulphur-type' (13%) and accompanied by a variety of health symptoms.

A passive ambient air quality monitoring campaign was conducted in 2015 and 2016 by Geozone (Pty) Ltd (Geozone) for EnviroServ. Average benzene concentrations measured below the National Ambient Air Quality Standard (NAAQS) of 1.6 ppb but annual average H_2S exceeded the World Health Organisation (WHO) odour detection threshold (0.1 ppb) and annoyance guideline (5 ppb on a 30-minute average). H_2S measurements onsite at the Shongweni Landfill exceeded the WHO health guideline (107.6 ppb on a 24-hour average). A short-term campaign (hourly) using Radiello samplers was conducted by Geozone for EnviroServ at the residences of community volunteers during an odour event. H_2S concentrations exceeded the WHO odour detection threshold (0.1 ppb) at all locations while 5 out of 6 of the monitoring points also exceeded the WHO annoyance guideline (5 ppb on a 30-minute average). All VOCs fell below detection limits. EnviroServ concluded from these results that it was unlikely that persons would experience or develop adverse health effects as a consequence of inhalation exposure to these measured ambient concentrations.

A continuous electronic nose (e-nose) monitoring campaign was conducted by e-Nose Africa cc (e-Nose) for UHA in 2016. e-Nose found a baseline odour with a similar signature to the odour measured at the landfill boundary. Two significant odour events occurred during the monitoring period. The first did not correlate with the typical Shongweni Landfill odour signature. While the first event may have been a household odour event (e.g. a cooking episode), the second odour event was a strong and sustained episode, near identical in character and intensity to that of the landfill boundary measurement. A strong southerly wind trajectory was measured during this odour event.

WSP conducted four volatile organic compound (VOCs) and one hydrogen sulphide (H_2S) sampling campaign for UHA. Samples were captured using Tedlar Bags and sorbent tubes for analysis by a South African National Accreditation Society (SANAS) accredited laboratory. The sampling campaigns revealed a consistent array of VOCs across samples. These included benzene, toluene, ethylbenzene, m/p-xylene, o-xylene, styrene, tetrachloroethene (Campaigns 1 and 2) and trichloroethene (Campaigns 3 and 4). This spectrum is consistent with the results presented in the Re-energise Africa (Pty) Ltd. report (Appendix G, Final Envitech Report, 17 March 2017), except for styrene which appears to have not been tested for in the *Re-energise Africa* assessment.

WSP's VOC Campaign 4 (09 June 2017) was blank corrected and samples were collected upwind and downwind of the EnviroServ Shongweni Landfill. The downwind samples included a community sample, collected at Plantations Estate. Results were as follows:

- In the upwind sample, all volatiles were below detection level except ethylbenzene (0.10 µg/m^3 in one sample), m/p-xylene (0.03 µg/m^3 in one sample) and toluene (average 0.38 µg/m^3 for the two samples).
- The downwind concentrations of benzene, ethylbenzene, m/p-xylene, o-xylene, toluene and styrene show the highest values across the three sites. This suggests the landfill is the source of these pollutants.
- These pollutants remained detectable at the community receptor, Plantations Estate, but at concentrations below those of the samples collected immediately downwind of the landfill site (except for trichloroethene, which was found to be higher within the community than immediately downwind of the site).
- Of particular relevance are the benzene concentrations (downwind average of 23.74 µg/m^3 on an averaging period between 15 and 20 minutes, and Plantations average of 17.53 µg/m^3 on a 20-minute averaging period) that are significantly higher than the NAAQS of 5 µg/m^3 (although not directly comparable since the NAAQS is based on an annual averaging period).

The H_2S results downwind of the site on the morning of 30 August 2017 showed:

- Concentrations (187 µg/m^3 and 180 µg/m^3) significantly higher than the WHO annoyance guideline (7 µg/m^3 on a 30-minute average) and health guideline (150 µg/m^3 on a 24-hour average).
  - The smell event, however, did not persist for 24-hours.

A once off dust fallout (DFO) monitoring survey of eight samplers located at strategic points surrounding the Shongweni Landfill and within the nearby community was conducted from 08 May – 31 May 2017 (23 days). Results revealed the following:

- Heavy metal fallout masses from highest to lowest were: DFO4, DFO2, DFO1, DFO5 and DFO8.
  - DFO4 lies north-north-east of Valley 2, along the south-south-westerly wind trajectory, which has high average wind speeds.
  - This site is also proximate to the Denny Mushrooms farm, another potential source of dust.
  - DFO2 is the most proximate sample to Valley 2 (as DFO6 was stolen).
  - DFO8 was the furthest site from the Shongweni Landfill.
- Mercury fallout was below detection level at all sites; and
- Barium and zinc were the heavy metals with the highest DFO rates (by mass) across the sites.

In the absence of validated emissions data for the Shongweni Landfill, a unity model (i.e. using an emission rate of one unit, in this case, 1 g/m^2/s) was run in CALPUFF View 8.4 for the area of Valley 2. Ambient concentrations calculated are relative concentrations, showing the atmospheric dispersion pattern across the landscape and revealing areas of highest potential impact. A tentative model calibration was conducted using ambient air quality monitoring data. Results for the specified sensitive receptors indicated:

- The Denny Mushrooms farm and an isolated house to the north-east of the landfill site showed the highest levels of exposure across averaging periods;
- Waterberry Close showed the third highest Rank 1 hourly average concentration.
- Ingane Yami Children's Home showed the fourth highest Rank1 hourly average concentration;
- The schools with the highest levels of exposure are Kwamanzini Primary School (Rank 1 hourly) and Ntee High School (Rank 1 24-hour and annual average).
- Rank 1 hourly benzene concentrations above 5 µg/m^3 occurred at Denny Mushrooms Farm (11.10 µg/m^3) and at House 1 (7.03µg/m^3). This falls below the short-term TCEQ ESL;
- Annual average benzene concentrations fell below the NAAQS (5 µg/m^3 on an annual averaging period) at all selected receptors;
- Rank 1 hourly H_2S concentrations were significantly higher than the WHO annoyance guideline (7 µg/m^3 on a 30-minute averaging period) at a number of receptors. The Rank 1 24-hour concentration does not reach the WHO health guideline (150 µg/m^3 on a 24-hour averaging period) at any of the selected receptors.

WSP's measurements for some VOCs are significantly higher than those produced in the Airshed Planning Professionals (Pty) Ltd (Airshed) report for EnviroServ (*Atmospheric Dispersion Simulations of Gaseous Emissions from the Shongweni Landfill Site, West of Durban*, and Report 16E2M01, dated 5th of April 2017). Since the odour event on the morning of 09 June 2017 extended for well over an hour, and was not an exceptional odour event (i.e. we do not expect these measurements to

represent worst case odour concentrations), WSP's results bring into question the dispersion modelling outputs in the Airshed assessment. Our concern is that the underestimates of ambient concentrations by the Airshed simulations could be indicative of inaccurate emission inputs to Airshed's CALPUFF model. The source of this issue would be the concentration and flux data provided to Airshed by Infotox (Pty) Ltd (Infotox). This could bring into question the results for all the VOCs and other odorous compounds, for which emission rates were developed from the Infotox dataset.

Other significant flaws in the Airshed assessment include:

- A short simulation duration which not only fails to meet the requirements set out in The Regulations Regarding Air Dispersion Modelling, Government Notice 533 of 2014 (Government Gazette 37804) but also fails to model peak pollution episodes in winter when pollutant accumulation on cool, calm nights is exacerbated by pre-frontal conditions; and
- VOC concentration percentiles and averaging periods do not accurately account for intermittent and short-term odour nuisance.
  - Hourly average concentrations of the various pollutants (e.g. thiols) are not sufficient for understanding odour events, which are likely to occur on shorter averaging periods.
  - Mean hourly concentrations (the finest temporal resolution of most atmospheric dispersion models) can be converted to peak short-term concentrations (e.g. for 10-minutes averages) using well-documented statistical relationships.

It is imperative that emissions data at various emission points on the EnviroServ site is collected over time (e.g. quarterly to account for seasonal variations) using validated sampling methods to ensure that the inputs to the dispersion model are representative of the emission reality. Further, modelling shortcomings (e.g. the input of a meteorological dataset that does not cover all seasons) needs to be addressed. Only then can there be any confidence in the findings of a health risk assessment based upon dispersion model outputs.

WSP recommends the following to UHA for further study:

- Further ambient gas monitoring with a high volume sampler for VOCs, aldehydes and mercaptans during odour events
- Additional sampling campaigns for H_2S and VOCs will assist in identifying the P100 hourly and 24-hour concentrations of these pollutants.
  - This will allow for more refined atmospheric dispersion model calibration and a more representative assessment of long-term concentrations of these pollutants in the absence of continuous monitoring across the study domain.
- Dynamic olfactometry to assess odour nuisance;
  - There is the potential to calibrate e-nose results with dynamic olfactometry results and then use the e-nose for further testing.
- Both DFO samplers located to the west of the landfill (DFO6 and DFO7) were unrecoverable in this campaign. A repeat assessment with samplers to the west of the landfill site would assist with interpreting the influence of the site of heavy metal dust concentrations.
- A background DFO site at significant distance from the Shongweni Landfill site (e.g. Waterfall) also would be useful to gauge whether the landfill is the source of the heavy metals detected in the dust fallout.

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GENERAL ACRONYMS

APPA	Atmospheric Pollution Protection Act
AQO	air quality officer
ASTM	American Society for Testing and Materials
BD	below detection
BDL	below detection limit
Cal-EPA	California Environmental Protection Agency
CH_2O	formaldehyde
CH_4	methane
CO	carbon monoxide
CO_2	carbon dioxide
DEA	Department of Environmental Affairs
DEM	digital elevation model
DFO	dust fallout
e-nose	electronic nose
EPA	Environmental Protection Agency
ESL	effects screening level
GCMS	gas chromatography-mass spectrometry
H_2S	hydrogen sulphide
I&APs	interested and affected parties
ICP-MS	inductively coupled plasma mass spectrometry
KZN	KwaZulu-Natal
MAC	maximum acceptable concentration
NAAQS	national ambient air quality standards
NEM:AQA	National Environmental Management Air Quality Act
NH_3	ammonia
NM	not measured
NO_2	nitrogen dioxide
NPO	non-Profit organisation
ODT	odour detection threshold
PAH	polycyclic aromatic hydrocarbons
PM	particulate matter
PM_{10}	particulate matter consisting of particles less than or equal to 10µm in diameter
$PM_{2.5}$	particulate matter consisting of particles less than or equal to 2.5µm in diameter
QA/QC	quality assurance / quality control
SANAS	South African National Accreditation System
SANS	South African National Standards
SO_2	sulphur dioxide

STRM	shuttle radar topographic mission
TCEQ	Texas Commission for Environmental Quality
TDI	tolerable daily intact
TEF	toxic equivalency factors
TEQ	toxic equivalent
TLV	threshold limit value
UK	United Kingdom
UK EAL	United Kingdom Environmental Assessment Limit
URF	unit risk factor
US EPA	United States Environmental Protection Agency
USA	United States of America
VOC	volatile organic compounds
WHO	World Health Organisation

UNIT ACRONYMS

g/m^2/s	grams per square metre per second
hPa	hectoPascals
km	kilometres
km^2	square kilometre
m	metre
m/s	metres per second
mg	milligram
mg/m^2/day	milligrams per square metre per day
mm	millimetre
^{o}C	degrees Celsius
^{o}E	degrees east
^{o}S	degrees south
OU/m^3	odour units per cubic metre
ppb	parts per billion volume
ppm	parts per million volume
µg/m^3	micrograms per cubic metre
µm	micrometre

CORPORATE ABBREVIATIONS

Airshed	Airshed Planning Professionals (Pty) Ltd.
e-Nose	e-Nose Africa cc
EnviroServ	EnviroServ (Pty) Ltd.
Envitech	Envitech Solutions (Pty) Ltd.
Geozone	Geozone Environmental (Pty) Ltd.
Golder	Golder Associates (Pty) Ltd.
Infotox	Infotox (Pty) Ltd.
Re-energise	Re-energise Africa (Pty) ltd.
Skyside	Skyside (Pty) Ltd.
UHA	Upper Highway Air
WSP	WSP Environmental (Pty) Ltd.
X-lab	X-lab Earth (Pty) Ltd.

1 INTRODUCTION

Upper Highway Air (UHA) is a non-profit organisation (NPO) established in 2016 in response to the increase in frequency and intensity of odour nuisance and health impacts experienced by the communities of the Outer West region of Durban, KwaZulu-Natal. The NPO ascribes the source of complaints to emissions from the EnviroServ (Pty) Ltd (EnviroServ) Shongweni Landfill. The volunteer-run body relies on community and donor funding to provide the public with information and a complaints platform, as well as legal representation for registered interested and affected parties (I&APs). UHA appointed WSP Environmental (Pty) Ltd (WSP) to undertake an independent air quality assessment to:

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- Undertake predictive modelling to assess the dispersion potential of odorous emissions from the Shongweni Landfill;
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1.1 REGULATORY FRAMEWORK

The complex and dynamic nature of odour, the variability of the constituent gases over time, the influence of meteorological conditions and the subjectivity of olfactory perception all complicate the effective regulation of odour[1]. Environmental odour can have a significant negative impact on both quality of life and economic activity even if the constituent gases at ambient concentrations pose little threat to human health (in the generally accepted meaning of the term). The regulation of odour internationally is generally designed around the nuisance impact, either under air quality or nuisance regulations. In South Africa, odour regulations are yet to be promulgated.

1.1.1 SOUTH AFRICA

Until 2004, South Africa's approach to air pollution control fell under the Atmospheric Pollution Prevention Act 45 of 1965 (APPA), which was repealed with the promulgation of the National Environmental Management: Air Quality Act 39 of 2004 (NEM:AQA). NEM:AQA represented a shift in South Africa's approach to air quality management, from source-based control to a more integrated approach that includes ambient standards.

The objectives of NEM:AQA are to:

- Protect the environment by providing reasonable measures for:
  - — The protection and enhancement of air quality;
  - — The prevention of air pollution and ecological degradation; and
  - — Securing ecologically sustainable development while promoting justifiable economic and social development.
- Give effect to the Constitutional right to an environment that is not harmful to their health and well-being[2]

Significant functions detailed in NEM:AQA include:

- The National Framework for Air Quality Management;

[1] Naddeo, V.; Belgiorno, V. and Zarra, T. (2013): *Introduction* in Belgiorno, V.; Naddeo, V. and Zarra, T. (ed.) Odour Impact Assessment Handbook, Wiley & Sons, Chichester, 1 - 5.
[2] *Constitution of the Republic of South Africa (No. 108 of 1996).*

- Institutional planning matters, including:
  - The establishment of a National Air Quality Advisory Committee;
  - The appointment of Air Quality Officers (AQOs) at each level of government;
  - The development, implementation and reporting of Air Quality Management Plans at national, provincial and municipal levels;
- Air quality management measures including:
  - The declaration of Priority Areas where ambient air quality standards are being, or may be, exceeded;
  - The listing of activities that result in atmospheric emissions and which have the potential to impact negatively on the environment and the licensing thereof through an Atmospheric Emissions License;
  - The declaration of Controlled Emitters;
  - The declaration of Controlled Fuels;
  - Procedures to enforce Pollution Prevention Plans or Atmospheric Impact Reporting for the control and inventory of atmospheric pollutants of concern; and
  - Requirements for addressing dust and offensive odours.

With respect to odour control, Section 35 of NEM:AQA (under Part 6: Control measures in respect of dust, noise and offensive odours) states the following:

- The minister or MEC may prescribe measures for the control of offensive odours emanating from the specified activities; and
- The occupier of any premises must take all reasonable steps to prevent the emission of any offensive odour caused by any activity on such premises.

NUISANCE

Common law entitles everyone to the undisturbed use and enjoyment of his or her land as long as he or she complies with legislation, regulations, and by-laws and as long as that use poses no threat to anyone or their property[3]. Conversely, common law imposes duties on neighbours to tolerate and to endure to a certain extent their neighbour's reasonable exercise of ownership powers or rights. If one neighbour exceeds the regulatory demarcation of tolerance, however, he has exceeded the legal limit of reasonable exercise of his ownership rights and this constitutes a nuisance.

If the issue cannot be addressed between the neighbours, a written complaint should be made to the Local Authority before the Court is approached. Should this prove unsuccessful, then the offended neighbour can approach the court for an interdict to prevent the nuisance. Not all forms of nuisance are actionable. An actionable nuisance occurs when the actions of the offending property are outside of what is proper, befitting and socially adequate in the light of the convictions of the society – *secundum bonos mores* (Regal v African Superslate (Pty) Ltd 1963 (1) SA 102 (AD)). If the application for an interdict is successful, but the offending neighbour persists with his or her unlawful actions, he or she may be found guilty of contempt of court, in which case the court may impose a fine or imprisonment.

According to Section 16 of the eThekwini Municipality: Nuisances and Behaviour in Public Places By-law (adopted by Council on 24 June 2015): "*no owner, occupier or person in control of land or premises may use or allow land or premises to be used in a manner which creates or is likely to create a nuisance*." Nuisance is defined in the by-law as "*any conduct or behaviour by any person or the use, keeping, producing, by-producing, harbouring or conveying, as the case may be, of any item, substance, matter, material, equipment, tool, vegetation or animal or causing or creating any situation or condition in or on private property or in a public place or anywhere in the municipality which causes damage, annoyance, inconvenience or discomfort to the public or to any person, in the exercise of rights common to all or of any person*."

This by-law binds all persons under the jurisdiction of the eThekwini Municipality. Any person convicted of an offence under this by-law is liable to an initial fine of an amount not exceeding R40 000 and / or to imprisonment for a period

[3] Section 36 of the Constitution provides that no right is absolute; all rights can be limited if this is just and equitable in our democratic society.

not exceeding two years, with an additional R200 and / or 10 day imprisonment for each day on which such offense continues.

1.1.2 INTERNATIONAL APPROACHES TO ODOUR

The nations of the European Union, Canada and Australia have established odour regulations that incorporate odour standards. Sophisticated tools such as dynamic olfactometry and dispersion modelling are applied for establishing nuisance potential. Complaints are also investigated by trained inspectors, who use a checklist to characterise the odour based on hedonic tone, frequency and intensity, etc.[4] Where an offense has been committed (including failure to comply with permit conditions), the regulator has reasonable grounds to suspend the activity or take enforcement action.

In the United States (US), odour is regulated by individual states, with methods of investigation varying significantly between areas. Some states have odour emission standards while others use the judgement of inspectors to substantiate complaints and determine whether control needs to be enforced. The Texas Commission for Environmental Quality (TCEQ) has a formal Nuisance Protocol, based on the State's nuisance law, used to regulate odorous emissions. In response to complaints, odours are classified using the categories in Table 1-1.

Table 1-1: Odour categories applied by the Texas Commission for Environmental Quality (TCEQ)[5]

Category 1	No Odour.
Category 2	Odour is barely detectable. Odour is faint. Odour is very intermittent and faint. Odour is not strong enough or of sufficient duration to characterise.
Category 3	Odour is light and not objectionable. Odour is noticeable but not unpleasant.
Category 4	Odour is light to moderate, but not unpleasant. Odour is somewhat objectionable but not sufficient to interfere with the normal use and enjoyment of property. Odour is strong and objectionable, but very intermittent and because of lack of duration would not tend to interfere with normal use and enjoyment of property. Odour is strong but not at all unpleasant and would not create adverse reactions or interfere with the normal use and enjoyment of property.
Category 5	Odour is capable of causing nausea. Odour is capable of causing headaches. Odour is overpowering and highly objectionable. Odour creates the need to leave the area. Odour is offensive enough to prevent working or playing in the yard. Odour tends to stay in the residence and make it difficult to sleep, eat, etc. Odour interferes with entertaining guests. Odour interferes with normal activities of office workers. Odour interferes with normal outdoor work activities.

1.2 STANDARDS AND GUIDELINES

1.2.1 GASEOUS POLLUTANTS

Published odour detection thresholds (ODT), irritant levels and toxicological health indicators for individual compounds can vary by several orders of magnitude between references. A summary of the standards and guidelines applied in this assessment is provided in Table 1-2. When applicable, the local National Ambient Air Quality Standard (NAAQS) has been applied but, in the absence of local standards, international guidance from reputable sources has been sought. The

[4] Minnesota Pollution Control Agency (2004): A review of National and International Odor Policy, Odor Measurement Technology and Public Administration, SRF No. 0034734.
[5] Ibid 4.

thresholds provided are for specific time-weighted averages and therefore not directly applicable to concentrations measured over different averaging periods.

Table 1-2: Relevant national and international standards and guidelines

Compound	NAAQS		WHO HEALTH[6]		WHO ANNOYANCE[7]		UK EAL ANNUAL		UK EAL 1 HOUR		TCEQ ESL ANNUAL		TCEQ ESL 1 HOUR		ODT	
Unit	ppb	µg/m³	ppb	µg/m³	ppb	µg/m³	ppb	µg/m³	ppb	µg/m³	ppb	µg/m³	ppb	µg/m³	ppb	µg/m³
1,3,5-trimethylbenzene	-	-	-	-	-	-	254.3	1250	7628.5	37500	11	54	890	4400	550[g]	2703.7
Benzene	1.6[a]	5[a]	0[b]	0[b]	-	-	1.6	5.0	61	195	1.4	5	53	170	12000[g]	38336.4
Ethylbenzene	-	-	-	-	-	-	1015.6	4410	12712	55200	130	570	6000	26000	92[h]	399.5
m/p-xylene	-	-	-	-	-	-	1015.7	4410	15246.6	66200	41	180	510	2200	2100[i]	9118
o-xylene	-	-	-	-	-	-	1015.7	4410	15246.6	66200	41	180	510	2200	5400[i]	23446
Styrene	-	-	61[c]	260[c]	16.4[f]	70[f]	187.8	800	187.8	800	33	140	26	110	16.4[j]	70
Tetrachloroethene	-	-	37[a]	250[a]	1179.5[f]	8000[f]	508.7	3450	1179.5	8000	3.8	26	290	2000	1179.5[j]	8000
Toluene	-	-	69[c]	260[c]	265.4[f]	1000[f]	506.8	1910	2122.8	8000	320	1200	1200	4500	265.4[j]	1000
Trichloroethene	-	-	0[d]	0[d]	-	-	204.7	1100	186.1	1000	10	54	100	540	8200[k]	44068.9
Hydrogen Sulphide	-	-	107.6[e]	150[e]	5.0[f]	7[f]	100.4	140	107.6	150	-	-	120	167.3	0.1 - 1.4[j]	0.2 - 2
Formaldehyde			81.4[f]	100[f]	81.4[f]	100[f]	4.1	5.0	81.4	100	2.7	3.3	12	15	24 - 49[j]	30 - 60

ppb parts per billion (based on 20°C and 1 atmosphere)
µg/m³ micrograms per cubic meter
NAAQS National Ambient Air Quality Standard[8]
UK EAL United Kingdom Environmental Assessment Level[9]
TCEQ ESL Texas Commission for Environmental Quality: Exposure Screening Levels
ODT Odour detection threshold
a Annual time-weighted average
b Benzene is carcinogenic to humans and no safe levels of exposure can be recommended by the World Health Organisation. The continuous exposure concentrations of airborne benzene associated with an excess lifetime risk of 1:10 000, 1:100 000 and 1:1000 000 for leukaemia being 17 µg/m³, 1.7 µg/m³ and 0.17 µg/m³ respectively.
c 1-week time-weighted average
d Trichloroethene is genotoxic and carcinogenic therefore no safe levels of exposure can be recommended by the World Health Organisation. The continuous exposure concentrations of airborne trichloroethene associated with an excess lifetime risk of 1:10 000, 1:100 000 and 1:1000 000 for Leydig cell tumours being 230 µg/m³, 23 µg/m³ and 2.3 µg/m³ respectively.
e 24-hour time-weighted average
f 30 minute time-weighted average

[6] World Health Organisation (2000): Ambient Air Quality Guidelines for Europe (URL: http://www.euro.who.int/__data/assets/pdf_file/0005/74732/E71922.pdf)
[7] Ibid 6.
[8] National Ambient Air Quality Standards, Government Notice 1210 of 2009, Government Gazette 32816.
[9] Environment Agency (2016): Air emissions risk assessment for your environmental permit (URL: https://www.gov.uk/guidance/air-emissions-risk-assessment-for-your-environmental-permit)

g Amoore, J.E. and Hautala, E. (1983): *Odor as an Aid to Chemical Safety: Odour Thresholds Compared with Threshold Limit Values and Volatilities for 214 Industrial Chemicals in Air and Water*. Journal of Applied Toxicology. Vol.3 No.6
h Koster, E. P. (1971): Adaptation and cross-adaptation in Olfaction. Utrecht, The Netherlands
i Punter, P. H. (1980): *Measurement of human olfactory thresholds for several groups of structurally related compounds*. Chem. Senses 7: 215-235
j World Health Organisation (2000): Ambient air quality guidelines
k May, J. (1966): *Odour Thresholds of solvents for assessment of solvent odours in the air*. Staub Reinhalt. Luft 26: 385-389

1.2.2 DUST FALLOUT

Relevant standards for dust fallout (DFO) are provided in the National Dust Control Regulations, Government Notice 827 of 2013 (Government Gazette 36974). Acceptable DFO rates for both residential and non-residential areas are provided in Table 1-3.

Table 1-3: Acceptable dust fallout rates (Government Notice 827, 1st of November 2013)

RESTRICTION AREAS	30 DAY AVERAGE DFO (MG/M²/DAY)	PERMITTED FREQUENCY OF EXCEEDANCE	REFERENCE METHOD
Residential Area	D < 600	Two within a year, not sequential months	ASTM D1739
Non-Residential Area	600 < D < 1,200	Two within a year, not sequential months	ASTM D1739

Any person who conducts an activity that might give rise to dust in quantities that may exceed the standards above must, upon receipt of a written notice from the local AQO, implement a dustfall monitoring program and submit a dustfall report to the AQO within a period of time specified by the AQO. A schedule for submission of subsequent reports (annually or more frequently) will be approved by the AQO. Representative meteorological data is a requirement for dust fallout reporting as stipulated in Section 5 of the National Dust Control Regulations.

In the case of exceedances of the standard, the subsequent DFO report must clearly indicate these, and within three months of submission of the dust monitoring report, the facility must develop and submit a revised dust management plan to the AQO for approval. Such a plan must:

- Identify all possible sources of dust within the affected site;
- Detail the best practicable measures to be undertaken to mitigate dust emissions;
- Detail an implementation schedule;
- Identify the line management responsible for implementation;
- Incorporate the DFO monitoring plan; and
- Establish a register for recording all complaints received regarding dustfall, and for recording follow up actions and responses to the complainants.

2 LITERATURE REVIEW

2.1 ODOUR

2.1.1 DEFINING ODOUR

The sensation of odour occurs when airborne compounds stimulate receptors in the nasal cavity. These sensations are induced either by the olfactory epithelium in the nose (resulting in odour sensations described by adjectives i.e. floral, fishy, faecal, etc.) or by stimulating the trigeminal nerve endings in the nose, throat and lungs at elevated concentrations (inducing irritant sensations, i.e. tickling, burning, itching, etc.). Olfaction, in contrast to irritation, has multiple dimensions, including intensity, identity and hedonic tone ('pleasantness'). Sensory irritation can be induced by a single odorous compound above its irritant threshold or by the cumulated effect of low concentrations of multiple odorous compounds[10]. The function of the olfactory system is to allow for the learning of odours particular to an individual's life experiences and environment, while the function of the intranasal trigeminal system is to prevent the inhalation of potentially life-threatening substances by triggering protective reflexes such as sneezing, neurogenic inflammation of the mucosa and watering eyes[11]. Sensory irritation is related to chemical reactivity and therefore this irritation initiates protective physiologic reflexes and alerts the exposed individual to possible danger. Prolonged exposure to high levels of irritants may result in the development of tracheobronchitis, chemical pneumonitis or noncardiogenic pulmonary oedema[12].

The ability to detect a smell, the perception of the scent sensation, and the physical response to an odour varies significantly from person to person, making the perception of odour highly subjective. Olfactory sensitivity is influenced by age, sex, lifestyle and previous exposure. These factors influence how an individual will physiologically react to an odour and whether the odour is perceived psychologically as a nuisance or not. Elderly people tend to be less perceptive of odour while, on average, females are more aware of ambient odours than men. Lifestyle choices such as smoking can also influence an individual's level of odour sensitivity. In addition to the variation in inter-individual odour sensitivity, adaptation or habituation as a result of prolonged or continuous exposure, even over a few minutes, is typically responsible for a 60% decrease in the perceived intensity of an odour. Chronic exposure to extreme concentrations of some odorous agents can produce a reversible condition known as olfactory fatigue or paralysis[13].

The concentration at which an odour is just detectable to the human nose is known as the threshold concentration. For individual odorous compounds (e.g. hydrogen sulphide, H_2S), this concentration can be expressed in mass per unit volume (e.g. $\mu g/m^3$), parts per unit volume (e.g. ppmV) or in odour units per unit volume (e.g. OU/m^3). Environmental odours generally are complex mixtures of compounds that are best expressed in odour units per cubic metre (OU/m^3). An odorous gas mixture has a concentration of 1 OU/m^3 (i.e. its detection threshold as determined through dynamic olfactometry) when at least 50% of the exposed population are able to perceive it. At this threshold concentration, the odour is detected with certainty, but not necessarily recognised as any specific smell.

Threshold concentrations are not uniquely defined, even for single compounds, and considering odour perception is subject dependent, the use of a perceptibility threshold interval (i.e. the range between the lowest concentration at which the odour can be detected and the concentration at which an odour should be detected by 100% of the population) is deemed appropriate when evaluating measured concentrations against an array of published threshold values. While the detection threshold is the concentration at which the odour can be sensed, a higher concentration is usually required before the odour can be positively identified. The recognition threshold represents the concentration at which an odour becomes recognisable as a specific odour by 50% of the exposed population. The recognition threshold is on average

[10] Schiffman, S.S. and Williams, C.M. (2005): *Science of odour as a potential health issue* in Journal of Environmental Quality, 34, 129-138.
[11] Guarneros, M.; Drucker-Colín, R; Esquivelzeta, J. and Hudson, R. (2011): *Adverse effect of air pollution on odour perception* in Advanced Topics in Environmental Health and Air Pollution Case Studies.
[12] Shusterman, D. (1992): *Critical Review: The Health Significance of Environmental Odor Pollution* – Archives of Environmental Health, 47: 1.
[13] Ibid 12.

three times the detection threshold. The annoyance threshold represents the concentration necessary to provoke a sensation of annoyance[14].

In the case of gaseous mixtures, intensification or masking may occur[15]. Repeated exposure to an odorant can result in the enhancement of odour recognition and detection. This phenomenon has been found in individuals who live in communities impacted by industrial odour sources. On the other hand, very high concentrations can result in olfactory fatigue and the odour is no longer perceived until after a prolonged break from the odour.

2.1.2 EFFECTS OF ODOUR EXPOSURE

Odorous activities tend to elicit more community complaints than emission of perhaps more hazardous yet odourless air pollutants (e.g. nitrogen dioxide, NO_2). This is due to the offensive sensory properties of odours as well as the association made with health symptoms. Some health professionals consider ailments associated with offensive odour to be psychosomatically induced. However, research has shown that odours can exacerbate chronic respiratory problems such as asthma. A study on the potential health issues associated with odorous emissions from animal manures and other bioaerosols was conducted in 1999 by the United States Environmental Protection Agency (US EPA)[16]. The study identified various mechanisms by which ambient odours may produce health symptoms in communities:

- Symptoms may be induced by exposure to compounds with odour properties at levels that also cause toxicological effects. Irritation is the cause of the health symptoms while the odour sensation serves as an exposure marker. When irritant compounds come into contact with the upper and lower airway, systematic responses may include: altered respiratory rate; reduced respiratory volume; contraction of the larynx and bronchi; increased nasal secretions, inflammation and nasal airflow resistance; increased blood pressure; and sneezing. Repeated exposure to odorous irritants can induce chronic respiratory disorders.
- Health symptoms occur at concentrations detectable by the human nose but not at concentrations where exposure to the compound is defined as toxic. This mechanism is typical of exposure to sulphur-containing compounds (e.g. H_2S). Exposure to malodours may exacerbate pre-existing illnesses through impacts on mood and induced stress. Communities involuntarily and regularly exposed to odour compounds have been found to suffer from increased tension, depression and fatigue. Learned associations may also play a role in perceptions of health symptoms resulting from odour. If an unpleasant odour had previously been associated with a particular illness, the odour sensation alone can possibly be enough to recreate those symptoms subconsciously even in the absence of physical illness.
- The odour compound is part of a mixture that contains a co-pollutant (i.e. pesticide or bacterial endotoxin) that is responsible for the reported health symptoms. Odorous compound mixtures may contain non-odorous pollutants such as NO_2 or carbon monoxide (CO), particulates or toxicants that are the actual cause of health effects.

ODOUR ANNOYANCE AND NUISANCE

Considering that the odour threshold for many odorous chemicals are several orders of magnitude less than will cause adverse health effects for people or the environment, odorous compounds have the ability to create a significant nuisance at much lower concentrations than a public health problem. Studies have established that the public tends to assign a higher importance to malodour than to more hazardous pollutants that cannot be perceived by the human senses. According to the World Health Organisation (WHO), health is not only defined as the absence of disease but also a state of complete physical, mental and social wellbeing. If adverse psychological states bear a demonstrable relation to an external environmental factor (such as noise, dust or odour), the terms annoyance or nuisance are used to characterise this adversity[17].

Annoyance is defined as the human reaction that occurs because of exposure to an ambient stressor (odour) resulting in a negative state of mind requiring some degree of coping to overcome. Nuisance is caused by repeated events of annoyance over an extended period of time that leads to modified behaviour (e.g. complaint reporting, closing of windows, avoiding use of the garden, keeping odour diaries, participating in protest action, etc.). Nuisance occurs when

[14] Naddeo, V.; Belgiorno, V. and Zarra, T. (2013): *Odour Characterisation and Exposure Effects* in Belgiorno, V.; Naddeo, V. and Zarra, T. (ed.) Odour Impact Assessment Handbook,Wiley & Sons, Chichester, 7 - 28.
[15] Ibid 14.
[16] Ibid 10.
[17] Ibid 14.

people are affected by an odour in their living or working environment that is perceived as negative. Odour nuisance can have a detrimental effect on an individual's sense of wellbeing and therefore a negative effect on health.

The concept of 'environmental worry' has been postulated as the cause of physiological symptoms experienced by those exposed to environmental odours at concentrations much lower than those expected to result in toxic effects. Repeated exposure to odours can result in severe annoyance with the exposed individual becoming particularly physiologically and / or psychologically sensitive to the odour, increasing the likelihood of complaint. Despite this, it is known that prolonged and repeated exposure to environmental odours can generate undesirable reactions in people such as unease, irritation, discomfort, anger, depression, nausea, headache and vomiting. Other effects regularly reported by people subjected to odour nuisance include difficulty breathing, frustration, stress, being woken at night, odour invading homes and businesses, reduced appetite, reduced amenity, embarrassment with guests and decline in business[18].

A series of conclusions about how people perceive odour have been draw from studies of exposure to environmental odour at different concentrations over different exposure periods. Community surveys have found that where odour nuisance has been abated, perceived odour impact is still reported for prolonged periods, up to several years even after the odour is no longer present. These studies show that:

- Odour nuisance is not a result of short-term exposure but rather manifests over a prolonged period of impact;
- Odour nuisance is not reduced by short periods of mitigation or slight improvements in odour concentration because the association between an individual's perception and experience of nuisance from an odour is persistent and long-lasting. Exposure to the same odour at low concentrations causes greater nuisance for previously impacted individuals than for others with no history of exposure;
- Nuisance is cumulative, developing over time, with memories of extreme exposure events dominating an individual's perception of the odour; and
- Under conditions of moderate exposure, symptom reporting because of odour exposure is mediated by annoyance and environmental worry while symptoms experienced under conditions of extreme exposure was found to both be directly and indirectly manifested by the level of exposure[19].

ODOUR TOXICITY

Many odorous compounds are toxic at high concentrations, and in cases of acute exposure, eye, skin or nose irritation can occur. Such exposure is most likely to occur as the result of an industrial accident (e.g. ruptured chemical storage tanks, severe upset conditions in chemical processes, etc.). On the other hand, many air pollutants are regulated for their acute toxicity (i.e. ozone, sulphur dioxide, NO_2, CO, lead, PM_{10}, $PM_{2.5}$ and benzene) do not have prominent odours at the levels at which they are regulated.

In the working environment, the maximum concentration to which a worker can be exposed to a hazardous substance during a period of time without experiencing negative effects is known as the Threshold Limit Value (TLV). The concentration value that can never be exceeded, not even for a brief period of time is known as the Maximum Allowable Concentration (MAC)[20]. Even though the occupational hygiene industry has determined these limits of safe exposure and possible toxicity, acute odour related symptoms have been documented in the absence of exposure deemed to be toxicologically credible. For example, some compounds which are known to cause acute symptoms at concentrations many times higher than their odour thresholds (e.g. H_2S, mercaptans and thiophenes) are common culprits for symptom reporting. An extensive literature review of odour related health studies by the California Environmental Protection Agency (Cal-EPA) also found that air pollution related health impacts reported by communities surrounding hazardous waste facilities frequently defy explanation in classical toxicological terms.

General health complaints (e.g. sleep disorders, headache, cough, throat and eye irritations) and gastrointestinal dysfunction (e.g. nausea, vomiting and loss of appetite) have been associated with odorous gas mixtures with constituents below reported toxicological limits for the specific compound. Explanations include that the perceived odour exposure or environmental worry rather than the inherent toxic nature of compound exposure causes the response. However, this explanation cannot account for the response in young children or animals who are not consciously aware of the implications of exposure. Another possible explanation is that the mixture of compounds itself

[18] Ibid 1.
[19] Steinheider, B.; Both. R. and Winneke. G. (1998): *Field studies on environmental odors inducing annoyance as well as gastric and general health-related symptoms* in Journal of Psychophysiology. 12: 64-79.
[20] Ibid 14.

has toxicological impacts at concentrations lower than those defined for each chemical constituent. Odours tend to be hypoadditive, where one odour usually masks another, while irritants tend to by hyperadditive in that the physical symptoms each constituent triggers can compound in severity within the mixture[21]. Another explanation is that the symptoms experienced by sensitive (or sensitised) individuals are the result of an exacerbation of underlying conditions (e.g. bronchial asthma) or are a physiological reflex or warning function to prevent the further intake of toxic material before the acute toxicity level is reached. Protective symptoms experienced by exposed individuals could include vomiting, which is one of the body's means of clearing the digestive system, or sneezing, which is one of the body's means of clearing the respiratory system.

Although it is usually acute symptoms that are reported, the long-term health risks to communities exposed to airborne chemicals from industrial sources is relevant when assessing odour impact. The low concentrations typically seen with odour pollution has associations with the development of latent diseases even if not with the acute symptoms typically reported. Young children and the elderly have an elevated vulnerability to environmental exposure to air pollution as children breathe more air per kilogram of body weight than adults do, while senior community members generally suffer from age related impaired lung function[22].

2.1.3 ODOUR MEASUREMENT AND ASSESSMENT

Odour emissions arise from either point (e.g. stack or vent), area (e.g. effluent pond) or volume (e.g. building) sources and can be categorised as either active (intended release of gases) or fugitive (unintended release of gases). An odour monitoring plan should include source characterisation, the specific operating conditions of the source under investigation, the number of location of sampling points, the methods used (i.e. materials, volumes, etc.), and appropriate meteorological conditions (i.e. temperature, pressure, humidity, wind direction and velocity) for monitoring[23].

Options for objective odour measurement include analytical methods (e.g. constituent gas analysis) and more sensorial approaches (e.g. technologies such as the electronic nose also known as an e-nose) that can be applied at source and at sensitive receptors. The overall purpose of sampling is to obtain representative and objective quantitative data that characterise the odour and its spread.[24]Meteorological data can assist with odour source appropriation. Mathematical dispersion models are also an effective tool for simulating how odour disperses in the atmosphere in order to calculate ground-level odour concentrations in the space-time domain[25]. More subjective approaches for an odour assessment include the use of complaints datasets or odour diaries. There is no single definitive method for measuring and assessing odour impact on the exposed population. Conclusions are best based on a variety of evidence for a triangulation of findings. The FIDOL for odour characterisation and assessment incorporate both objective and subjective components for assessing the significance of impact:

F - Frequency of detection: how often an individual is exposed to odour in the ambient environment. This is influenced by source characteristics, prevailing wind trajectories and the topography of the area. Frequency is usually greatest in areas downwind of the emission source, particularly under conditions of atmospheric stability and low wind speeds.

I - Intensity of perception: an individual's perception of the odour's strength (not to be confused with the odour's character or quality)

D - Duration of exposure: the length of odour exposure episodes, which is also influenced by source characteristics, prevailing wind trajectories and the topography of the area.

O - Offensiveness: also known as the hedonic tone, is the subjective rating of the odour as being pleasant (positive) or unpleasant (negative).

L - Location sensitivity: the sensitivity of the impacted area and the likelihood of a person being annoyed to the point where they find the odour objectionable (e.g. sensitive areas include residential neighbourhoods while those living

[21] Ibid 12.
[22] Ibid 10.
[23] Ibid 24.
[24] Zarra, T.; Naddeo, V. and Belgiorno, V. (2013): *Instruments and Methods for Odour Sampling and Measurement* in Belgiorno, V.; Naddeo, V. and Zarra, T. (ed.) Odour Impact Assessment Handbook, Wiley & Sons, Chichester, 31 - 83.
[25] Capelli, L.; Sironi, S.; Del Rosso, R. and Guillot, J. (2013): *Measuring odours in the environment vs. dispersion modelling: A Review* in Atmospheric Environment, 79: 731-743.

in rural areas may be more tolerant due to the persistent background odours arising from composting or other familiar agricultural practices).

In addition, cultural issues, background odours, and even an individual's mental state and physical health may need to be considered in assessing the degree of adverse effects caused by environmental odour. In some cases, people may find an odour offensive resulting in an adverse response if they perceive the activity causing the odour to be unsavoury (e.g. human sewerage treatment) even if the other FIDOL factors indicate low significance. Similarly, communities are likely to be more tolerant of odours if their livelihoods are directly linked to the emission source[26].

2.1.4 ODOUR CONTROL

Most environmental odour problems involve exposure to potent odorants at sub-irritant concentrations; however, large differences in concentrations are usually accompanied by relatively small differences in perceived magnitude. Therefore, a reduction in perceived odour intensity in the community often requires a significant reduction in odorant concentrations, particularly with regard to potent odorants such as reduced sulphur gases[27].

The majority of odour abatement strategies include a combination of the following measures to alleviate, abate or mitigate odour impact on neighbouring receptors:

- Prevention: Odour formation can be prevented at source by utilising effective process design and operations (e.g. maintaining aerobic conditions in waste treatment facilities since anaerobic conditions promote the generation of odorous volatile compounds such as fatty acids and reduced sulphur compounds);
- Dispersion control: Adhering to buffer zones or erecting turbulence inducing structures (e.g. trees) can assist in diluting the odour concentration before reaching sensitive receptors;
- Minimisation: Inhibit or neutralize the unpleasant hedonic tone of the emission with masking agents; and
- Treatment: Implement technologies to reduce the odour concentration in the emission before it is exhausted to atmosphere. Odour treatment is usually considered a last resort when prevention and control of dispersion are not sufficient to avoid odour nuisance.

Measures orientated towards preventing odour formation at source will nearly always cost less than implementing minimisation or treatment technologies later. However, according to Estrada *et al* (2013)[28], end-of-pipe treatment technologies have consistently proven to be the most effective odour abatement measures despite requiring the highest investment and operating costs. One commonly applied end-of-pipe treatment technology is the incineration (also known as flaring) of gaseous pollutants (particularly volatile organic compounds) at high temperature. The application of flaring for the treatment of odorous pollutants presents a number of drawbacks such as additional fuels being required to attain the high temperatures needed for the complete destruction of odorants, as pollutant concentrations are not normally high enough to self-maintain spontaneous oxidation. Additional input fuel will result in atmospheric impacts derived from the combustion of fossil fuels. Flare efficiencies of up to 99.9% can be expected for odour removal when correctly operated and maintained and therefore can be considered a viable option when evaluating the social and health benefits of this control measure[29].

2.2 LANDFILL EMISSIONS

Sources of atmospheric emissions from landfill sites include:

- Windblown dust generated from the surface of the landfill or when waste is tipped;
- Gases generated as the waste breaksdown which is not extracted and treated;
- Combustion activities used to burn off landfill gas, including flares or engines;

[26] Naddeo, V.; Belgiorno, V. and Zarra, T. (2013): *Procedures for Odour Impact Assessment* in Belgiorno, V.; Naddeo, V. and Zarra, T. (ed.): Odour Impact Assessment Handbook. Wiley & Sons, Chichester, 187 - 203.
[27] Ibid 12.
[28] Estrada, J.M.; Lebrero, R.; Quijano, Q.; Kraakman, N.J.R. and Muñoz, R. (2013): *Strategies for Odour Control* in Belgiorno, V.; Naddeo, V. and Zarra, T. (ed.): Odour Impact Assessment Handbook, Wiley & Sons, Chichester, 86 - 124.
[29] Ibid 28.

- Leachate produced as the waste breaksdown; and
- Discharges from leachate treatment processes.

Landfill gas is the principal component of landfill emissions to atmosphere. It is the by-product of the anaerobic process of biodegradable waste degradation that occurs after being deposited into the landfill body. The composition of this gas varies from site to site according to the type of wastes present and phases of waste degradation. In general, landfill gas contains approximately 65% methane (CH_4) and 35% carbon dioxide (CO_2), with trace amounts (<1%) of organic gases or vapours. Although trace components can comprise less than 1% of total landfill emissions, the impact on the receiving environment may be higher than that of bulk gases due to potential health and odour impacts[30]. Of the 557 individual trace components of landfill gas[31], 30 substances are highlighted by the Environment Agency of Wales, based on their inherent toxic and odour properties (Table 2-1)[32]. Personal exposure to landfill gases occurs by inhalation of airborne emissions and particulates, however exposure of neighbouring communities to fugitive (uncontrolled) emissions can be minimised if a landfill gas collection and control system is in place and managed efficiently. Collection and control systems involve the active extraction and combustion of landfill gases in engines or flares, resulting in secondary pollutants.

Table 2-1: Priority trace components of landfill gas based on potential health and odour impact

TRACE COMPONENT	POTENTIAL IMPACT	CATEGORY
1,1-dichloroethane	Health	Halocarbon
1,2-dichloroethane	Health	Halocarbon
1,1-dichloroethene	Health	Halocarbon
1,2-dichloroethene	Health	Halocarbon
1,3-butadiene	Health	Aliphatic hydrocarbon
1-butanethiol	Odour	Organosulphur
1-pentene	Odour	Aliphatic hydrocarbon
1-propanethiol	Odour	Organosulphur
2-butoxyethanol	Health	Alcohol
Arsenic (as As)	Health	Inorganic
Benzene	Health	Aromatic hydrocarbon
Butyric acid	Odour	Carboxylic acid
Carbon disulphide	Health and odour	Organosulphur
Chloroethane	Health	Halocarbon
Chloroethene (vinyl chloride)	Health	Halocarbon
Dimethyl disulphide	Odour	Organosulphur
Dimethyl sulphide	Odour	Organosulphur
Ethanal (acetaldehyde)	Odour	Aldehyde
Ethanethiol	Odour	Organosulphur
Ethyl butyrate	Odour	Ester
Furan (1,4-epoxy-1,3-butadiene)	Health	Ether
Hydrogen sulphide	Health and odour	Inorganic
Methanal (formaldehyde)	Health	Aldehyde
Methanethiol	Odour	Organosulphur

[30] Environment Agency (2010): Guidance for Monitoring Trace Components in Landfill Gas, Bristol (URL: www.environment-agency.gov.uk).
[31] Parker, T.; Dottridge, J. and Kelly, S. (2002): Investigation of the Composition and Emissions of Trace Components in Landfill Gas, Environment Agency - R&D Technical Report P1-438/TR (URL: www.environment-agency.gov.uk).
[32] Ibid 30.

TRACE COMPONENT	POTENTIAL IMPACT	CATEGORY
Styrene	Health	Aromatic hydrocarbon
Tetrachloromethane	Health	Halocarbon
Toluene	Health	Aromatic hydrocarbon
Trichloroethene	Health	Halocarbon
Mercury (as Hg)	Health	Inorganic

Landfill emissions and their potential health impacts are summarised below[33].

FUGITIVE EMISSIONS

BULK GASES

Both CH_4 and CO_2 are odourless and colourless gases that act as asphyxiants. At concentrations above 6%, CO_2 causes headache, dizziness, palpitations, hypertension and depression of the central nervous system. At concentrations between 5 and 15%, CH_4, inhalation can cause nausea, vomiting, headache and loss of coordination. Emissions of bulk gases should be controlled through a landfill gas management system based around active gas extraction and gas combustion.

TRACE GASES

The trace component of landfill gas makes up approximately 1% of raw landfill gas. The exact composition of this trace component depends on the types of waste in the landfill, but includes halogenated hydrocarbons and aromatic hydrocarbons. The percentage of fugitive gas escaping will depend on the overall collection efficiency on-site (if any), site engineering and the volume of gas generated. If the gas extraction and control system is efficiently managed, exposure to fugitive emissions offsite should be minimal. VOCs are also generated during the combustion of landfill gases in engines and flares, however, combustion methods can be effective at destroying VOCs with an efficiency of 96 – 99.9%.

Fenceline monitoring of (uncategorised) landfill facilities across the United Kingdom (UK) conducted by the Environmental Protection Agency (EPA) has found the majority of VOCs emitted remain below relevant health criteria values (HCVs)[34]. Some VOCs, including chloroethene, 1,2-dichloroethane, dimethyl sulphide, dimethyl disulphide, formaldehyde, methyl mercaptan, styrene and stibine were found to be present at concentrations higher than HCVs. Although there is limited toxicity data available for some of the chemicals identified, the EPA concluded that VOC levels found at the boundaries of landfill sites were unlikely to result in significant adverse health effects provided that the facility is well managed.

HYDROGEN SULPHIDE

H_2S is a colourless, yet flammable gas with a characteristic odour of rotten eggs. It is produced at landfill sites when high sulphate-bearing materials are mixed with biodegradable waste. H_2S concentrations in landfill gas can vary significantly from site to site as it depends on the composition of the waste present as well as the design and appropriate management of the facility. Landfilling of biodegradable waste materials with high sulphur content has been prohibited in England and Wales since 2005. At low concentrations H_2S can result in irritation to the mucous membranes of the eyes and respiratory tract. Other health symptoms have been reported, although the effects of repeated exposure are difficult to interpret due to the co-exposure to other chemicals. Odour complaints are usually a result of H_2S. The WHO recommends an ambient air quality guideline of 150µg/m^3 over a 24 hour period and 7µg/m^3 over a 30 minute exposure period to avoid substantial complaints about sensory annoyance. Fenceline monitoring of landfill facilities conducted by the EPA found H_2S levels to occasionally exceed the WHO sensory-based guideline, however below levels associated with toxic effects. The EPA concluded that H_2S odours has the potential to affect nearby residents and therefore odour control at landfill sites is imperative.

[33] Macklin, Y.; Kibble, A. and Pollitt, F. (2011): Impact on health of emissions from landfill sites – Advice from the Health Protection Agency, RCE-18.

[34] A generic term used to describe a benchmark level of exposure to a chemical derived from available toxicity data for the purposes of safeguarding human health (e.g. a tolerable daily intake)

PARTICULATES

Exposure to particulates that can enter the respiratory system is associated with a range of adverse effects on health. Coarser particulates (>PM_{10}) are unlikely to penetrate the nose and larynx, however, finer particulates (<$PM_{2.5}$) can deposit deeper into the lungs. Particulates emissions are particularly dangerous for sensitive individuals, including those with pre-existing lung and heart disease. The distance travelled by dust emissions is dependent on the particle size and on the atmospheric dispersion potential. The ability of dust particles to stay airborne is dependent on their size and wind speeds. Strong and turbulent winds can keep coarser particles airborne for longer. PM_{10} has been noted to travel up to 1 km while ultrafine particles can be expected to travel much further. Environmental permits in the UK require that dusts must be adequately controlled using dust suppression measures so as not to cause adverse impacts on public health. Particulates can also contain heavy metals such as arsenic, cadmium, chromium, cobalt, copper, lead and manganese.

BIOAEROSOLS

The handling and processing of compostable organic waste material at landfill sites can generate an aerosol of micro-organisms (including pathogens and allergens such as bacteria, fungi and microbial toxins), which when suspended in the air is known as a bioaerosol. There is much uncertainty surrounding the health risks of bioaerosols from an occupational hygiene perspective and exposure in the ambient environment. Current evidence suggest that communities situated further than 250 m from the source are unlikely to be exposed to dangerous levels as bioaerosols disperse rapidly.

ODOURS

Landfill odours are typically associated with facilities receiving biodegradable waste. Odorous emissions are often accompanied by community complaints of adverse health effects. Often the reported symptoms include headaches, nausea, drowsiness, fatigue and respiratory problems which are non-specific to one particular compound. Odour perception is influenced by many factors including sensitivity and prior exposure to the odour making individual response highly variable. Psychological and social factors also play a role with published studies showing strong correlations between perceived odour annoyance and the development of symptoms. Methyl mercaptan, dimethyl sulphide and dimethyl disulphide are odorous compounds with low odour thresholds which have been measured by the EPA to exceed odour thresholds offsite. All landfills should have effective management plans to reduce odours, which should be subject to a regular, and comprehensive risk assessment process, including an evaluation of key substances emitted and modelling and monitoring to assess the impact of emissions on neighbouring communities.

LEACHATE

Leachate generally is discharged following treatment in an onsite process and subsequent treatment offsite at a waste water treatment works. Leachate can become low in oxygen, resulting in the generation of odorous compounds, such as sulphides, resulting in odour complaints from nearby residential areas.

GAS COMBUSTION

ACID GASES

Acid gases emissions are a result of the landfill gas combustion process. Acid gases include NO_2, sulphur dioxide (SO_2) and halides (e.g. Hydrochloric Acid and Hydrogen Fluoride). Emissions from landfill sites can contribute to existing background levels of these pollutants in the local area, which is particularly important for NO_2 and SO_2 which can be produced in significant quantities from many other industrial and transport sources. Therefore, any additional contribution from landfill sites could have an impact on local air quality. The concentration required to produce health effects in sensitive individuals (i.e. asthmatics, children, elderly, immune-compromised individuals, etc.) would be far less than that required for non-sensitive individuals. Boundary measurements of these gases at landfill sites in the UK have found that concentrations were typically below health-based standards. Provided the site is properly managed and regulated, it is unlikely that acid gases from combustion processes will significantly affect local air quality.

TOXIC ORGANIC MICROPOLLUTANTS

Toxic organic micropollutants includes polychlorinated dibenzo-para-dioxins and polychlorinated dibenzofurans, collectively known as dioxins and furans. These can form during the combustion of chlorine containing landfill gas. The

recommended tolerable daily intake (TDI)[35] for dioxins can be used to assess the toxicity of mixtures of dioxins and furans by using Toxic Equivalency Factors (TEF). This allows for toxicity weighted concentrations to be expressed as a Toxic Equivalent (TEQ), a system recommended by WHO. The TDI for dioxins is 2 picograms (pg) per kilogram bodyweight per day which is intended to prevent any adverse effects to a developing foetus resulting from exposure *in utero* and therefore will protect against the risks of other effects including cancer. Site measurements of two landfill sites in the UK were compared with typical background concentrations in both a rural and urban setting. Average fenceline dioxins concentrations were found to be 170% of the typical UK rural background level and 42.5% of the typical UK urban background level. Total exposure to dioxins from these landfill sites, including ingestion of locally grown produce, was well below the 2 pg WHO-TEQ/kg/day.

Polycyclic aromatic hydrocarbons (PAHs) are a group of structurally similar chemicals also emitted as a product of landfill gas combustion. Studies have found an association between exposure to PAHs and tumours in the lung. Certain PAH compounds are considered to have potential genotoxic and carcinogenic properties[36].

[35] The amount that can be ingested over a lifetime without appreciable health risk.
[36] Cancer resulting from the mutation of genetic material.

3 STUDY BACKGROUND

3.1 LOCATION

Shongweni lies in the Upper Highway area, towards the western boundary of the eThekwini Metropolitan Municipality. Local topography can be described as undulating hills with elevations ranging between 370 m and 700 m above mean sea level (Figure 3-1). The Shongweni Landfill was established in 1992 when the region was predominantly a farming district on the western outskirts of Durban. The area has since developed beyond equestrian smallholdings and sugarcane plantations to a busy business district and desirable residential locale. The waste management facility is now surrounded by open farmland (sugarcane), with a mushroom growing operation (Denny Mushrooms) immediately north of EnviroServ's legal boundary and residential developments in most directions (Figure 3-2 and Table 3-1).

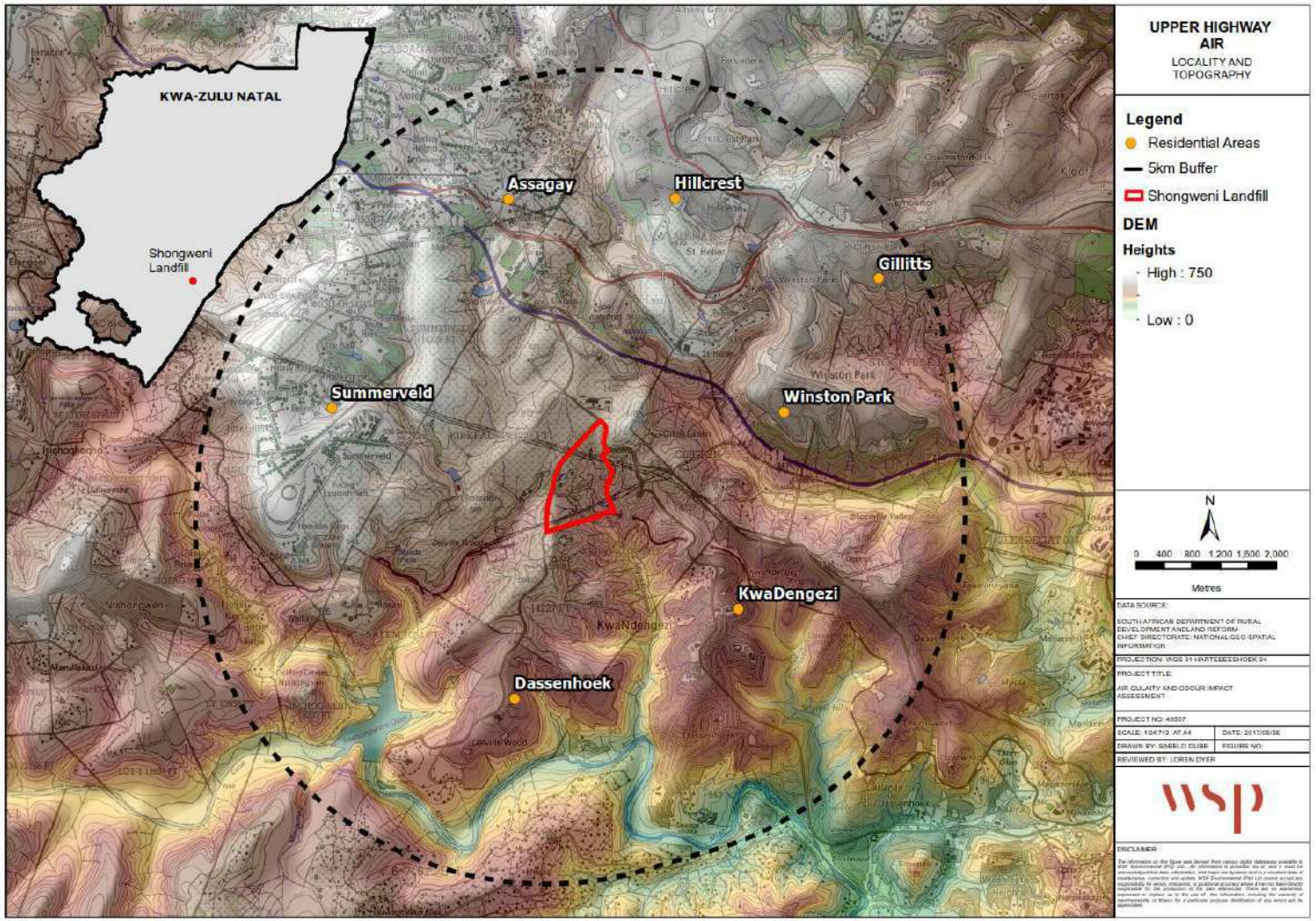


Figure 3-1: Study area and topography

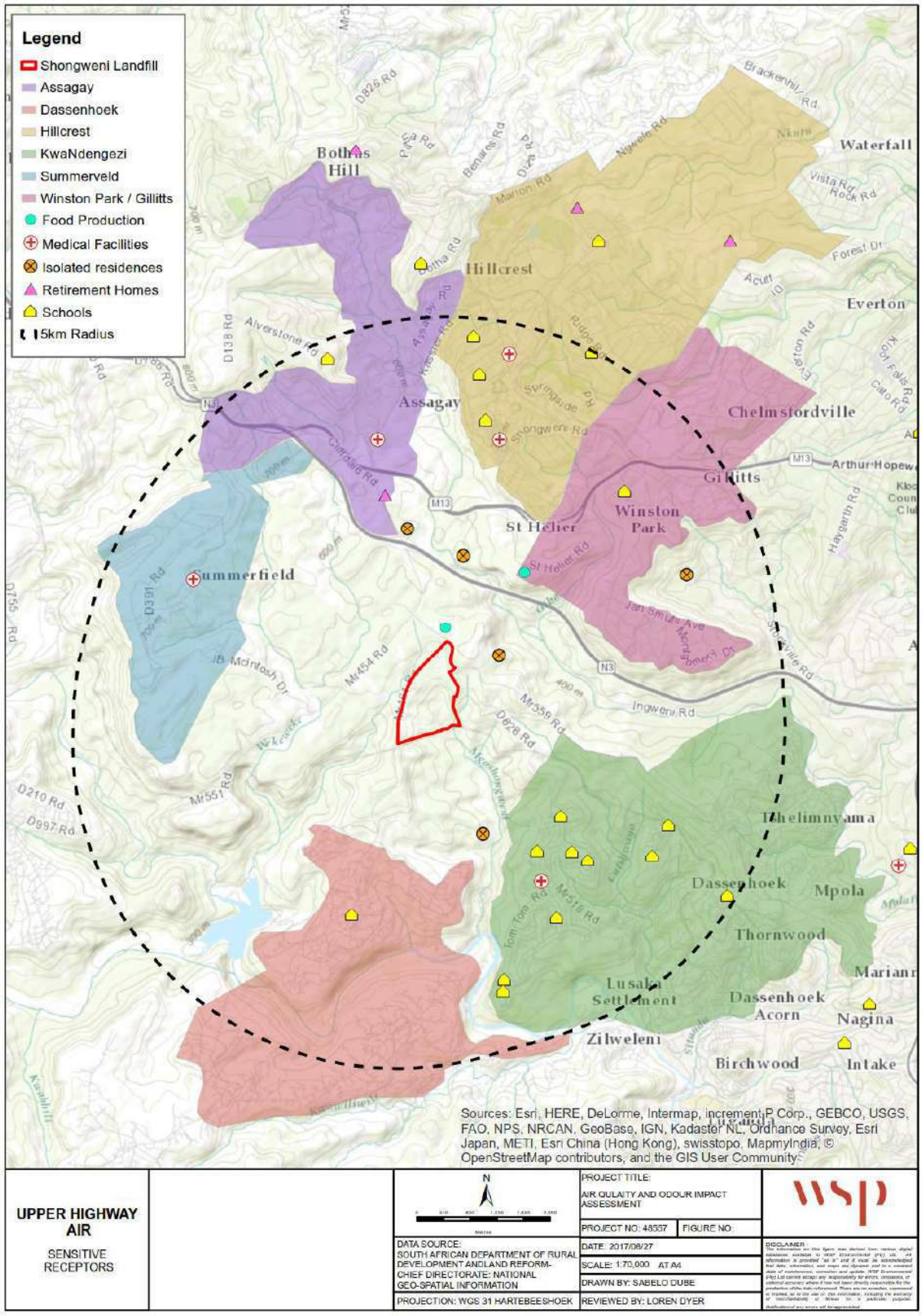


Figure 3-2: Selected sensitive receptors near the Shongweni Landfill

Table 3-1: Sensitive receptors within a 5 km radius of the Shongweni Landfill

RECPETOR	LATITUDE (°S)	LONGITUDE (°E)	AREA (KM²)	DISTANCE (KM)	ORIENTATION
Mushroom Farm	-29.816063°	30.753401°	-	1.0	NNE
Isolated house 1	-29.819608°	30.761678°	-	1.5	NE
Isolated house 2	-29.844433°	30.759041°	-	2.2	SSE
Waterberry Close	-29.805779°	30.755999°	-	2.5	NNE
Ingane Yami Children's Home	-29.830135°	30.776851°	-	2.5	E
KwaNdengezi	-	-	22.0	2.6	SE
St Helier Greenhouses	-29.808041°	30.765663°	-	2.6	NE
Dassenhoek	-	-	13.3	2.7	SSW
Kwamanzini Primary School	-29.842015°	30.771441°	-	2.7	SE
Isolated house 3	-29.801979°	30.747108°	-	2.8	N
Ntee High School	-29.846780°	30.767650°	-	2.8	SSE
Summerveld	-	-	7.0	3.0	WNW
Polo Pony Retirement Village	-29.797301°	30.743607°	-	3.1	NNW
Ndengetho High School	-29.846903°	30.773189°	-	3.2	SE
KwaNdengezi Clinic	-29.851096°	30.768293°	-	3.2	SSE
Thokozamnganga High School	-29.855586°	30.738107°	-	3.3	SSW
Winston Park / Gillitts	-	-	11.0	3.5	NE
Bhongo Primary School	-29.848114°	30.775706°	-	3.5	SE
Hillcrest	-	-	20.1	3.6	NNE
Botate Primary School	-29.856101°	30.770729°	-	3.9	SSE
Summerveld Equine Hospital	-29.808967°	30.713035°	-	3.7	NW
Hillcrest Private Hospital	-29.789572°	30.742421°	-	4.0	NNW
Assagay	-	-	9.8	4.1	NNW
Hillcrest Hospital	-29.789629°	30.761803°	-	4.2	NNE

RECPETOR	LATITUDE (°S)	LONGITUDE (°E)	AREA (KM²)	DISTANCE (KM)	ORIENTATION
Chief Lokothwayo Primary School	-29.847540°	30.785971°	-	4.2	SE
Dassenhoek High School	-29.843313°	30.788550°	-	4.3	ESE
Umthala Primary School	-29.864670°	30.762374°	-	4.3	SSE
Hillcrest Primary School	-29.786848°	30.759602°	-	4.4	NNE
Ndengezi Intermediate School	-29.866251°	30.762174°	-	4.5	SSE
Winston Park Primary School	-29.796828°	30.781675°	-	4.5	NE
Stockville	-29.808450°	30.791538°	-	4.6	NE

3.2 CLIMATE AND METEOROLOGY

Seasonal and diurnal pollutant concentration levels fluctuate in response to the changing state of atmospheric stability, associated variations in mixing depth and to the influence of mesoscale and macroscale wind systems on the transport of atmospheric contaminants. This section provides an overview of atmospheric conditions influencing dispersion and dilution of pollutant concentrations in the Upper Highway region.

3.2.1 MACROSCALE CIRCULATION

South Africa's climate and weather is controlled by three semi-permanent, subtropical high-pressure cells. These anticyclonic circulations form part of the discontinuous high-pressure belt that circles the southern hemisphere at approximately 30^{O}S[37] (Figure 3-3). Seasonal changes in the intensity and position of theses high-pressure cells, together with the influence of tropical easterly lows and travelling circumpolar westerly waves, drive South Africa's prevailing temperature and precipitation patterns[38].

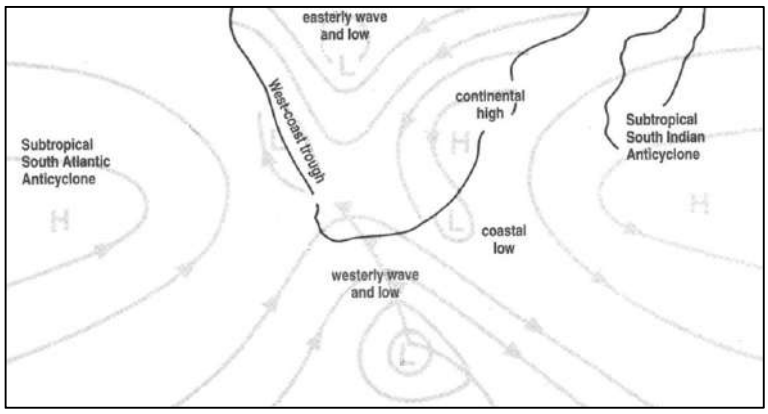


Figure 3-3: Atmospheric circulation and synoptic disturbances over southern Africa[39]

Anticyclonic systems are associated with atmospheric subsidence and stability, and the suppression of precipitation. These conditions are highly favourable for the formation of both elevated and surface inversions and thus limit vertical dispersion of pollutants. Absolutely stable layers occur over South Africa's interior plateau at approximately 700 hPa, 500 hPa and 300 hPa. Between the escarpment and the coastline, an absolutely stable layer forms at 800 hPa[40]. Surface inversions develop due to ground surface cooling overnight. As the sun rises the following morning, the stable layer is eroded from the bottom-up by surface heating. A mixing layer develops, allowing pollutants to rise and disperse[41].

Perturbations of the semi-stationary easterly waves take the form of open waves or closed lows which are associated with surface convergence and upper air divergence. This results in strong uplift, instability and sustained rainfall while surface divergence and upper air convergence on either side of the cyclonic system results in clear, dry conditions. These tropical disturbances are associated with copious rains if airflow has a northerly component and are mainly a summer phenomenon peaking during the months of December to February[42]. Although Durban experiences rainfall associated with these systems intermittently, it is unusual for the low pressure cell to reach as far south as Durban. Most of these systems dissipate with landfall over Mozambique.

[37] Turner, C.R.; Tosen, G.R. and Lennon S.J. (1995): *Atmospheric Pollution and Climate Change Impacts in South Africa* in Tytskrif vir Skoon Lug, 9(4).
[38] Tyson, P.D. and Preston-Whyte, R.A. (2000): The Weather and Atmosphere of Southern Africa, Oxford University Press, Cape Town.
[39] Ibid 38.
[40] Tyson, P.D.; Garstang, M., Swap, R., Kallberg, P. and Edwards, M. (1996): *An air transport climatology for subtropical Southern Africa* in International Journal of Climatology, 16: 265-291.
[41] Tyson, P.D.,; Kruger, F.J. and Louw, C.W. (1988): Atmospheric Pollution and its implications in the Eastern Transvaal Highveld, Foundation for Research and Development, Pretoria.
[42] Ibid 38.

Westerly perturbations include westerly waves, cut-off lows, southerly meridional flow, ridging anticyclones, west-coast troughs and cold fronts. Cyclonic systems are associated with surface convergence and upper-level divergence, resulting in stable conditions ahead of the system and cloudiness and precipitation following behind. These perturbations occur most frequently in winter and bring cool weather due to airflow from the southern polar latitudes. These systems tend to follow a south-easterly trajectory as they travel along the southern and eastern coast of South Africa and out over the Indian Ocean[43]. In winter, Durban regularly experiences the backing of the wind to the south-west, rainfall and cooler temperatures associated with the passing of a cold front.

3.2.2 MESOSCALE CIRCULATION

Air transport near the surface can either be induced by horizontal spatial discontinuities in temperature, pressure and density fields or by topographically induced local winds such as those on slopes and in valleys. Such mesoscale circulations have implications for the transport and recirculation of pollutants in an airshed.

On slopes, differential heating and cooling of the air produces local baroclinic fields. During the day, the absorption of radiation by the slopes warms the air near the surface, initiating low-level upslope anabatic flow with an upper-level return flow to complete the closed circulation. During the night, the mechanism and the circulation are reversed as surface cooling produces downslope katabatic flow and its return flow. The formation of frost hollows and the accumulation of fog and pollutants are associated with downslope flow[44].

Within valleys, local airflow is dependent on the geometry (depth and orientation) of valleys and the time of day or night. In valleys where slopes are equally heated (east-west valleys), early morning circulations are upslope while evening circulations are downslope. During the day, up-valley valley winds occur with an upper-level anti-valley wind to complete the closed circulation. During the night, down-valley mountain winds and the return anti-mountain wind occur. In valleys at right angles to the rising and setting sun (north-south valleys), the flow patterns are similar except that a unicellular circulation is set up at sunrise and sunset (Figure 3-4)[45].

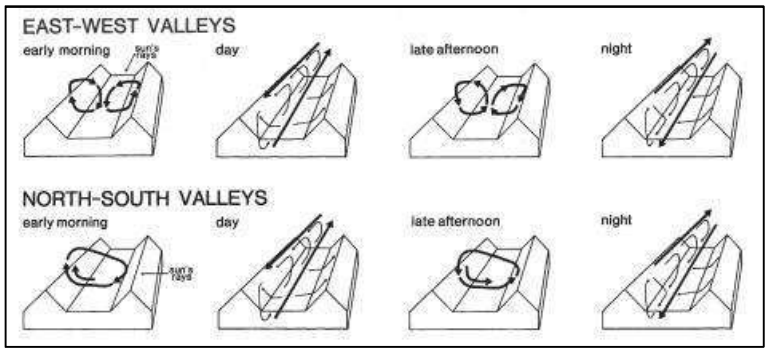


Figure 3-4 Diurnal variation of local airflow in valleys[46]

Across shorelines, similar baroclinic fields develop and decay with convective heating of the surface to produce sea and land breezes. By day, the sea-breeze advances inland while at night the system reverses and the land breeze blows out to sea[47].

These valley and mountain wind control the transport and dispersion of low-level pollutants within valleys. Nocturnal mountain winds can transport pollution long distances down valleys under stable conditions while daytime valley winds can effectively disperse and dilute pollution trapped within a valley. Valley winds dominate and are strongest in summer when heating effects are greatest while mountain winds dominate and are strongest in winter when cooling effects are strongest. The definition between local wind dispersion is often complex as these wind fields undergo stages of evolution and decay as one effect becomes integrated or overwhelmed by another[48].

Much like mountain and valley winds, temperature gradients between escarpments and plains produce large scale regional airflow. Mountain-plain winds produce airflow between cooler mountains and warmer plains at night while

[43] Ibid 38.
[44] Atkinson, B.W. (1981): *Meso-scale Atmospheric Circulations*, Academic Press, London.
[45] Ibid 38.
[46] Ibid 38.
[47] Ibid 38.
[48] Ibid 38.

Plain-mountain winds produce the opposite airflow between the warmer plains and the cooler mountains during the day. Tyson and Preston-Whyte (2000) uses the eastern-plateau slopes of KwaZulu-Natal to illustrate the diurnal patterns of these mesoscale wind conditions. Air masses carrying aerosols and trace gases have the ability to transport pollutants vast distances to impact on a regional scale (Figure 3-5).

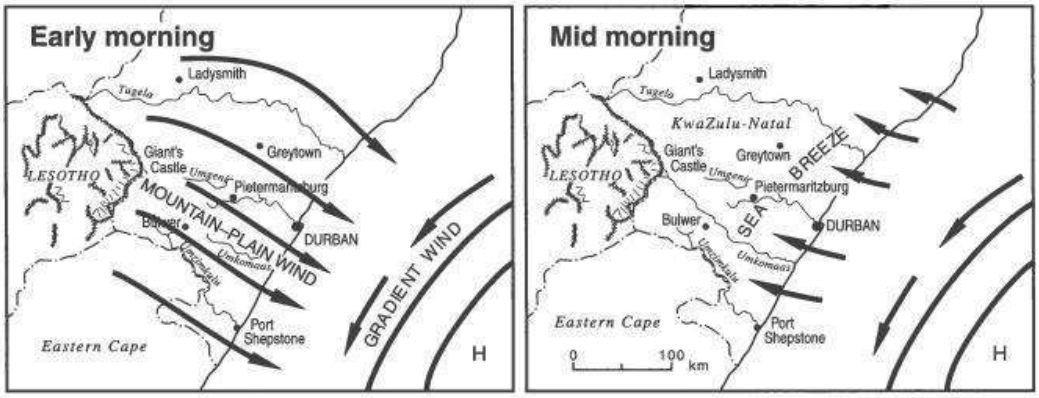


Figure 3-5: The diurnal variation of mesoscale winds between the escarpment and coastline over KwaZulu-Natal[49].

3.2.3 LOCAL METEOROLOGY

There are no meteorological stations operated by the South African Weather Service (SAWS) and the eThekwini Municipality within the study region. EnviroServ operate a weather station at the Shongweni Landfill but this data was not accessible to WSP. Meteorological variables for the region were sourced from weather stations owned and managed by UHA (Plantations, Summerveld and Winston Park) and Dr Lisa Ramsay (101 Acutts). These stations were installed between November 2016 (101 Acutts) and April 2017 (Winston Park). Data recovery data is presented in Table 3-2 and the location of these stations is shown in Figure 3-6.

Table 3-2: Meteorological station data used in this assessment

STATION	LATITUDE (°S)	LONGITUDE (°E)	ALTITUDE (M)	AVAILABLE DATA PERIOD (AT TIME OF ANALYSIS)	DATA RECOVERY (%)			
					Wind Direction	Wind Speed	Temp	Rainfall
101 Acutts	-29.7599°	30.8011°	621	14/11/2016 – 31/05/2017	94%	94%	94%	94%
Plantations	-29.7952°	30.7645°	676	30/03/2017 – 31/05/2017	96%	96%	100%	100%
Winston Park	-29.8151°	30.7762°	624	11/04/2016 – 31/05/2017	100%	100%	100%	100%
Summerveld	-29.7998°	30.7155°	755	25/04/2016 – 31/05/2017	100%	100%	100%	100%

[49] Ibid 38.

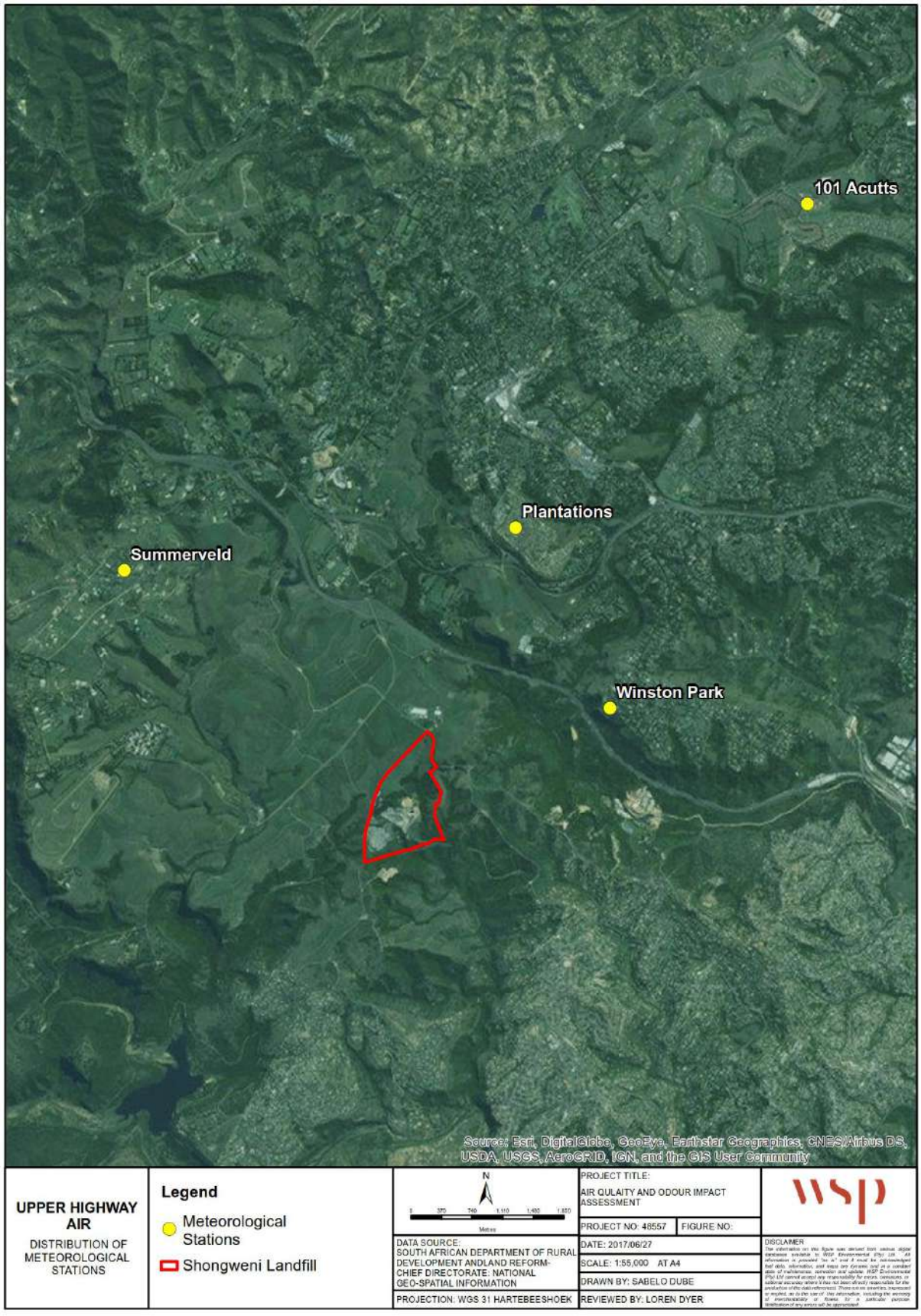


Figure 3-6: Distribution of meteorological stations in the Upper Highway area

Figure 3-7 presents the meteorological data collected by the 101 Acutts station for the period 14 November 2016 to 30 May 2017. Temperature, pressure and relative humidity over this period averaged at 21.18°C, 1017 hPa and 82.5% respectively. The maximum temperature measured was 37.29°C at 11h36 on 31 March 2017 and the minimum temperature measured was 11.26°C on 14 April 2017 at 20h37. Relative humidity ranged between 19% and 100% over the period.

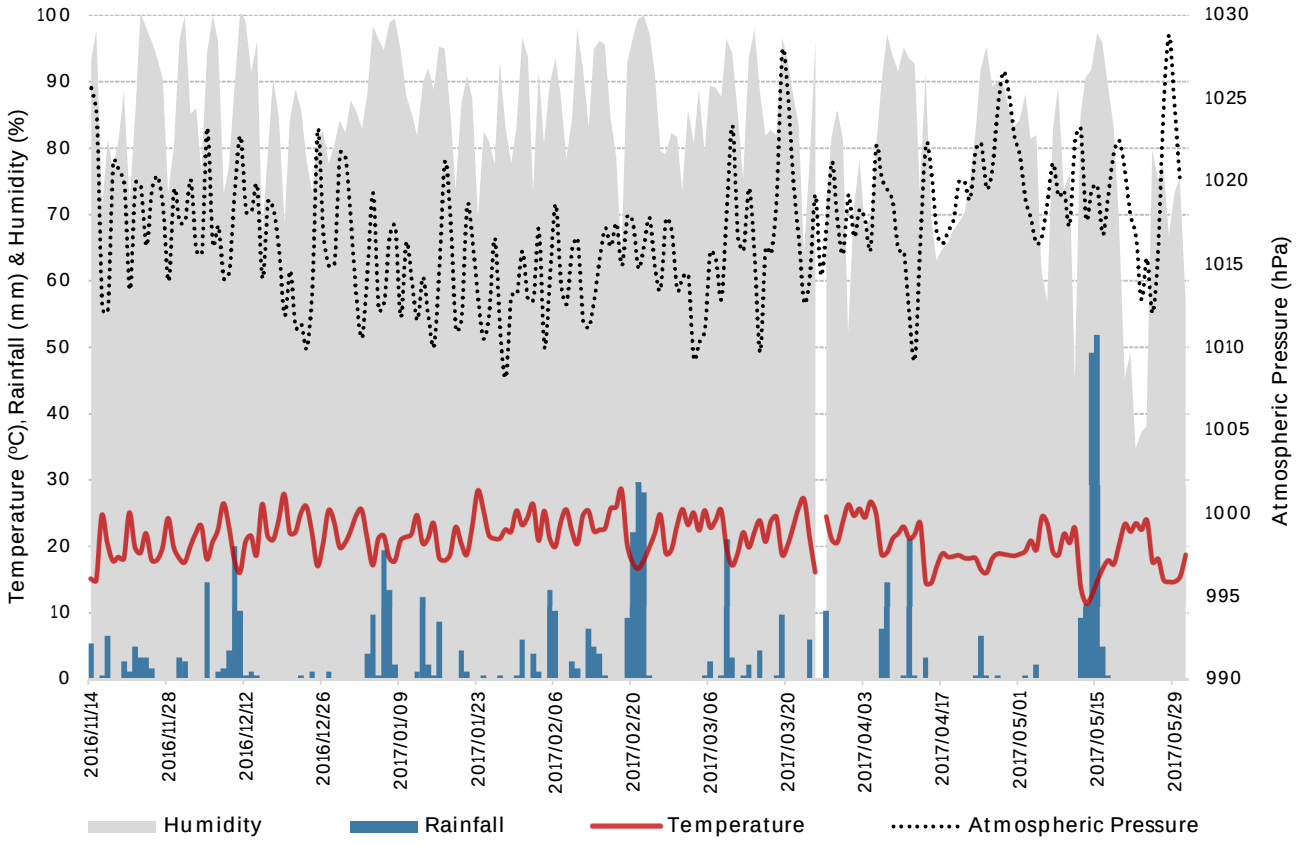


Figure 3-7: Meteorological data from the 101 Acutts station (November 2016 – May 2017)

Wind roses summarize wind speed and directional frequency at a location. Calm conditions are defined as wind speeds less than 0.3 m/s. Each directional branch on a wind rose represents wind originating from that direction. Each directional branch is divided into segments of colour, each representative of different wind speeds. Wind speed classes here are 0.3 – 2 m/s, 2 – 4 m/s, 4 – 6 m/s and > 6 m/s.

Due to the shorter datasets for the Winston Park and Summerveld stations, wind roses were developed only for the 101 Acutts (November 2016 – May 2017) and Plantations (March 2017 – May 2017) stations. Average wind roses are analysed for the full dataset, diurnally for early morning (00h00 – 06h00), morning (06h00 – 12h00), afternoon (12h00 – 18h00) and evening (18h00 – 23h00), and seasonally (as available) for summer (December, January and February) and autumn (March, April and May).

101 ACUTTS

Wind roses for the 101 Acutts station (14 November 2016 – 31 May 2017) are presented in Figure 3-8:

- Gentle to strong winds prevail from the south-easterly sector with a clear westerly component.
- Calm conditions were experienced 2.6% of the time.
- There is an increase in frequency and strength of the easterly to southerly components during the day and an increase in the strength and frequency of the westerly to northerly components at night.
- Due to the relatively short dataset (6.5 months), seasonal wind roses are produced only for summer and autumn.
  - Easterly to southerly winds dominate during the summer months (influence of strengthening sea breeze and plain-mountain wind) with a decrease in westerly to south-westerly winds (due to decreased influence of cold fronts).

- A significant westerly component emerges during autumn with strengthening of the mountain-plain wind, particularly at night, and increased frequency of cold fronts.
- Autumn is characterised by higher variability in wind direction compared to summer.

PLANTATIONS

Wind roses for this station (30 March 2017 – 31 May 2017) are presented in Figure 3-9.

- Gentle to strong winds prevail from the westerly sector with a gentler north-easterly component.
- A moderate south-easterly component prevails in the afternoons.
- After sunset, a moderate to strong westerly to north-westerly component develops.
  - This weakens after sunrise when the south-easterly component develops.
- Due to the short dataset (3 months), a seasonal comparison is not possible.

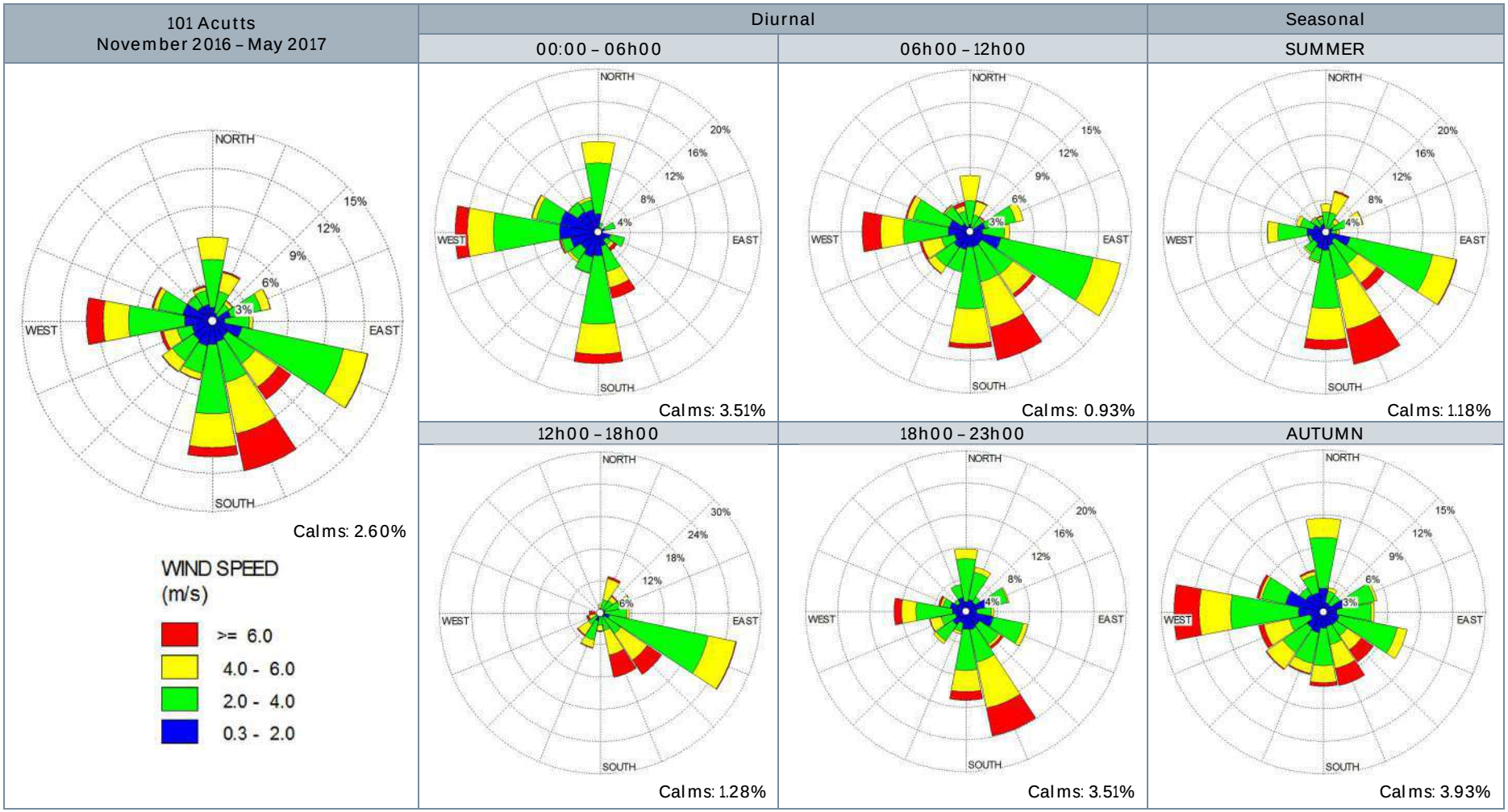
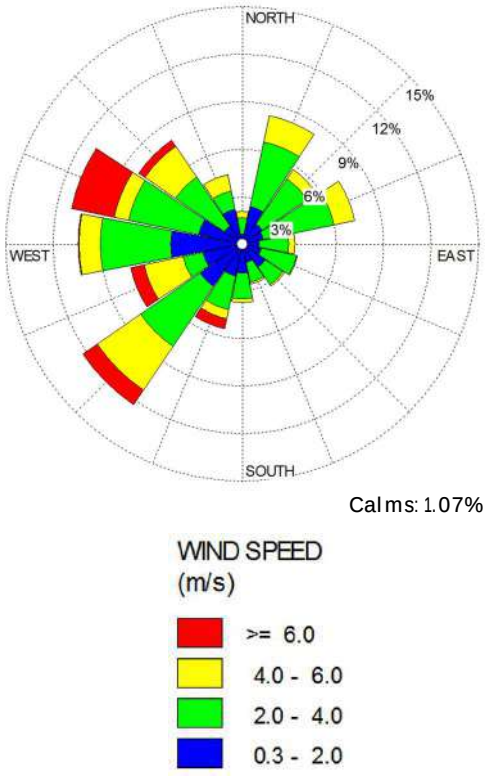
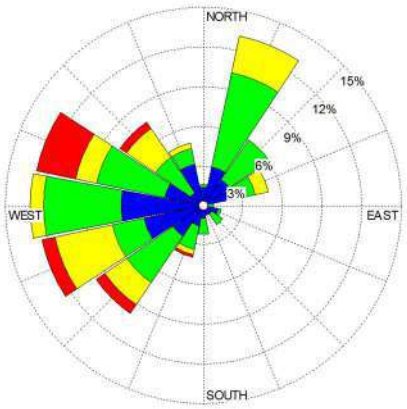
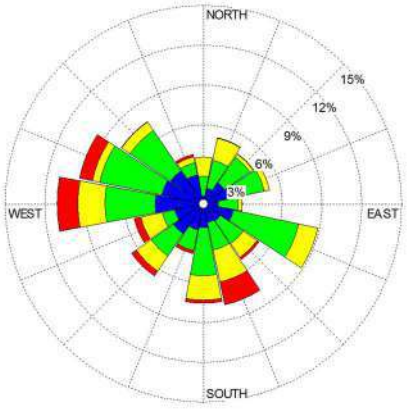
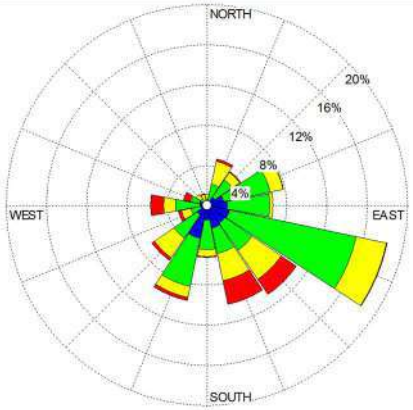


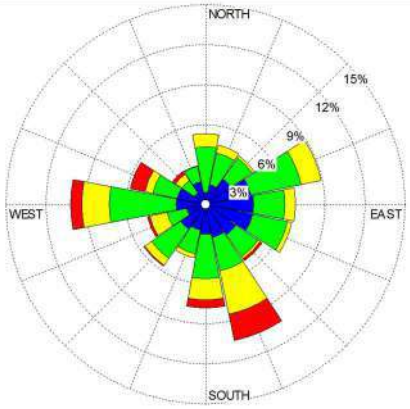
Figure 3-8: Wind roses for 101 Acutts (14 November 2016 – 31 May 2017)

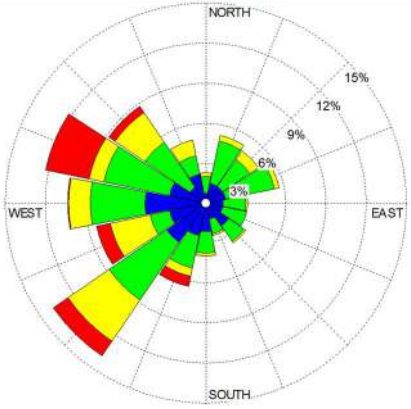
<table>
<tr><th rowspan="2">Plantations
March 2017 – May 2017</th><th colspan="2">Diurnal</th><th>Seasonal</th></tr>
<tr><th>00h00 – 06h00</th><th>06h00 – 12h00</th><th>SUMMER</th></tr>
<tr><td rowspan="2"> 

Calms: 1.07%
</td><td> 

Calms: 2.12%</td><td> 

Calms: 1.29%</td><td>No data</td></tr>
<tr><th>12h00 – 18h00</th><th>18h00 – 23h00</th><th>AUTUMN</th></tr>
<tr><td> 

Calms: 0.87%</td><td> 

Calms: 3.23%</td><td> 

Calms: 0.94%</td></tr>
</table>

Figure 3-9: Wind roses for Plantations (30 March 2017 – 31 May 2017)

3.3 UPPER HIGHWAY AIR COMMUNITY COMPLAINTS DATABASE

Community complaints are submitted via the UHA website and mobile phone application. Odour complaints via these channels are submitted directly to the eThekwini Municipality, EnviroServ and the national Department of Environmental Affairs (DEA). The UHA complaints input screen provides the opportunity for the complainant to report wind direction for the time of the complaint. To improve accuracy for the meteorological analysis, UHA also combined their complaints dataset with wind direction data from the local meteorological stations. It is the latter wind direction dataset that is used in the analysis that follows, rather than the data submitted by the complainant.

The complaint database was analysed for the period 01 January – 31 May 2017. A total of 92,497 complaints were submitted over this five month period. Results indicated:

- 85% of complaints reported the odour in residential areas within a 5 km radius of the Shongweni Landfill, including but not limited to, Hillcrest, Winston Park, Gillitts and Assagay (Figure 3-2 and Figure 3-10).
- 73.7% of odour complaints coincided with southerly wind trajectories (i.e. SW – SE), suggesting that the odour source is located to the south of the complainant communities.
    - 7.2% of complaints occurred during calm (stagnant) conditions (Figure 3-11 and Figure 3-12).
- The majority of complaints occurred between 06h00 and 09h00 and between 19h00 and 21h00 (Figure 3-13).
    - This is likely indicative of when residents wake up to perceive the odour and when they return home in the evening. Even if the odour event is sustained, a resident is less likely to report again after reporting earlier in the morning or evening despite that the system recommends hourly reporting if the odour event continues.
- The odour was described as 'refinery' (43%), 'chemical' (40%) or 'sulphur-type' (13%) (Figure 3-14) and accompanied by a variety of health symptoms (Table 3-3), including headaches (60% of complaints), throat irritation (80% of complaints), sinus (70% of complaints) and eye irritation (61% of complaints).

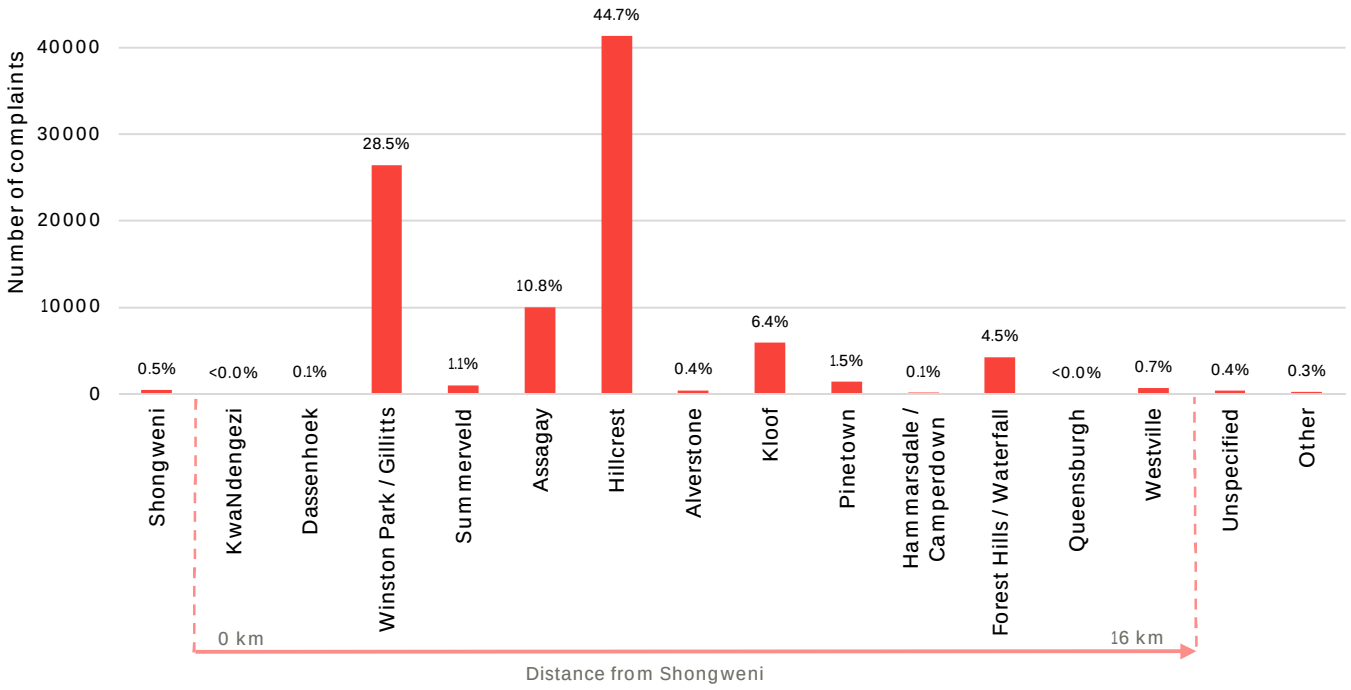


Figure 3-10: Number of complaints (01 January – 31 May 2017) received by area arranged in increasing distance from the Shongweni Landfill

Note: The purpose of Figure 3-10 is to show the number of complaints with distance from the Shongweni Landfill and not the weight of odour impact on each suburb. There are varying population densities across suburbs and there are certain suburbs underrepresented in the databased despite established odour impacts there.

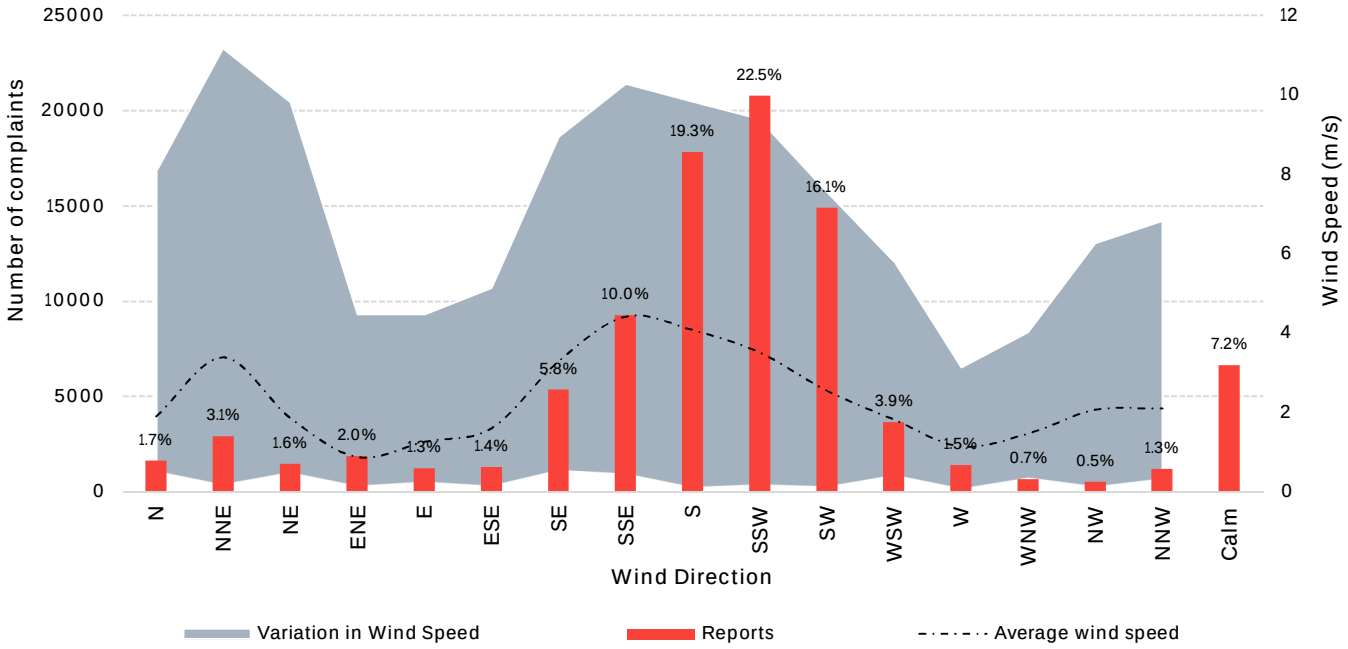


Figure 3-11: Number of complaints received by wind direction (01 January – 31 May 2017)

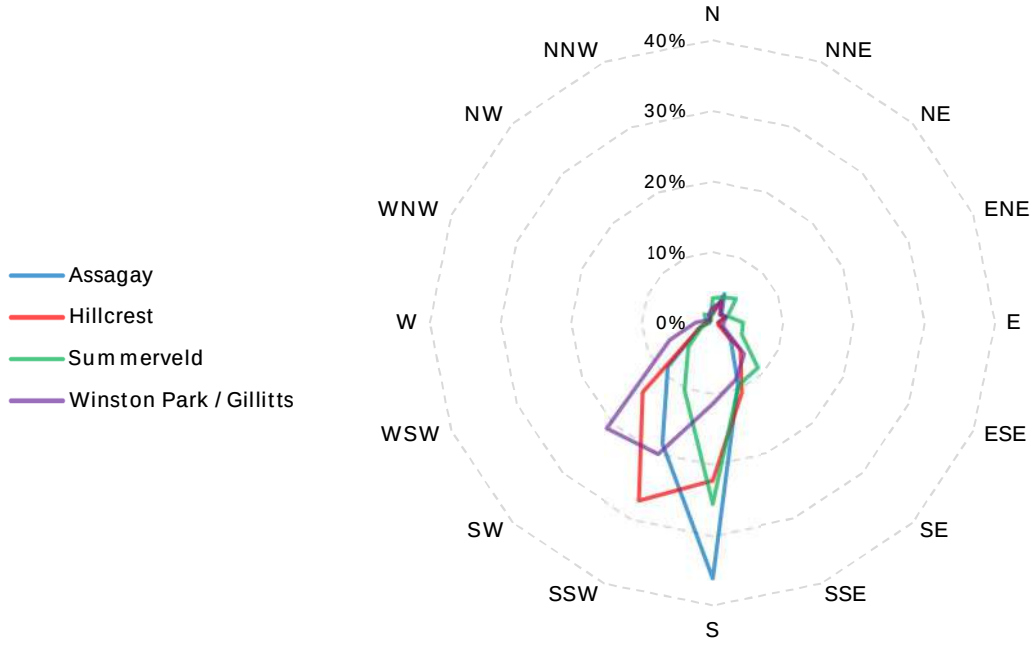


Figure 3-12: Wind direction during odour complaints by suburb (01 January – 31 May 2017)

Note: Data analysis revealed that the residents of communities such as Dassenhoek and KwaNdengezi do not actively participate in the reporting of odour events via the UHA channels. This may be due to lack of knowledge of the service or limited access to the service. As such, it should not be inferred that these communities are not impacted nor that there is no community impact during northerly wind trajectories.

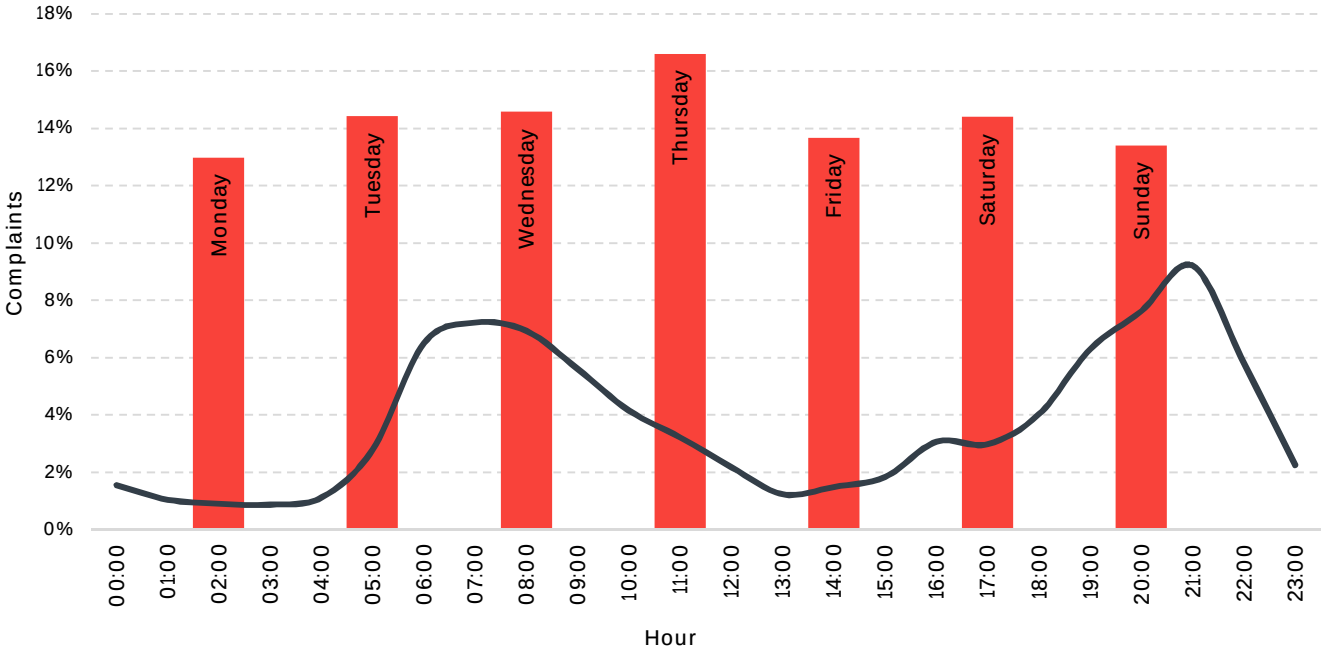


Figure 3-13: Complaints received by day of the week and by time of day (01 January – 31 May 2017)

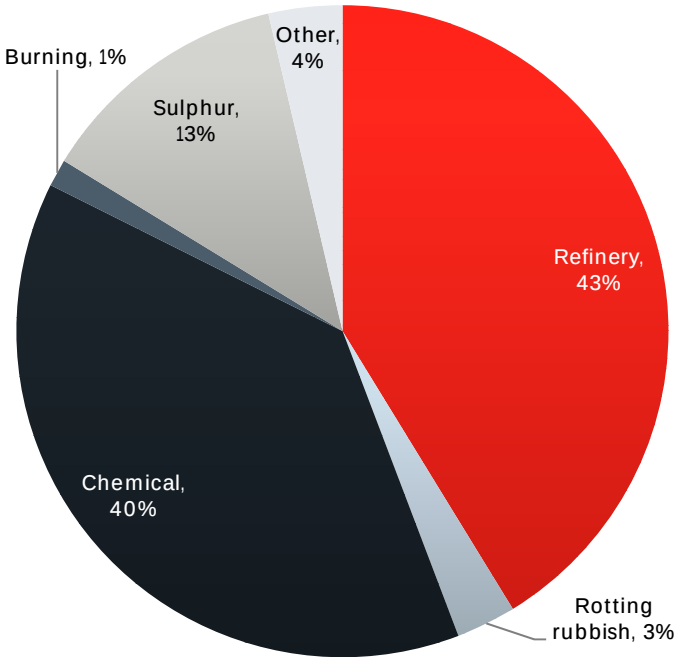


Figure 3-14: Reported odour descriptions (01 January – 31 May 2017)

Table 3-3: Reported health affects 01 January – 31 May 2017

AFFECT	FREQUENCY OF OCCURANCE
Throat irritation (including cough)	80%
Nuisance	72%
Sinus irritation	70%
Eye irritation	61%
Headache	60%
Gastric discomfort (including nausea and vomiting)	35%
Breathing difficulties (including asthma)	33%
Dermal irritation	21%
Fatigue	18%
Heart palpitations	15%

3.4 EXISTING AMBIENT AIR QUALITY AND ODOUR MONITORING DATA

This section summarises existing air quality datasets for the Upper Highway area.

3.4.1 GEOZONE FOR ENVIROSERV

Geozone Environmental (Pty) Ltd has been appointed by EnviroServ since 1998 to conduct air quality monitoring at and in the vicinity of the Shongweni Landfill. Ambient concentrations of H_2S, formaldehyde (CH_2O), ammonia (NH_3) and select VOCs were measured using Radiello passive samplers (Figure 3-15) over the period of August 2015 to August 2016. Measurements were conducted at the landfill boundary and at strategic positions in the surrounding area (Figure 3-16).

A passive sampler is an apparatus that contains a solid sorbent in an inert container into which vapours diffuse. Samplers are deployed for a designated sampling period and then collected for analysis where the analyte compounds trapped by the sorbent are extracted and measured. A time-weighted average concentration is then calculated. Appropriate quality assurance/quality control (QA/QC) in the form of media blanks, field blanks and duplicate samples, should be applied to maintain sample integrity and achieve measurement accuracy.

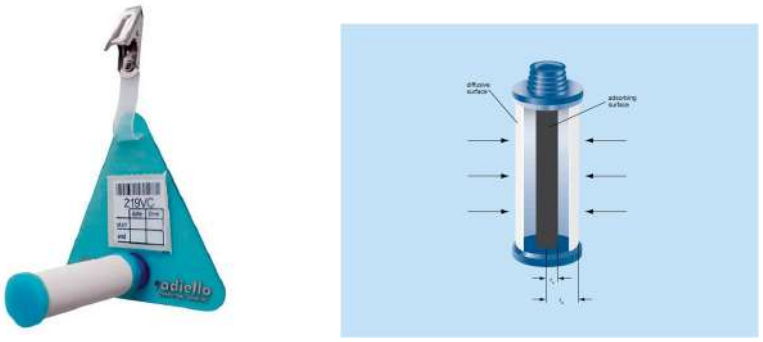


Figure 3-15: Assembled Radiello passive sampler (left) and cross section of diffusive body and sorbent cartridge tube (right)

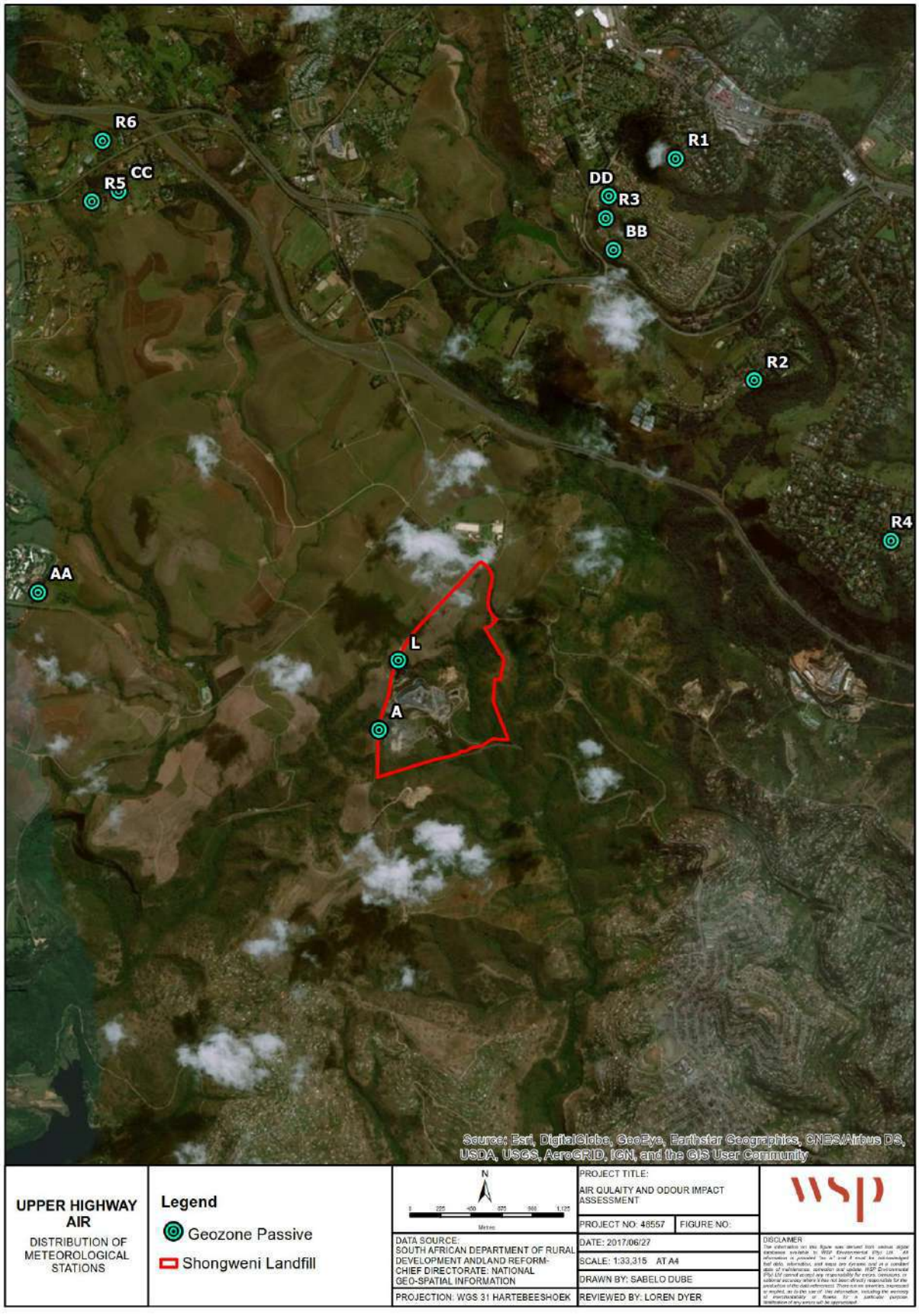


Figure 3-16: Geozone passive monitoring locations

Results of the monitoring campaigns[50] over the period August 2015 to August 2016 inclusive (i.e. 13 months) are presented in Table 3-4 for comparison with national standards and international exposure guidelines (Table 1-2). Results show:

- Average benzene concentrations measured at all monitoring points remained below the NAAQS (1.6 ppb, annual averaging period);
- Average formaldehyde concentrations measured on the Shongweni Landfill (FF) exceeded the ODT (24.4 ppb);
- Average formaldehyde concentrations measured at the Denny Mushrooms farm (EE) exceeded the long-term (annual) TCEQ ESL (2.7 ppb);
- Average H_2S concentrations measured on the Shongweni Landfill (FF) exceeded the ODT (0.1 – 1.4 ppb), WHO annoyance (5 ppb, 30-minute averaging period) and health (107.6 ppb, 24-hour averaging period) exposure guidelines as well as the UK EAL (100.4 ppb, annual averaging period);
- Average H_2S concentrations measured at the Shongweni Landfill fenceline (A, L and E) and Denny Mushrooms farm (EE) exceeded the ODT (0.1 – 1.4 ppb) and WHO annoyance guideline (5 ppb, 30-minute averaging period);
- Average H_2S concentrations at community receptors (AA, BB, CC and DD) measured within the range of odour detection (0.1 – 1.4 ppb); and
- Concentrations of other detected compounds were below the relevant ODTs and exposure guidelines.

Table 3-4: Average ambient contaminant concentrations (August 2015 to August 2016 inclusive)

Sample Location	A	L	E	AA	BB	CC	DD	EE	FF
Average no. of samples[51]	13	17	8	8	3	5	5	2	2
Benzene (ppb)	0.31	0.40	0.27	0.16	0.40	0.45	0.87	0.71	0.62
Toluene (ppb)	0.98	1.06	0.64	0.32	0.60	0.44	1.07	0.47	1.07
Ethylbenzene (ppb)	0.45	0.26	0.17	0.10	0.10	0.12	0.15	0.10	0.23
Xylene (ppb)	1.16	1.08	0.53	0.26	0.41	0.25	0.68	0.31	0.86
Trimethylbenzene (ppb)	0.45	0.44	2.84	0.14	0.12	NM	0.49	NM	NM
Formaldehyde (ppb)	0.95	1.67	0.76	0.68	1.41	1.28	0.90	2.84	62.12
Hydrogen sulphide (ppb)	8.62	15.25	6.27	0.34	0.33	0.25	0.22	7.28	119.81

NM Not measured

A further monitoring campaign[52] was conducted at the residences of community volunteers (Table 3-5). Exposure periods ranged from 11 to 16 days. Findings included:

- Average benzene concentrations measured at all monitoring points remained below the NAAQS (1.6 ppb, annual averaging period);
- Average H_2S concentrations at all monitoring points measured within the range of odour detection (0.1 – 1.4 ppb); and
- Concentrations of other detected compounds remain below the relevant ODTs and exposure guidelines.

[50] Geozone ambient air quality monitoring results as supplied by EnviroServ in File no. 9 of subpoena
[51] Additional sampling points were added during the assessment period therefore monitoring locations do not have equal number of samples.
[52] Geozone ambient air quality monitoring results as supplied by EnviroServ in File no. 9 of subpoena

Table 3-5: Contaminant concentrations as measured at the residence of community volunteers

SAMPLE LOCATION	R 1	R 2	R 3	R 4	R 5	R 6
DURATION	21/06 – 28/06 2016	26/06 – 09/07 2016	27/06 – 12/07 2016	14/06 – 27/06 2016	13/06 – 27/06 2016	13/06 – 27/06 2016
Benzene (ppb)	0.49	0.81	0.94	0.33	0.29	0.40
Toluene (ppb)	0.64	0.58	1.13	0.41	0.37	0.47
Ethylbenzene (ppb)	BDL	0.09	0.19	BDL	BDL	BDL
Xylene (ppb)	0.41	0.40	0.93	BDL	0.21	0.26
Trimethylbenzene (ppb)	BDL	BDL	0.33	BDL	BDL	BDL
Formaldehyde (ppb)	BDL	BDL	BDL	BDL	BDL	BDL
Hydrogen sulphide (ppb)	0.13	0.32	0.27	0.19	0.15	0.15

BDL Below detection limit

The same sampling method was applied to a shorter averaging period to gauge pollutant concentrations during perceived odour events. Volunteers from the surrounding residential areas were provided with the sample media and instructions for collecting samples. Averaging periods ranged from one hour to two hours and five minutes and samples were collected during June or July 2016. Results[53] (Table 3-6) indicated:

- H_2S concentrations measured at the residences of community volunteers exceeded the ODT (0.1 – 1.4 ppb) at all locations while five of the six monitoring points also exceeded the WHO annoyance guideline (5 ppb, 30-minute averaging period); and
- Other contaminants measured remained below the detection limit at all locations.

Table 3-6: Short-term contaminant concentrations as measured by community volunteers

SAMPLE LOCATION	R1	R2	R3	R4	R5	R6
DATE AND DURATION	21/06/2016 1h10m	02/07/2016 2h00m	21/06/2016 1h20m	21/06/2016 1h30m	12/07/2016 1h00m	21/06/2016 2h05m
Benzene (ppb)	BDL	BDL	BDL	BDL	BDL	BDL
Toluene (ppb)	BDL	BDL	BDL	BDL	BDL	BDL
Ethylbenzene (ppb)	BDL	BDL	BDL	BDL	BDL	BDL
Xylene (ppb)	BDL	BDL	BDL	BDL	BDL	BDL
Trimethylbenzene (ppb)	BDL	BDL	BDL	BDL	BDL	BDL
Hydrogen sulphide (ppb)	1.97	6.08	6.72	5.34	12.14	7.77

BDL Below Detection Limit

Geozone concluded from these results that it was unlikely that persons would experience or develop adverse health effects as a consequence of inhalation exposure to these measured ambient concentrations. H_2S was found to exceed an unreferenced odour threshold along the site boundary. The landfill's leachate storage tanks were identified by the study to be a priority source of H_2S and abatement was recommended. Odour episodes triggering complaints were attributed to meteorological conditions (specifically low atmospheric pressure preceding cold fronts, south-westerly winds and periods of calm conditions). Based on the frequency, intensity, duration and offensiveness of the odour, Geozone concluded that the Shongweni Landfill's leachate tanks were not the sole source of objectionable odour nuisance. It was recommended that eThekwini Municipality investigate other odour sources in the area and enforce appropriate management measures. Potential odours sources were listed as the Denny Mushrooms farm, the wastewater treatment works, a local industrial park and a lawn fertilizer supplier.

[53] Ibid 52

3.4.2 GOLDER ASSOCIATES FOR UPPER HIGHWAY AIR

Golder Associates (Pty) Ltd (Golder) were contracted by UHA to review the ambient monitoring conducted by Geozone. The Technical Memorandum submitted by Golder concluded that the odour nuisance is not likely resulting from the pollutant array measured by Geozone and that the passive monitoring technique is unable to detect short-term concentration peaks of potential pollutants. Golder recommended monitoring of an alternate pollutant array as well as the use of more appropriate monitoring methods to detect concentration peaks.

3.4.3 E-NOSE AFRICA FOR UPPER HIGHWAY AIR

e-Nose Africa cc (e-Nose Africa) volunteered to conduct an odour investigation for UHA for the period of September to November 2016. The investigation note submitted by e-Nose Africa to UHA is attached under Appendix A. The purpose of this study was to ascertain whether the odour originating from the Shongweni Landfill had the same odour signature as the odour experienced by the Upper Highway community. Aims of the study were therefore to:

- Characterise the odour signature/s for the Shongweni Landfill;
- Determine whether the Shongweni Landfill signature/s is/are present at community receptors during odour episodes; and
- Statistically assess the degrees to which emissions from the Shongweni Landfill contribute to the odour nuisance experienced at these receptors.

Similar to the way the human brain processes multiple constituent gases detected by the nose as a singular and distinctive smell experience, an electronic nose (e-nose) can process and categorise odour signals recorded across an array of disparate compound sensors to produce a collective pattern representative of an odorous gas mixture. Each of the e-nose's sensors is calibrated to favour a particular 'family' of odour compounds. During a monitoring event, the individual sensors respond to the presence of their preferred odour 'family'. Environmental odours are composed of a bouquet of constituent gases that can activate across the sensor array. The sensor activation is collectively processed to produce a pattern of response that is then interpreted to determine the odour intensity and odour identity, otherwise known as the odour's signature.

An Mk 3 e-nose (Figure 3-17) with six sensors owned and maintained by e-Nose Africa was used for this assessment. Measurements were taken at points within the community and along the Shongweni Landfill boundary. The e-nose was placed in a home within the Plantations Estate for a six day period (13 to 18 November 2016) to record fluctuating odour episodes. The findings of this continuous odour exposure measurement are discussed below.

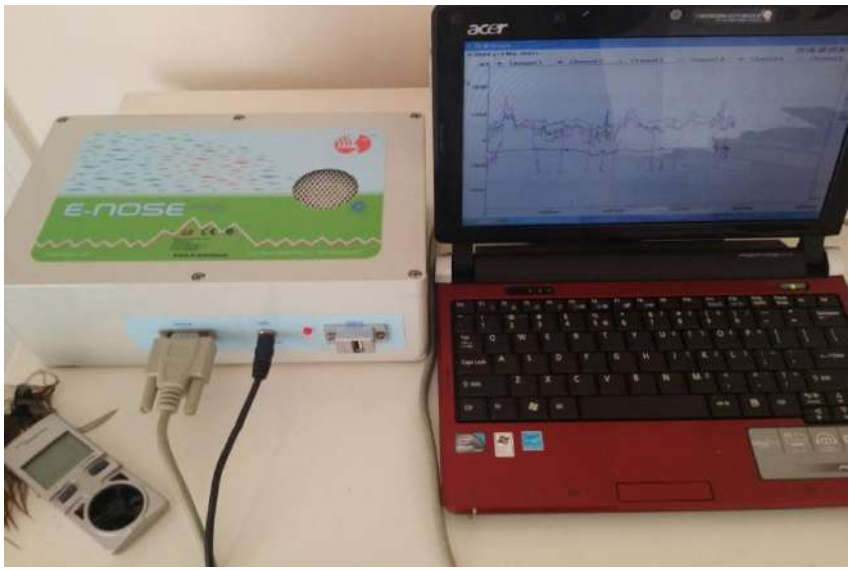


Figure 3-17: e-Nose odour monitoring equipment

Odour identity determines the relative source of a stimulus gas-mixture by correlating the pattern of sensor response with an odour signature obtained for the suspected odour source. The source signature is created from the response of

each sensor to an odour producing a characteristic, yet stable pattern regardless of odour intensity. Figure 3-18 presents the direct linear correlation between monitoring conducted at Plantations Estate (Hillcrest) and the signature measured at the Shongweni Landfill boundary. Linear correlation is approximately 90% during baseline periods (Œ), which indicates a strong similarity between the odour signature measured at the receptor and the odour signature measured at the potential source. The strong decorrelation at marker • indicates that the Shongweni Landfill stimulus evident during baseline periods is displaced at the monitoring site by a stimulus unfamiliar to the e-nose dataset for the duration of this odour event. Results also show that odour events of significant magnitude occur in addition to baseline periods already dominated by the Shongweni Landfill signature. During event Ž a correlation of up to 100% is achieved indicating that the stimulus at Plantations Estate was identical to the Shongweni Landfill signature measured at the landfill boundary in both character and intensity.

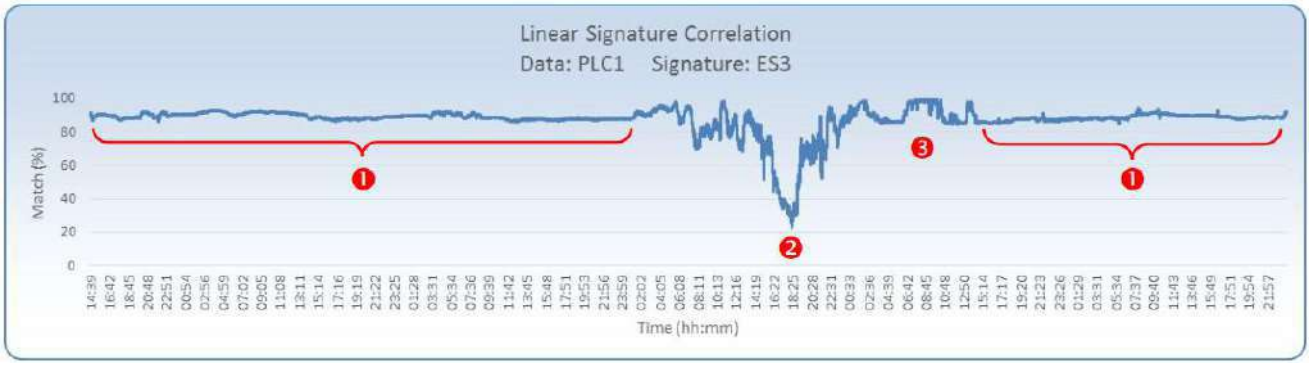


Figure 3-18: Linear signature correlation

To emulate habituation (i.e. the dynamic human odour experience, where continuous exposure to low-level or stable odour concentrations are subconsciously ignored while the olfactory system remains highly sensitive to transient concentration fluctuations or changing odour characters) and better predict the human response to odour events, measurements were processed to supress baselines and accentuate peaking odour transients. The habituated correlation is therefore the calculated probability that a human being would associate the perceived odour with that of the measured odour source in order to determine a match.

Figure 3-19 indicates that the Shongweni Landfill odour constitutes more than half the baseline activation at Plantations Estate and therefore appears to be the dominant contributor to odour experienced over baseline periods (Œ). These baseline periods are also perceived by the human nose as less statistically linear with both peaks and troughs now evident. The perception of the Shongweni Landfill odour drops off during event • with an alternate stimulus (or combination of stimuli) perceived at this time. During event Ž simulated habituation peaks at 100%. The average human observer in Plantations Estate would have experienced this odour as a continuous, very high intensity event, identical in character to the odour an individual would experience at the Shongweni Landfill boundary.

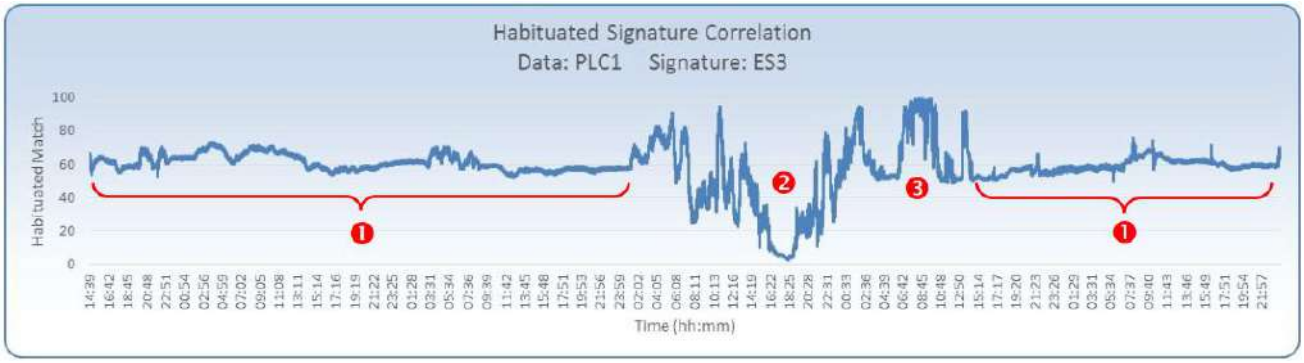


Figure 3-19: Habituated signature correlation

Signature loading is defined as the proportion of the total odour measured at the receptor (Plantations Estate) that represents the odour signature under investigation (Shongweni Landfill). Figure 3-20 presents the total chemical load at Plantations Estate that owes its origin to the odour signature measured at the Shongweni Landfill boundary. Input data for Figure 3-20 has been normalised so that the maximum odour load in the air at any given time is 100%. The green band of the stacked curve indicates the total odour loading at Plantations Estate during the 6-day monitoring period. The red band of the stacked curve indicates the component within the total odour load at Plantations Estate that

matches the signature measured at the Shongweni Landfill boundary. Both bands combined represent the total odour loading of 100%. The solid black line represents the absolute odour load of the Shongweni Landfill signature. This is included for comparison with the levels measured at Plantations Estate for the purposes of assessing the strength of the odour encountered at Plantations relative to the original signature measured at the landfill boundary.

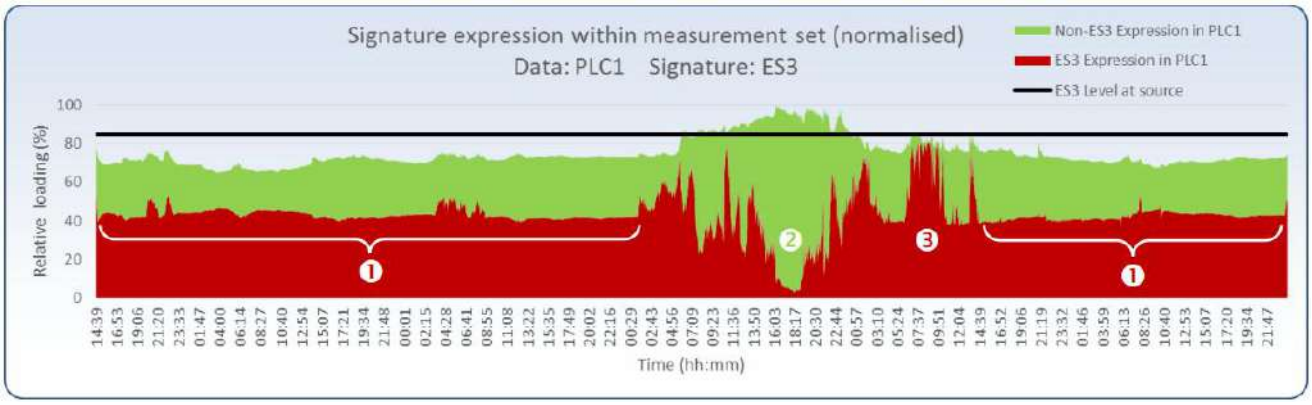


Figure 3-20: Signature loading of odour measured by e-nose at Plantations Estate

During baseline periods (Œ), the level of the Shongweni Landfill expression encountered at the Plantations Estate constitutes 50% to 65% of the source intensity (black line). This absolute level is consistent over the monitoring period and can therefore be presumed to extend beyond the survey period. The total odour loading experienced at Plantations Estate peaked during event •, however, without the source signature, inferences made from these results would be mere assumptions. The Shongweni Landfill expression dominated odour event Ž, which manifested as a sustained episode, near identical in character and intensity to that of the source boundary measurement.

Wind conditions experienced during these events are presented in Figure 3-21. These conditions were recorded by the meteorological station located at 101 Acutts as this was the only operational station in the area during the e-nose monitoring period. These wind roses indicate significant variation in the wind field between the baseline odour conditions (Œ) and the distinct odour episodes • and Ž. When baseline conditions were observed, moderate south easterly wind trajectories dominated. Odour event • was characterised by gentle west–south-westerlies. Winds originating from a south-easterly direction re-emerged during event Ž, however a strong southerly component is also evident during this time. The Shongweni Landfill lies to the south of Plantations.

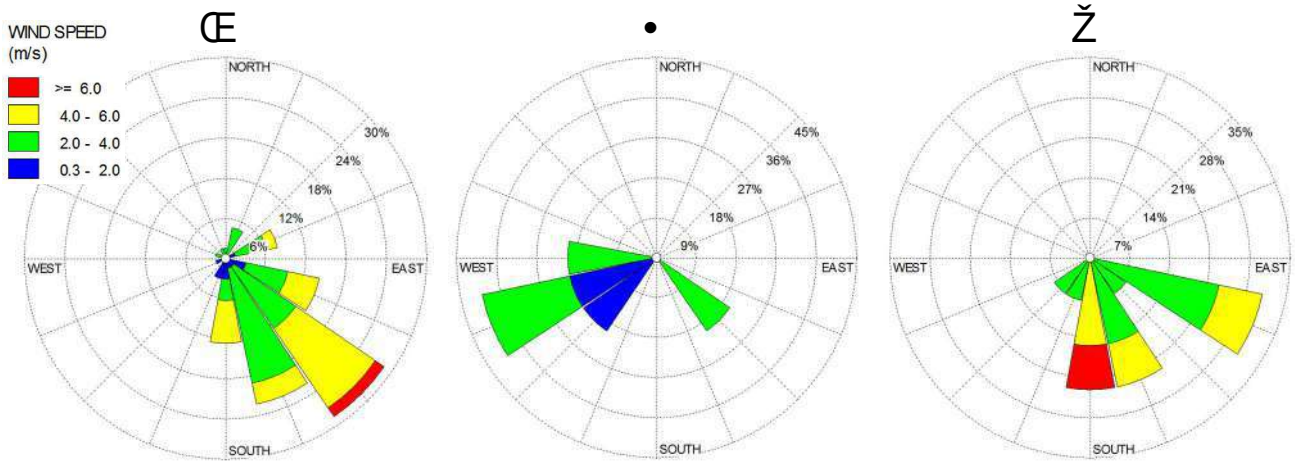


Figure 3-21: Wind field observations for odour episodes recorded by the e-nose

3.4.4 AIRSHED AS APPOINTED BY INFOTOX FOR ENVIROSERV

Infotox (Pty) Ltd. (Infotox) was appointed by EnviroServ to quantify gaseous emissions from the Shongweni Landfill as well as conduct a health risk assessment of these emissions. Aished Planning Professionals (Pty) Ltd. (Airshed) was subsequently appointed to carry out atmospheric dispersion simulations of the measured landfill gas emissions to assist with estimating community exposure concentrations.

The Airshed report (*Atmospheric Dispersion Simulations of Gaseous Emissions from the Shongweni Landfill Site, West of Durban*, Report 16E2M01, dated 5th of April 2017) presented dispersion simulation results modelled using the Level 3 CALPUFF model. These results are based on a two-month (December 2016 – January 2017) simulation period. Model inputs included gaseous emissions rates based on the site measurements conducted by Infotox.

Various assumptions and limitations are noted in the Airshed report. No conclusions, no interpretation nor any comparison of tabulated results with NAAQS or other international guidelines are given. Predicted concentrations were compared with measured observations using an 'order of magnitude test'. Predicted H_2S concentrations along the landfill boundary were found to be 146% higher than concentrations observed at the Valley 2 Dam air quality monitoring station while predicted concentrations at the landfill's entrance were over-predicted by an "*by an order of magnitude.*" (Airshed Report no.16EWM01 pg 45). No comparison of predicted concentrations with monitoring stations located in Plantations, Winston Park or KwaNdengezi was provided due to "*relatively high [H2S] concentrations observed from directions other than in the direction of the Shongweni Landfill Site.*" (Airshed Report no.16EWM01 pg 62).

4 WSP FIELD INVESTIGATION

Ambient air quality and dust fallout (DFO) monitoring undertaken by WSP under appointment by UHA is presented here. Ambient gas monitoring to investigate odour events is reported on in Section 4.1 while results of DFO monitoring are presented in Section 4.2

4.1 AMBIENT GASES

Ambient H_2S and speciated VOCs were selected for measurement during short-term monitoring campaigns. H_2S has a characteristic odour and is commonly associated with landfill odour episodes. VOCs were selected due to community concerns regarding exposure these (particularly the known carcinogen, benzene) and the 'refinery' description of the odour in the complaints dataset.

H_2S samples were collected directly to charcoal sorbent tubes during an odour event on the morning of 30 August 2017.

VOC samples were pumped either into Tedlar bags in the field for transfer to Tenax sorbent tubes in the laboratory, or directly onto the Tenax sorbent tubes in the field. The latter sampling methodology is in accordance with the US EPA TO-14a. Pump flow rates were controlled internally and the pumps were checked against a Bios Defender standard prior to use. Four VOC sampling campaigns took place:

- The first campaign, at 07h15 on 06 April 2017, comprised the collection of a Tedlar bag sample using a pre-calibrated sampling pump downwind of the landfill site (Figure 4-1 and Appendix B). This was a screening exercise to determine the pollutants detectable downwind of the landfill fenceline. Conditions were cool with a moderate south-westerly wind.
- The second campaign, in the early afternoon of 08 May 2017, took place at the landfill fenceline (Figure 4-1 and Appendix B). A Tedlar bag sample and three Tenax sorbent tubes were collected, as well as a tube field blank. Conditions were sunny with cloud patches and gentle north-easterly winds.
- The third campaign took place in the early afternoon of 15 May 2017. This was a screening exercise to determine pollutant array at receptors away from the landfill boundary. Three Tenax sorbent tubes were collected, two at residential locations (Waterberry Close and Vecchio, Plantations Estate) and a third along the M13 motorway below Plantations Estate (Figure 4-1 and Appendix B). Conditions were cool and overcast with gusty winds and intermittent rainfall periods.
- The fourth campaign (09 June 2017) was the key campaign with blank-corrected samples collected simultaneously upwind, downwind and in the community by three teams during an odour event. Two successive samples were collected at each site directly onto Tenax sorbent tubes. In addition, a Tedlar bag sample was collected at the downwind site for comparison. Sampling commenced at 05h09 with all samples collected by 06h35. Averaging periods ranged between 15 and 48 minutes (Figure 4-1 and Appendix B). Conditions were cool with west-south-westerly winds (gusty at times).

After sampling, sealed tubes and Tedlar bags were transported to Skyside (Pty) Ltd in Riverhorse Valley, Durban, from which they were transferred for analysis at X-Lab Earth (Pty) Ltd. (X-lab) in Randburg (South African National Accreditation System, SANAS, accredited laboratory number T0775). There the samples were analysed for either H_2S or a full spectrum of VOCs. The gas chromatography-mass spectrometry (GCMS) component of the analysis falls under X-Lab's current accreditation. While X-Lab conforms to ISO/IEC 17025 standards, the thermal desorption components of these analyses currently fall outside of the scope of X-Lab's accreditation. WSP is not aware of another local laboratory that is accredited for this technique. Laboratory reports are attached in Appendix C.

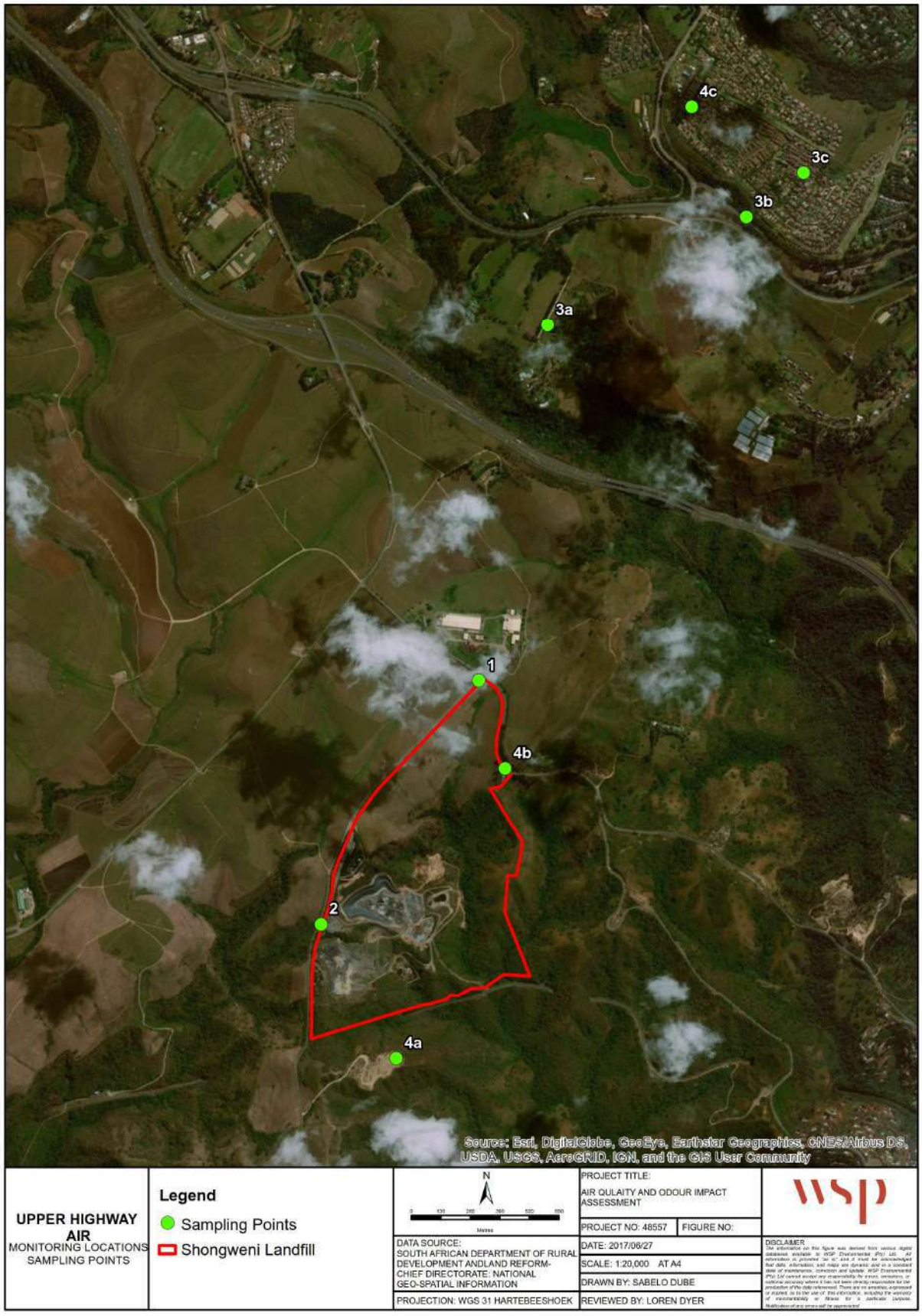


Figure 4-1: Volatile organic compound sampling points

Figure 4-2: Hydrogen sulphide sampling points

4.1.1 RESULTS

The H_2S results (Table 4-1) downwind of the site on the morning of 30 August 2017 showed concentrations (187 µg/m^3 and 180 µg/m^3 on a 10-minute averaging period) significantly higher than the WHO annoyance guideline (7 µg/m^3 on a 30-minute average). The odour event persisted for well over an hour on this particular morning as perceived by the field team.

The four VOC sampling campaigns revealed a consistent array of VOCs across samples. This included benzene, toluene, ethylbenzene, m/p-xylene, o-xylene, styrene, tetrachloroethene (Campaigns 1 and 2) and trichloroethene (Campaigns 3 and 4). This spectrum is consistent with the results presented in the Re-energise Africa (Pty) Ltd report (Appendix G, Final Envitech Solutions (Pty) Ltd. Report, 17 March 2017), except for styrene which appears was not tested for in this assessment. A summary of results is as follows:

- Campaign 1 was a screening exercise with one air sample collected to a Tedlar bag in the morning downwind of the site. Results were not blank corrected. Highest VOC concentrations included tetrachloroethene, styrene, toluene and benzene.
- Campaign 2 comprised one sample collected to a Tedlar bag and two samples collected directly to Tenax tubes along the landfill site fenceline during the early afternoon. Results were blank corrected. Concentrations measured were significantly lower than Campaign 1 but with a similar array of pollutants (except for 1,3,5-trimethylbenzene, which was detected in Campaign 1 but not in Campaign 2). Results are likely lower because they were blank corrected, and environmental conditions were more conducive to vertical dispersion than during Campaign 1.
- Campaign 3 comprised two community samples and a sample along the M13 motorway. Once again this was a screening exercise (this time to gauge concentrations at some distance from the landfill boundary) and results were not blank corrected. The pollutant array detected was identical to Campaign 2, except that trichloroethene was detected in Campaign 3 (but not detected in Campaign 2) while tetrachloroethene was not detected in Campaign 3 (but was detected in Campaign 2).
- Results from Campaign 4 were blank corrected and there are upwind and downwind samples for comparison.
  - In the upwind sample, all volatiles were below detection level except ethylbenzene (0.10 µg/m^3 in one sample), m/p-xylene (0.03 µg/m^3 in one sample) and toluene (average 0.38 µg/m^3 for the two samples).
  - The downwind concentrations of benzene, ethylbenzene, m/p-xylene, o-xylene, toluene and styrene show the highest values across the three sites.
  - The same pollutants remained detectable at the community receptor in Hillcrest, Plantations Estate (Figure 4-1), but at concentrations below those of the samples collected immediately downwind of the landfill site. These results indicate that the source of the VOC array detected is the landfill site.
  - Of particular relevance are the benzene concentrations (downwind average of 23.74 µg/m^3 on an averaging period between 15 and 20 minutes, and Plantations average of 17.53 µg/m^3 on a 20-minute averaging period).
  - Trichloroethene was measured at a higher concentration in Plantations (30.64 µg/m^3 in one sample) than immediately downwind of the landfill (highest downwind measurement was 10.23 µg/m^3).

Table 4-1: Gaseous measurement results

VOLATILE ORGANIC COMPOUNDS																												
Sample location	1 (Screening)		2						3a		3b		3c		4a				4b						4c			
	Downwind		Shongweni Landfill Fenceline						Waterberry		M13		Plantations		Upwind				Downwind						Plantations			
Date	06-Apr-17		08-May-17						15-May-17						09-Jun-17													
QA/QC	No blank		Blank corrected*						No blank						Blank corrected*													
Unit	ppb	µg/m³	ppb	µg/m³	ppb	µg/m³	ppb	µg/m³	ppb	µg/m³	ppb	µg/m³	ppb	µg/m³	ppb	µg/m³	ppb	µg/m³	ppb	µg/m³	ppb	µg/m³	ppb	µg/m³	ppb	µg/m³	ppb	µg/m³
1,3,5-trimethylbenzene	1.1	5.5	BD	BD	BD	BD	BD	BD	BD	BD	BD	BD	BD	BD	BD	BD	BD	BD	BD	BD	BD	BD	BD	BD	BD	BD	BD	BD
Benzene	9.5	30.5	0.9	2.9	BD	BD	1.1	3.7	4.7	14.9	7.3	23.5	3.0	9.5	BD	BD	BD	BD	3.3	10.5	9.3	29.8	9.7	30.9	6.2	19.8	4.8	15.3
Ethylbenzene	2.3	10.0	0.9	3.9	0.2	1.0	0.3	1.2	1.6	7.0	1.5	6.3	0.9	4.0	0.0	0.1	BD	BD	0.4	1.6	0.3	1.4	1.1	4.7	0.1	0.5	0.1	0.5
m/p-xylene	4.1	18.0	3.2	13.7	0.9	4.0	1.1	4.7	3.1	13.7	2.4	10.2	2.1	9.0	0.0	0.0	BD	BD	1.1	4.7	0.7	3.0	3.5	15.4	0.3	1.3	0.3	1.3
o-xylene	2.0	8.5	1.6	6.8	0.4	1.7	0.5	2.2	1.2	5.4	1.0	4.4	0.9	4.1	BD	BD	BD	BD	0.4	1.9	0.3	1.3	1.4	5.9	0.1	0.6	0.1	0.5
Styrene	18.0	76.5	0.5	2.0	0.2	0.9	0.2	0.9	2.3	9.6	3.8	16.2	0.8	3.5	BD	BD	BD	BD	0.4	1.7	0.7	2.8	0.3	1.4	0.1	0.4	0.1	0.4
Tetrachloroethene	143	967	0.2	1.3	0.1	0.4	0.0	0.3	BD	BD	BD	BD	BD	BD	BD	BD	BD	BD	BD	BD	BD	BD	BD	BD	BD	BD	BD	BD
Toluene	15.0	56.5	2.5	9.4	0.5	1.7	0.5	2.0	8.6	32.3	13.6	51.2	8.4	31.7	0.2	0.7	0.0	0.1	4.3	16.3	3.1	11.6	10.7	40.4	3.5	13.1	2.2	8.3
Trichloroethene	BD	BD	BD	BD	BD	BD	BD	BD	2.8	14.9	3.4	18.1	1.9	10.5	BD	BD	BD	BD	1.9	10.2	0.2	0.9	BD	BD	5.7	30.6	BD	BD

HYDROGEN SULPHIDE						
Sample location	1a		1b			
	Upwind		Downwind			
Date	30-Aug-17					
QA/QC	Blank corrected*					
Unit	ppb	µg/m³	ppb	µg/m³	ppb	µg/m³
Hydrogen sulphide	BD	BD	134.2	187	129.1	180

BD Below detection

* If a field blank measured below the detection limit for a specific pollutant, the blank mass on the tube was assumed to be half the detection limit.
Samples shaded in grey were collected in a Tedlar bag before transfer to Tenax tubes in the laboratory. All other samples were collected directly to Tenax tubes in the field.
Conversions from µg/m³ to ppb assumed at ambient temperature (20°C) and 1 atmosphere (1013.25 hPa)

4.2 DUST FALLOUT

Deposition of large (>10 µm) solid particles is a function of the airborne concentration and the particle gravitational speed. The monitoring of fugitive dust is therefore conducted principally by passive dust deposition gauges, whereby an open-mouthed container is partially filled with distilled water and exposed for a designated period of time. The container is then collected and the insoluble particles are removed by filtering the water and weighing, whilst the soluble particle mass is determined after evaporation of a sample of the filtered solution. This is a standardised sampling technique in South Africa, commonly referred to as 'bucket-monitoring' that was originally derived from the American Society for Testing and Materials (ASTM) standard method for collection and analysis of DFO (ASTM D1739). It has now been defined in the local context as a South African National Standard (SANS 1929:2005/2009).

The sampling equipment consists of a non-directional fallout bucket with a circular opening of 19 cm and a depth of 33 cm. The specifications are as close as possible (with available materials) to those recommended by the ASTM. The low aspect ratio (i.e. the height to width ratio) is required to keep collected particulates in the bucket before they settle in the sample water. The ASTM stipulates that the stand which supports the container needs to be two meters above the ground as there is a large variability in the concentration of particles subject to settling at heights less than two meters. The units are exposed for a predetermined period stipulated in the SANS 1929:2005 prescribed methodology as 30 (± 2) days (where possible).

The ASTM method stipulates that the stand which supports the container needs to be two metres above the ground as there is a large variability in the concentration of particles subject to settling at heights less than two metres.

A once off DFO monitoring survey of eight samplers, located at strategic points surrounding the Shongweni Landfill and within the nearby community (Table 4-2 and Figure 4-3) was conducted from 08 May – 31 May 2017 (23 days). The monitoring network complied with the SANS 1929:2005 and ASTM D1739 reference methods for the design and analysis of samples. The sampling period however was shorter than the recommended 30 (± 2) days. By 31 May 2017, two samplers had been removed and it was decided by the team to collect the remaining samplers for analysis.

Following collection, the samples were sent to a SANAS accredited laboratory for analysis of total insoluble and soluble fallout. Analysis included inductively coupled plasma mass spectrometry (ICP-MS) to determine the elemental composition of each DFO sample.

Table 4-2: Dust fallout monitoring sites

ID	Location	Classification	Latitude (°S)	Longitude (°E)	Comments
DFO 1	TH Watch Tower	Non-residential	-29.8194	30.7566	
DFO 2	Eskom Hill	Non-residential	29.8255	30.7545	
DFO 3	Transnet Control Room	Non-Residential	-29.8338	30.7666	Stolen/Removed
DFO 4	Denny Mushrooms	Non-residential	-29.8164	30.7518	
DFO 5	Quarry	Non-residential	-29.8328	30.7497	
DFO 6	Sugarcane opp. Valley 1	Non-residential	-29.8290	30.7450	Stolen/Removed
DFO 7	Sugarcane north of ES gate	Non-Residential	-29.8211	30.7479	Dead bird in bucket – sample discarded
DFO 8	TH Site Office	Non-residential	-29.8026	30.7468	

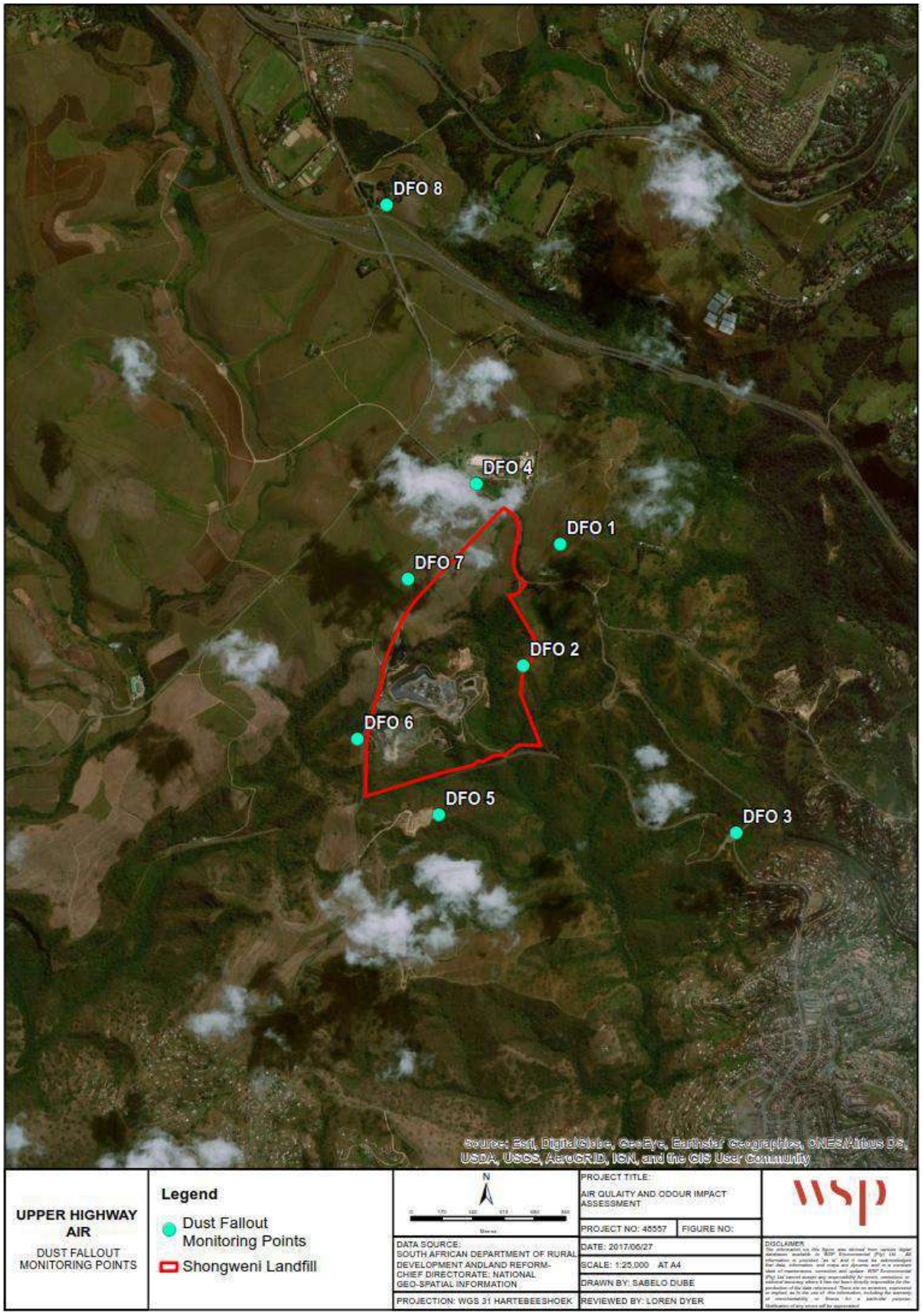


Figure 4-3: Dust fallout monitoring points

4.2.1 RESULTS

Upon collection, two samplers (DFO3 and DFO6) had been removed, while a third (DFO7) was contaminated and had to be discarded. The remaining samples were sent to a SANAS accredited laboratory for analysis of soluble and insoluble particulates in line with ASTM D1739. A summary of the results is presented in Table 4-3, while the insoluble and soluble components of the analysis are presented individually in Error! Reference source not found.. Total analyte (soluble and insoluble) are presented in Error! Reference source not found.. Wind fields recorded during this period by the Plantations meteorological station are shown in Figure 4-4.

Results are summarised as follows:

- All sites show compliance with the National Dust Control Regulations Non-Residential fallout standard.
- Highest DFO rates occurred at DFO4 (205.40 mg/m^2/day) and DFO1 (145.62 mg/m^2/day).
  - These sites lie north-north-east of the Valley 2, along the south-south-westerly wind trajectory which has high average wind speeds.
  - These sites also are the most proximate to Denny Mushrooms, another potential source of dust
- Heavy metal fallout masses from highest to lowest: DFO4, DFO2, DFO1, DFO5 and DFO8. The locations of these sites are as follows:
  - DFO4 lies north-north-east of Valley 2, along the south-south-westerly wind trajectory, which has high average wind speeds.
  - This site is also proximate to Denny Mushrooms, another potential source of dust.
  - DFO2 is the most proximate sample to Valley 2 (as DFO6 was stolen)
- Mercury fallout was below detection levels at all sites.
- Barium and zinc were the heavy metals with the highest DFO rates (by mass) across the sites.
- Cobalt and vanadium fallout was measured only at DFO1. Highest manganese and tin fallout (by mass) was measured at DFO1. Second highest molybdenum, nickel and copper fallout (by mass) was measured at DFO1.
- Highest zinc and chromium fallout (by mass) was measured at DFO2. Second highest arsenic and barium fallout (by mass) was measured at DFO2.
- Lead fallout was detected only at DFO4. Highest arsenic, barium, copper, iron, lead, nickel and titanium fallout (by mass) was measured at DFO4. Second highest chromium, strontium, tin and zinc fallout (by mass) was measured at DFO4.
- Tungsten fallout was detected only at DFO5. Highest molybdenum and strontium fallout (by mass) was measured at DFO5. Second highest titanium fallout (by mass) was measured at DFO5.
- Tin measured only at DFO1 and DFO4.
- Molybdenum measured only at DFO1 and DFO5.

Unfortunately both samples located to the west of the landfill (DFO6 and DFO7) were unrecoverable in this campaign. A repeat assessment with DFO samplers to the west of the landfill site would assist with interpreting the influence of the site of heavy metal dust concentrations. A background DFO sample at significant distance from the Shongweni Landfill site also would be useful to gauge whether the landfill is the source of the heavy metals detected in the dust fallout.

Table 4-3: Total dust fallout monitoring results

ID	Location	Average DFO Rate (mg/m^2/day)	National Dust Control Regulations (Non-Residential)	Compliant?
DFO 1	TH Watch Tower	145.62	1,200	Yes
DFO 2	Eskom Hill	44.45	1,200	Yes
DFO 4	Denny Mushrooms fenceline	205.40	1,200	Yes
DFO5	Quarry	72.04	1,200	Yes
DFO 8	TH Site office	27.59	1,200	Yes

Table 4-4: Dust fallout components (soluble and insoluble) as total mass (milligrams per site)

CATEGORY	ANALYTE	DFO1 (mg)		DFO2 (mg)		DFO4 (mg)		DFO5 (mg)		DFO8 (mg)	
		Insoluble	Soluble	Insoluble	Soluble	Insoluble	Soluble	Insoluble	Soluble	Insoluble	Soluble
Heavy Metal	Arsenic	0.00E+00	2.45E-03	0.00E+00	5.78E-03	0.00E+00	1.46E-02	0.00E+00	3.87E-03	0.00E+00	2.45E-03
Heavy Metal	Barium	9.00E-01	5.95E-03	1.00E+00	5.39E-03	1.10E+00	3.64E-03	6.90E-01	2.88E-02	8.50E-01	3.85E-03
Heavy Metal	Chromium	7.00E-04	1.09E-02	3.00E-04	4.24E-01	9.00E-04	4.19E-01	5.00E-04	3.74E-01	6.00E-04	2.80E-01
Heavy Metal	Cobalt	0.00E+00	7.00E-04	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Heavy Metal	Copper	5.00E-03	2.07E-02	0.00E+00	1.16E-03	1.00E-02	1.91E-02	3.00E-03	3.87E-03	0.00E+00	2.10E-03
Heavy Metal	Iron	5.70E-02	3.85E-02	3.90E-02	0.00E+00	1.40E-01	0.00E+00	4.40E-02	0.00E+00	1.40E-01	0.00E+00
Heavy Metal	Lead	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.55E-04	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Heavy Metal	Manganese	2.00E-03	1.44E-02	2.00E-03	4.24E-03	8.00E-03	4.55E-03	3.00E-03	0.00E+00	4.00E-03	8.75E-03
Heavy Metal	Molybdenum	0.00E+00	3.50E-04	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	8.60E-04	0.00E+00	0.00E+00
Heavy Metal	Nickel	0.00E+00	2.10E-03	0.00E+00	3.85E-04	0.00E+00	2.28E-03	0.00E+00	8.60E-04	0.00E+00	3.50E-04
Heavy Metal	Strontium	1.30E-02	1.09E-02	1.70E-02	3.47E-03	1.90E-02	8.19E-03	1.70E-02	4.73E-02	1.30E-02	1.75E-03
Heavy Metal	Tin	0.00E+00	7.35E-03	0.00E+00	0.00E+00	0.00E+00	1.37E-03	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Heavy Metal	Titanium	7.00E-04	5.95E-03	1.10E-03	6.16E-03	3.90E-03	1.14E-02	1.00E-03	1.08E-02	3.00E-03	4.55E-03
Heavy Metal	Tungsten	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.44E-03	0.00E+00	0.00E+00
Heavy Metal	Vanadium	0.00E+00	2.10E-03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Heavy Metal	Zinc	7.10E-01	7.00E-02	8.70E-01	2.70E-02	8.90E-01	0.00E+00	6.20E-01	0.00E+00	6.10E-01	3.85E-02
Heavy Metal	SUBTOTAL	1.69E+00	1.92E-01	1.93E+00	4.77E-01	2.17E+00	4.84E-01	1.38E+00	4.74E-01	1.62E+00	3.42E-01
Other Metal	Aluminium	3.00E-01	5.60E-02	2.40E-01	5.39E-03	3.10E-01	5.01E-03	2.20E-01	0.00E+00	2.30E-01	1.75E-03
Other Metal	Boron	4.90E-01	7.70E-02	6.60E-01	5.39E-03	7.10E-01	9.10E-04	4.90E-01	9.46E-03	5.40E-01	7.00E-04
Other Metal	Calcium	7.60E-01	3.43E+00	5.00E-01	1.54E+00	1.30E+00	1.96E+00	1.90E+00	4.30E+00	3.90E-01	5.60E-01
Other Metal	Magnesium	5.90E-02	4.20E-01	3.30E-02	1.27E-01	1.00E-01	2.59E-01	7.00E-01	2.02E+00	4.40E-02	9.80E-02
Other Metal	Potassium	7.20E-01	3.29E+00	8.90E-01	3.08E-01	9.10E-01	1.68E+00	6.90E-01	3.87E+00	6.60E-01	2.10E-01
Other Metal	Silicon	0.00E+00	2.14E+00	0.00E+00	1.39E+00	0.00E+00	1.91E+00	0.00E+00	4.73E+00	0.00E+00	5.95E-01
Other Metal	Sodium	1.60E+00	3.85E+00	2.00E+00	3.50E+00	2.00E+00	2.41E+00	1.60E+00	2.02E+01	1.60E+00	8.40E-01
Other Metal	SUBTOTAL	3.93E+00	1.33E+01	4.32E+00	6.88E+00	5.33E+00	8.23E+00	5.60E+00	3.51E+01	3.46E+00	2.31E+00
Non-metal	Phosphorus	6.60E-02	1.30E+00	0.00E+00	1.04E-01	1.10E-01	1.46E+00	0.00E+00	1.46E-01	0.00E+00	1.23E-01
Non-metal	Selenium	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	8.60E-04	0.00E+00	0.00E+00
Non-metal	Sulphur	8.20E-02	2.17E+00	1.00E-02	8.47E+00	3.60E-02	1.37E+01	2.00E-02	1.76E+01	1.30E-02	1.23E+01
Non-metal	SUBTOTAL	1.48E-01	3.47E+00	1.00E-02	8.57E+00	1.46E-01	1.51E+01	2.00E-02	1.78E+01	1.30E-02	1.24E+01
ALL	TOTAL	5.77E+00	1.69E+01	6.26E+00	1.59E+01	7.65E+00	2.38E+01	7.00E+00	5.34E+01	5.10E+00	1.50E+01