BONNIEVALE WASTE DISPOSAL FACILITY

AIR QUALITY IMPACT ASSESSMENT AND BUFFER ZONE DETERMINATION

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GLOSSARY AND ABBREVIATIONS

ATSDR	Agency for Toxic Substances and Disease Registry
CH_4	Methane
DEA	Department of Environmental Affairs
DEADP	Department of Environmental Affairs and Development Planning
DWAF	Department of Water Affairs and Forestry
DOCf	Degradable organic carbon
ESLs	Effects screening levels
HAP	Hazardous air pollutant
IPCC	Inter-governmental Panel on Climate Change
LandGEM	Landfill Gas Emissions Model
LFG	Landfill gas
MfE	Ministry for Environment
Mg	Megagram
m/s	Meter per second
NO_2	Nitrogen dioxide
NSW	New South Whale
O_3	Ozone
OU	Odour unit
PM_{10}	Particulate matter with aerodynamic diameters of 10 micrometres or less.
$PM_{2.5}$	Particulate matter with aerodynamic diameters of 2.5 micrometres or less.
SA	South Africa
SABS	South African Bureau of Standards
SO_2	Sulphur dioxide
TCEQ	Texas Commission on Environmental Quality
USEPA	US Environmental Protection Agency
UTM	Universal Transverse Mercator coordinate system
VOCs	Volatile organic compounds
WDF	Waste Disposal Facility
WHO	World Health Organisation
yr	Year

1 INTRODUCTION

The Bonnievale Waste Disposal Facility (WDF) is a small landfill site for general waste, located approximately 1.5 km west of the main town of Bonnievale in Western Cape. The site is classified as G:S:B- site, which means that it accepts general waste, it is small in size and without the generation of leachate. The site has been in operation since August 1998 and has a footprint of approximately 2.5 hectares.

DDA Environmental Engineers was appointed by Legacy Environmental Management Consulting to undertake the air quality impact assessment and buffer zone determination study for the Bonnievale WDF.

1.1 Terms of Reference

The terms of reference for this study were:

- Establish an emissions inventory for the landfill site based on the waste deposition quantities;
- Obtain local meteorological data and determine the meteorological conditions of the area, which affect the dispersion of emissions;
- Perform dispersion modelling utilising the USEPA air pollution dispersion model AERMOD and determine the ground-level concentrations of the air pollutants;
- Compare the modelled concentrations with international guidelines and determine the odour and health impacts; and
- Assess the impacts and provide recommendations regarding the buffer zone of the landfill site.

1.2 Study Approach

The air quality study was based on the following methodology:

Firstly, the landfill gas (LFG) emissions from the site were quantified. The LFG emissions were estimated based on the waste deposition quantities, with the use of the USEPA Landfill Gas Emissions Model (LandGEM).

Secondly, three years of hourly meteorological data for the study area were obtained from the Department of Environmental Affairs and Development Planning (DEADP) and processed, in order to generate the meteorological parameters for input into the air pollution dispersion model.

Thirdly, the AERMOD model was used to simulate the dispersion of the air pollutants around the site. With the use of AERMOD, the resulting ground-level concentrations for various pollutants in the surrounding communities were determined.

Lastly, the modelled concentrations for specified averaging periods were compared against air quality standards or guidelines for each of the pollutants to determine the air quality and health impacts. Based on the predicted impacts, a suitable buffer around the site was determined.

1.3 Outline of Report

Section 2 of the report describes the baseline environment, which includes the study area and area's meteorology. The relevant air quality guidelines and standards are described in Section 3. The lateral migration risk assessment is described in Section 4 and the establishment of the emission inventory is documented in Section 5. The air pollution dispersion modelling and the ground-level concentration results are presented in Section 1. Lastly, the conclusions and buffer zone determination can be found in Section 7 and 8.

2 BASELINE CHARACTERISATION

2.1 Site Description

The Bonnievale WDF is located in Bonnievale Western Cape (see Figure 2-1). The town of Bonnievale is about 1.5 km to the east of the site. The closest residential areas are the informal settlement approximately 100 north and Happy Valley which is located about 500 m southwest of the site.

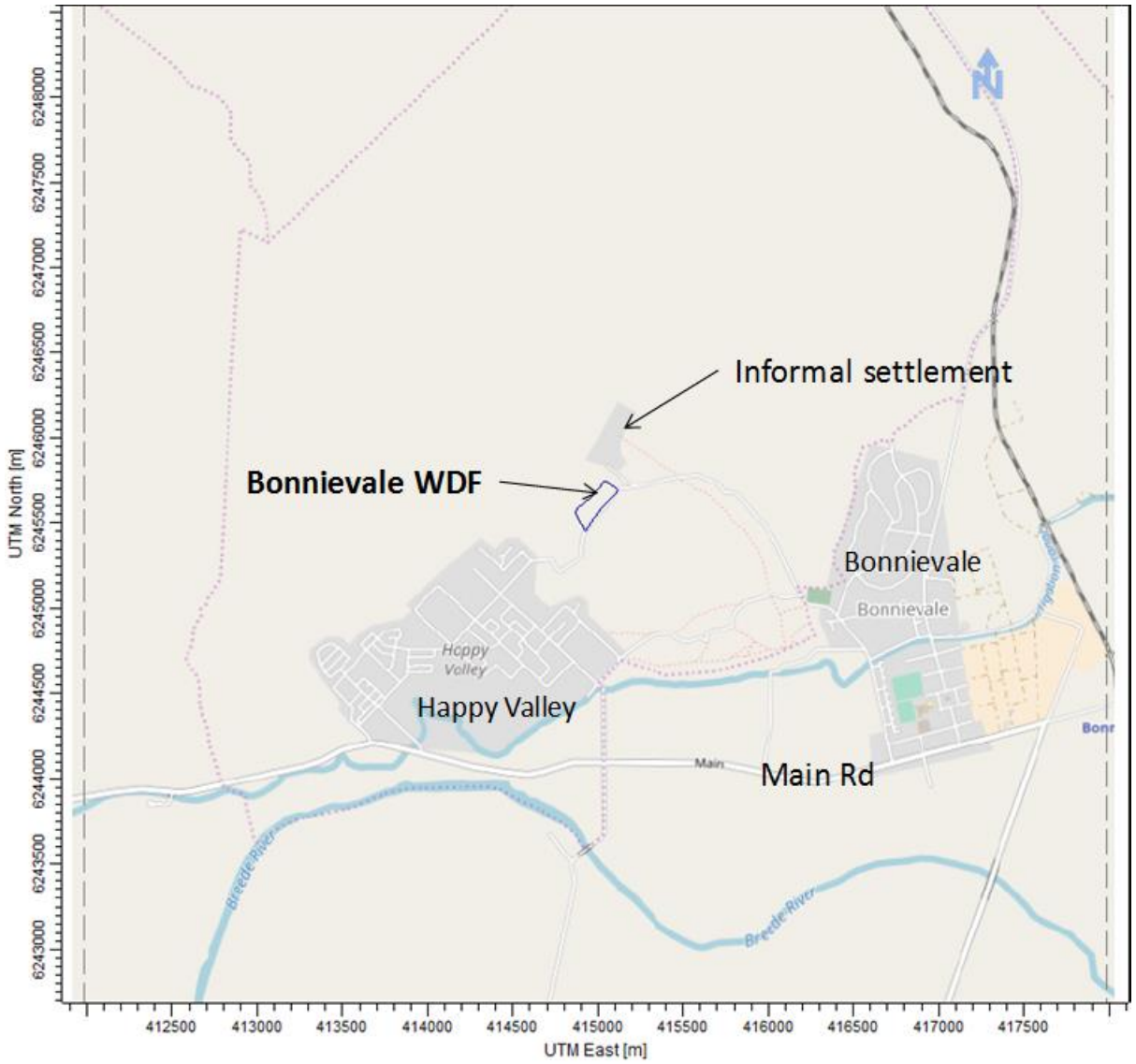

Figure 2-1. Locality Map

The WDF has been in operation since 31 July 1998. Historically, households and businesses waste was accepted at the site. Domestic waste was later sent to the Ashton Waste Disposal Facility from 2001/2002. In 2013/2014 green waste chipping operations started at the site and the waste is stockpiled, windrowed, chipped and sold twice a year.

Currently, the WDF receives garden and park waste and builders rubble from Bonnievale. Based on the October 2015 and January 2017 topographical surveys, an average of 96 m^3 of airspace is used per month. With a permitted height of 3 m, and 1:4 side slopes, the remaining airspace is approximately 28,000 m^3. With the above-mentioned average monthly disposal volume and an annual growth rate of 1.79%, the Bonnievale WDF will reach capacity by August 2036 (JPCE, 2017).

2.2 Meteorology

Turbulent, high-velocity winds such as pre-cold front north-westerly winds help to dilute air pollutants at their source and to disperse them as they travel downwind, whereas gentle breezes under stable atmospheric conditions do little to dilute and disperse air pollution.

Cold, gentle winds flow down the slope on calm nights under clear skies, also flowing into hollows and into and down valleys. Such winds travel at less than 1 metre per second (m/s). Walls, steep embankments and tree plantations can impede this air and mix it with the air above it, so helping to reduce the impact on air quality.

Transport and dispersion of air pollutant are affected by wind speed, wind direction, atmospheric turbulence parameters, the ambient temperature, as well as the mixing height. The atmospheric boundary during the day is normally unstable, as a result of the sun's heating effect on the earth's surface. The thickness of the mixing height depends strongly on solar radiation, amongst other parameters. This mixing layer gradually increases in height from sunrise, to reach a maximum at about five to six hours thereafter. Cloudy conditions, surface and upper air temperatures also affect the final mixing height and its growth. During these conditions, dispersion plumes can be trapped in this layer and result in high ground-level concentrations. This dispersion process is known as Fumigation and is more pronounced during the winter months due to strong night-time inversions, weak wind conditions and slower developing mixing layers.

Temperature

The historical monthly average maximum and minimum temperature profile of Bonnievale is presented in Figure 2-2 below (Climate Bonnievale, 2017). The mean daily maximum temperature in the Bonnievale area ranges between 28°C and 18°C, and the mean daily minimum temperature 16°C and 6°C.

The air temperature is utilised in the dispersion modelling as one of the incorporated parameters for the parametrisation of the atmospheric conditions. Temperature plays an important role in the transportation and dispersion of the air pollutants since it affects the plume buoyancy and the atmospheric boundary layer development.

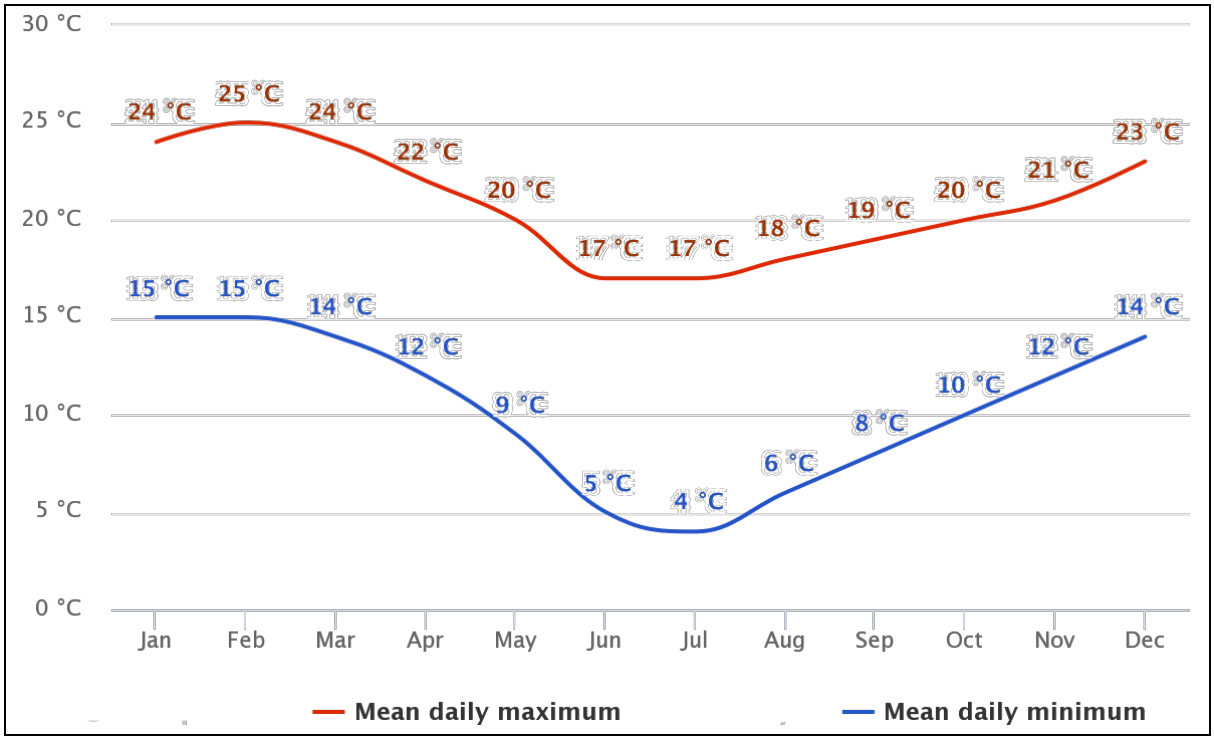

Figure 2-2. Monthly Temperature Profile

Precipitation and Air Pollution

Precipitation assists in the removal of air pollutants from the atmosphere. Gaseous air pollutants and particulate matter are removed by the falling rain droplets through adsorption and deposition.

Rainfall in Bonnievale occurs throughout the year. The historical average monthly precipitation profile is shown in Figure 2-3 below (Climate Bonnievale, 2017). As can be seen, the highest monthly maximum precipitation is 32 mm in October, and the lowest is 12 mm in June.

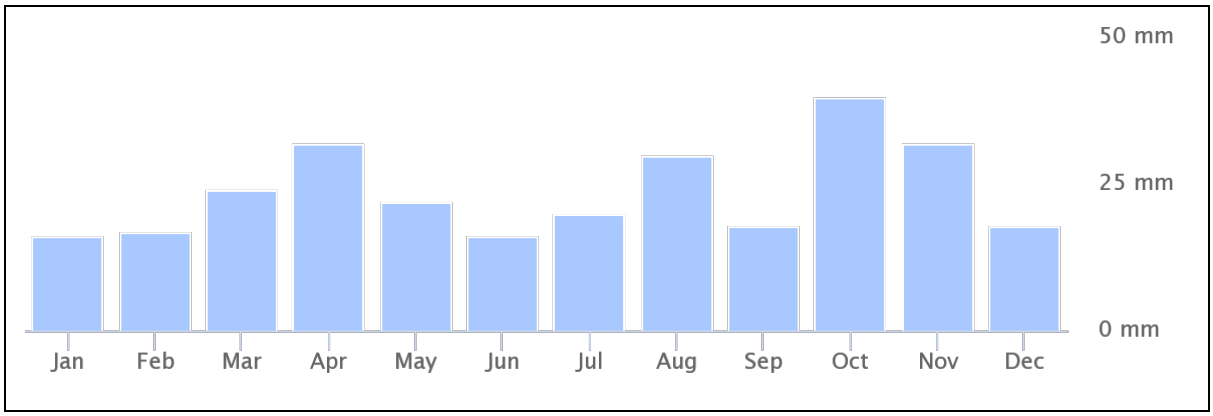

Figure 2-3. Monthly Precipitation Profile

Local Wind Field

Since meteorological data is not available at the project site, meteorological data from the Department of Environmental Affairs and Development Planning (DEADP) was used instead. This set of data was generated by utilising a prognostic mesoscale model called the Weather Research and Forecast Model and a modelling resolution of 3 km. The modelled data with the centre point at -33.91172 (Latitude) and 20.06649 (Longitude) was obtained from the DEADP and utilised in the dispersion modelling.

The hourly surface and upper air meteorological data for the years 2008-2010 were used as input into the model. The data was also used for the establishment of the local wind field as wind roses. The wind roses were generated for all hours, daytime, night-time, as well as for the winter and summer periods and are illustrated in the figures below. These wind roses depict the frequency of the wind speeds for each of the 16 cardinal wind directions. The wind directions in the figures show from where the wind blows. The wind classes are indicated by coloured bars, and the frequencies of occurrence for each wind direction are specified by the dashed circles.

Figure 2-4 shows the wind roses of all hours, daytime and night-time. As can be seen, the predominant winds are from the south-easterly and north-westerly. The winds from other directions are minimal. This corresponds with the major topographic features in the extended area, since the site is situated in the Breede River Valley with the Langeberg Mountain range to the north and the Riviersonderend Mountains to the southwest.

The wind speed frequency distributions for all hours, daytime and night-time, are also shown in Figure 2-4. It is evident that moderate winds dominate during daytime and light to moderate winds prevail at night-time. Calm wind conditions occur 1.19% during daytime and increase to 5.78% at night. The average winds are 5.35 m/s and 3.48 m/s for daytime and night-time respectively.

Also, the wind roses and wind speed frequency distributions were also generated for the winter and summer periods and are shown in Figure 2-5. It is clear that north-westerly winds are predominant in winter and south-easterly in summer. The wind speeds in winter and summer are low to moderate. The average wind speeds in winter and summer are 4.09 m/s and 4.74 m/s respectively. The calm wind conditions are 5.31% and 1.67% for winter and summer respectively.

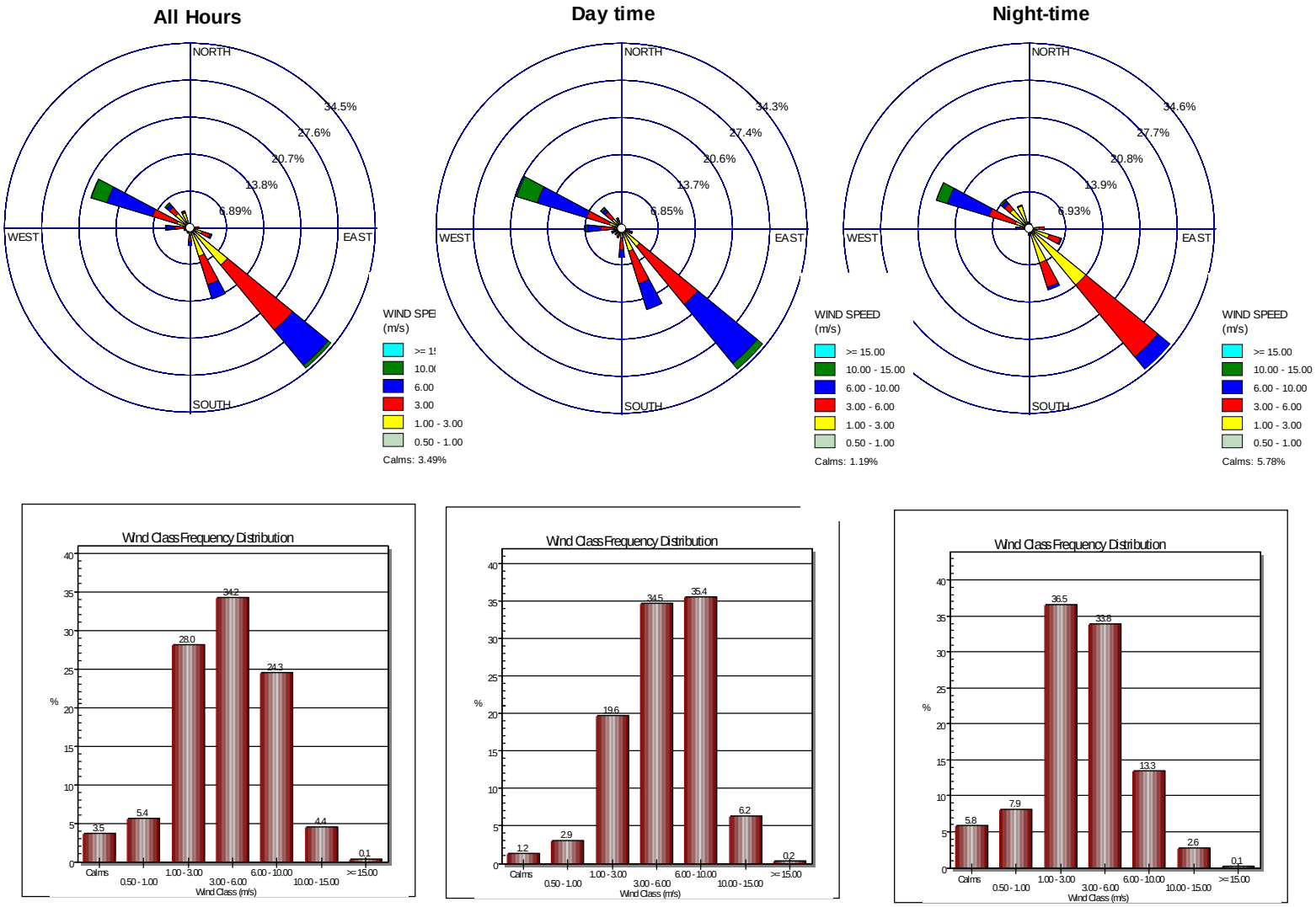

Figure 2-4. Wind Rose and Wind Speed Frequency Distribution: All-hours, Daytime and Night-time

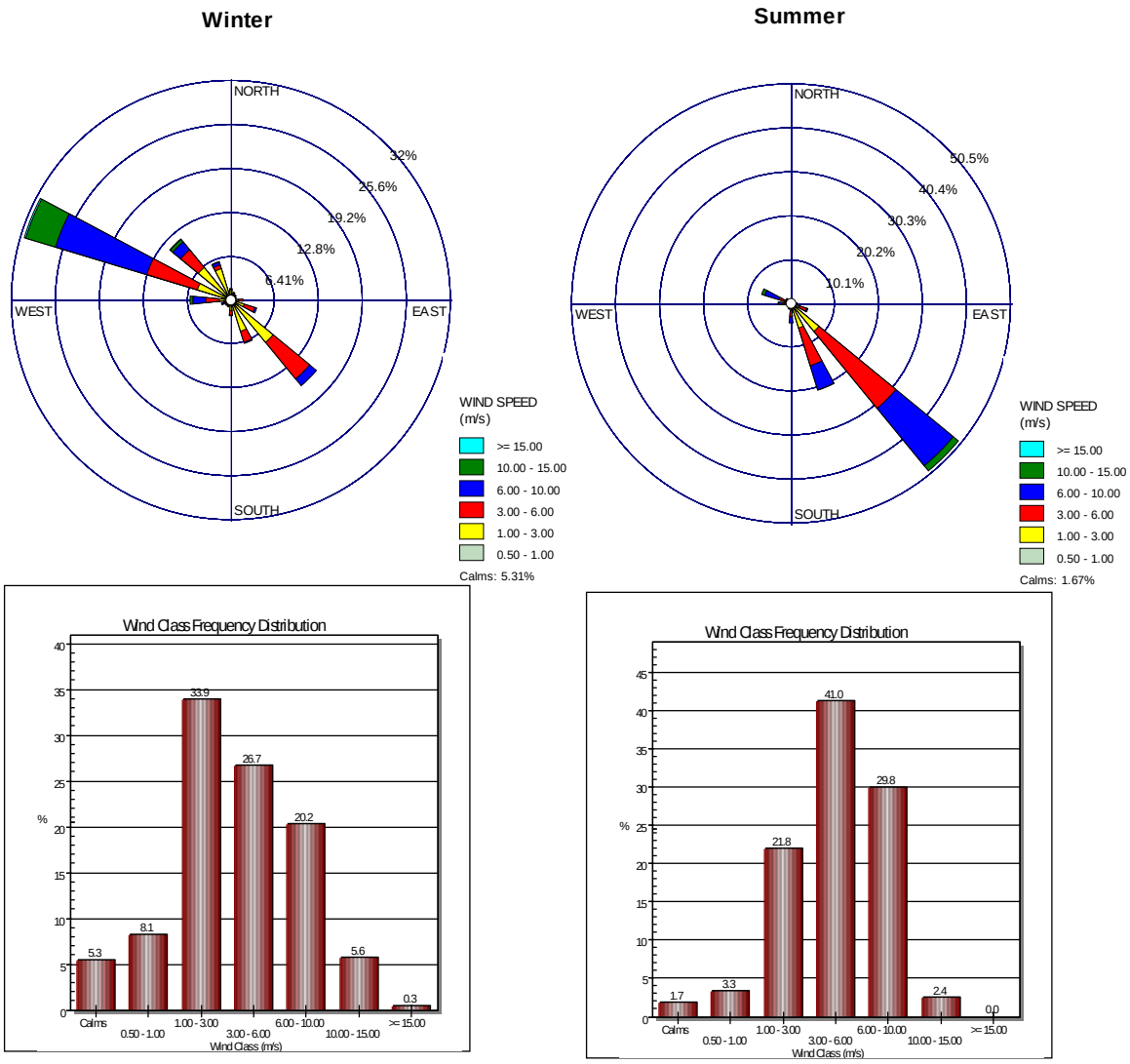

Figure 2-5. Wind Rose and Wind Speed Frequency Distribution: Winter and Summer

3 AMBIENT AIR QUALITY GUIDELINES AND STANDARDS

3.1 South African Ambient Air Quality Standards

The South African national ambient air quality standards for criteria pollutants, i.e. sulphur dioxide, nitrogen dioxide, ozone, benzene, carbon monoxide and PM_{10}, were first published in the Government Gazette No. 32816, of the 24th of December 2009. The Department of Environmental Affairs (DEA) subsequently published the national ambient air quality standards for $PM_{2.5}$ in the Government Gazette No. 35463, Notice No. 1210, on the 29th June 2012. The South African (SA) National Ambient Air Quality Standards are presented in Table 3-1 below.

Table 3-1. SA National Ambient Air Quality Standards

Pollutant	Molecular Formula	Averaging Period	Concentration		Frequency of Exceedance	Compliance Date
			µg/m³	ppb		
Sulphur Dioxide	SO_2	10 minute	500	191	526	Immediate
		1 hour	350	134	88	Immediate
		24 hour	125	48	4	Immediate
		1 year	50	19	0	Immediate
Nitrogen Dioxide	NO_2	1 hour	200	106	88	Immediate
		1 year	40	21	0	Immediate
Particulate Matter	PM_{10}	24 hour	75	-	4	1 Jan 2015
		1 year	40	-	0	1 Jan 2015
	$PM_{2.5}$	24 hour	40	-	4	1 Jan 2016 – 31 Dec 2029
		24 hour	25	-	4	1 January 2030
		1 year	20	-	0	1 Jan 2016 – 31 Dec 2029
		1 year	15	-	0	1 January 2030
Ozone	O_3	8 hour	120	61	11	Immediate
Benzene	C_6H_6	1 year	5	1.6	0	1 Jan 2015
Lead	Pb	1 year	0.5	-	0	Immediate
Carbon Monoxide	CO	1 hour	30	26	88	Immediate
		8 hour (calculated on 1 hourly averages)	10	8.7	11	Immediate

3.2 Health Risk Assessment Criteria

Internationally, concentration guidelines for toxic and carcinogenic pollutants are issued by organisations such as the World Health Organisation (WHO), the Texas Commission on Environmental Quality (TCEQ), the U.S. Environmental Protection Agency (USEPA) and the Agency for Toxic Substances and Disease Registry (ATSDR).

Several of the compounds contained in the LFG are toxic, suspected or confirmed carcinogens. The ambient concentration limits and guidelines for the selected pollutants included in this study are shown in Table 3-2 and were based on international sources, i.e. the TCEQ and USEPA.

The guideline concentrations are the Effects Screening Levels (ESLs), as recommended by the TCEQ. The ESLs are presented as "short-term" and "long-term" exposures. Long-term ESLs are applicable to annual averaging periods, whereas short-term ESLs are given for hourly to daily periods. It should be noted that these ESLs are not ambient air standards but are used as screening levels. They are based on data related to health effects, vegetation or corrosion effects and odour nuisance potential. If the predicted ambient concentrations do not exceed these levels, no adverse health or welfare effects would be expected to occur. Should ambient concentrations exceed these limits, a more in-depth assessment would be warranted.

According to the USEPA's carcinogen risk assessment guideline 2005, hazardous substances are categorised into the following categories based on their potential to cause cancer in humans:

- Carcinogenic to humans,
- Likely to be carcinogenic to humans,
- Suggestive evidence of carcinogenic potential,
- Inadequate information to assess carcinogenic potential,
- Not likely to be carcinogenic to humans.

The USEPA established risk assessment guidelines to provide consistency and technical support between USEPA and other regulatory agencies. The USEPA has developed the unit risk factors (URFs) (for inhalation) and slope factors (SFs) (for ingestion) for evaluating risks from carcinogenic substances. The unit risk factor is the upper-bound excess lifetime cancer risk estimated to result from continuous exposure to a substance at a concentration of 1 $\mu g/m^3$ in air. Therefore, the carcinogenic risk in a 1 million population is calculated by the ambient concentration multiplied by the unit risk factor and 10^6.

In the present study, both the carcinogenic risk (long-term) and the health risks, in terms of the short-term and long-term non-carcinogenic health risks were estimated. The 1-hour and annual ground-level concentrations were compared against their respective guidelines for each pollutant to obtain the short-term and long-term risk index, which were expressed as the fraction of each guideline. The cumulative index for all examined compounds for the 1-hour and annual averaging periods were used for the assessment of the non-cancer toxic effects. The calculated cumulative health indexes were then plotted as contour maps.

Regarding the carcinogenic risk estimation, the annual concentrations of carcinogenic and possible carcinogenic compounds were multiplied by their respective unit risk factors to produce the resulting risk. A risk more than $1x10^{-4}$ is considered unacceptable by the USEPA, and a risk smaller than $1x10^{-6}$ is considered negligible.

A risk lower than the $1x10^{-5}$ level is considered acceptable and falls within the range of concern if it is above $1x10^{-5}$. In the latter case, depending on the number of persons exposed to this risk and the likelihood of being exposed over a lifetime (70 years), further investigations and possible actions to control that risk may be required.

Table 3-2. Air Quality Guidelines and Cancer Unit Risk Factors

Compound	Guideline Concentration (µg/m^3)			Carcinogenic Classification
	1-hour ESL [a]	Annual ESL [a]	Unit Risk Factors [b]	US EPA [d]
1,1,1-Trichloroethane (methyl chloroform) – HAP	2800	1500		
1,1,2,2-Tetrachloroethane - HAP/VOC	70	7		
1,1-Dichloroethane (ethylidene dichloride) - HAP/VOC	4000	400		
1,1-Dichloroethene (vinylidene chloride) - HAP/VOC	210	100		
1,2-Dichloroethane (ethylene dichloride) - HAP/VOC	650	2.9		
1,2-Dichloropropane (propylene dichloride) - HAP/VOC	460	46		
2-Propanol (isopropyl alcohol) - VOC	4920	492		
Acetone	7800	4800		
Acrylonitrile - HAP/VOC	330	2.1		
Benzene - HAP/VOC	170	4.5	7.80E-06	A
Bromodichloromethane - VOC	700	70		
Carbon disulfide - HAP/VOC	7500	32		
Carbon tetrachloride - HAP/VOC	130	13	6.00E-06	B2
Carbonyl sulfide - HAP/VOC	130 (odour)[c]	2.6		
Chlorobenzene - HAP/VOC	460	46		
Chlorodifluoromethane	18000	1800		
Chloroethane (ethyl chloride) - HAP/VOC	2700	270		
Chloroform - HAP/VOC	100	10	2.30E-05	B2
Chloromethane - VOC	1030	103		
Dichlorobenzene - (HAP for para isomer/VOC)	900	160		
Dichlorodifluoromethane	50000	5000		
Dichlorofluoromethane - VOC	420	42		
Dichloromethane (methylene chloride) - HAP	3600	350		
Dimethyl sulfide (methyl sulfide) - VOC	7.6 (odour)[c]	25		
Ethanol - VOC	18800	1880		
Ethyl mercaptan (ethanethiol) - VOC	1 (odour)[c]	1.3		
Ethylbenzene - HAP/VOC	26000	570		
Ethylene dibromide - HAP/VOC	4	0.4		
Fluorotrichloromethane - VOC	56000	5600		
Hexane - HAP/VOC	6200	200		

Compound	Guideline Concentration (µg/m^3)			Carcinogenic Classification
	1-hour ESL [a]	Annual ESL [a]	Unit Risk Factors [b]	US EPA [d]
Hydrogen sulfide	11(odour)	--		
Methyl ethyl ketone - HAP/VOC	18000	2600		
Methyl isobutyl ketone - HAP/VOC	820	82		
Methyl mercaptan - VOC	1.9 (odour)[d]	1		
Pentane - VOC	59000	7100		
Perchloroethylene (tetrachloroethylene) - HAP	2000	26		
t-1,2-Dichloroethene - VOC	7900	790		
Toluene - HAP/VOC	4500	1200		
Trichloroethylene (trichloroethene) - HAP/VOC	540	54	4.10E-06	A
Vinyl chloride - HAP/VOC	20000	1.2	4.40E-06	A
Xylenes - HAP/VOC	2200	180		

a) TCEQ ESLs.

b) US-EPA IRIS IRCs.

c) Guideline value was set for odour/nuisance potential.

d) A: Carcinogenic to humans.
B1: Probably carcinogenic to humans, with limited human evidence.
B2: Probably carcinogenic to humans, with little or no human data.

3.3 Odour Impact Assessment Criteria

Odour is defined as a sensation resulting from the reception of a stimulus by the olfactory sensory system. The sensory perception of odours has four distinct properties: intensity, detectability, character and hedonic tone. The combined effects of these properties are related to the annoyance that may be caused by an odour. Several of the compounds contained in the LFG have a very distinct and 'offensive' odour.

The detectability of an odour is a sensory property that refers to the theoretical minimum concentration that produces an olfactory response or sensation. This point is called the odour threshold and defines one odour unit (OU) per cubic metre (m^3). The odour unit is calculated by dividing the concentration of a substance by its odour threshold.

In practice, 'offensive' odour can only be judged by public reaction to the odour, preferably under similar social and regional conditions. The nuisance level can be as low as 2 OU and as high as 10 OU for less offensive odours. Usually, for proposed and existing facilities, an odour performance criteria of 7 OU is likely to represent the level above which odours could be offensive for an individual with a 'standard sensitivity' to odours.

Currently, in South Africa, there are no guidelines for controlling and managing odours. However, various odour thresholds and guidelines have been published internationally, such as those presented in the following sections.

3.3.1 New South Wales

The Department of Environment and Conservation in New South Wales (NSW) has established a set of odour assessment criteria for various population densities. A summary of the odour criteria is shown in Table 3-3 (NSW, 2006). It is population dependent, and as the population density increases, the increased possibility of sensitive individuals raises the potential for odour complaints.

Table 3-3. NSW EPA Population Density Criteria for Odour Performance

Population of affected community	Odour assessment criteria (OU)
Rural single residence (≤ 2)	7
~ 10	6
~ 30	5
~ 125	4
~ 500	3
Urban area (≥ 2000) and/or schools and hospitals	2

3.3.2 New Zealand

Odour modelling guidelines were developed for assessing and managing odour in New Zealand by the Ministry for the Environment (MfE). These guidelines were intended to be used for comparisons with dispersion modelling results, in order to determine whether offensive effects are likely to occur.

The guidelines in the guidance document: Good Practice Guide for Assessing and Managing Odour in New Zealand (MfE 2003), are summarised in Table 3-4 below.

Table 3-4. New Zealand Odour Modelling Guidelines

Sensitivity of the receiving environment	Concentration (OU)	Percentile
High: residential/living, light commercial, education, institution, recreation	2	0.1% and 0.5%
Moderate: light industrial	5	0.1% and 0.5%
Low: heavy industrial, public roads	5-10	0.1% and 0.5%

The concentrations in the table above are the recommended values for the modelling of hourly odour concentrations. The percentile allows for a small level of exceedance of the predicted concentrations, in order to account for the fact that the worst-case meteorological

conditions, which generate the exceedances, occur rarely, i.e. less than 0.1% or 0.5% of the time. Therefore, the 0.5 percentile means that the guideline value can be exceeded for 0.5% of the time.

For the odorous compounds, a similar approach to the non-toxic endpoint was utilised. Several odorous compounds were included in the determination of the odour impact. The primary odorous compounds were hydrogen sulphide, methyl mercaptan, ethyl mercaptan, and dimethyl sulphide.

3.4 Dust Fallout Guidelines

The South African Bureau of Standards (SABS) has published dust deposition standards that are based on the cumulative dust fall levels in South African National Standard (SANS) 1929:2011. Four bands have been developed against which dust fallout can be evaluated (see Table 3-5). These dust fall levels were taken into consideration for the determination of the levels of a nuisance in surrounding communities.

Target, action and alert thresholds for ambient dust deposition and permissible frequency of exceedances are given in Table 3-6.

Table 3-5. Four-band Scale Evaluation Criteria for Dust Deposition (SANS 1929:2011)

No	Band Description Label	Dust Fallout Rate (D) ($mg/m^2/day$) (30-day average)	Comments
1	Residential	D < 600	Permissible for residential and light commercial.
2	Industrial	D < =1200	Permissible for heavy commercial and industrial.
3	Action	1200 < D < =2400	Requires investigation and remediation if two sequential months lie in this band, or more than three occur in a year.
4	Alert	D > 2400	Immediate action and remediation required following the first incidence of the dust fallout rate being exceeded. Incident report to be submitted to the relevant authority.

Table 3-6. Target, Action and Alert Thresholds for Dust Deposition (SANS 1929:2011)

Level	Dust Fallout Rate (D) (mg/m^2/day) (30-days average)	Averaging Period	Permitted Frequency of Exceeding Dust Fall Rate
Target	300	Annual	N/A
Action Residential	600	30 days	Three within any year, no two sequential months.
Action Industrial	1,200	30 days	Three within any year, not sequential months.
Alert Threshold	2,400	30 days	None. The first incidence of dust fall rate being exceeded requires remediation and compulsory report to the relevant authorities.

On 1st of November 2013, the Government Notice 827 - National Dust Control Regulations published regarding section 53 (o) of the National Environmental Management: Air Quality Act, 2004 (Act No. 39 of 2004) was promulgated. The Regulations prescribe general measures for the control of dust in all areas. A standard for the acceptable dust fall rate is set out in the Regulations for residential and non-residential areas, and are shown in Table 3-7 below.

Table 3-7. Acceptable Dust Fall Rates

Restriction Area	Dust Fall Rate (D) (mg/m^2/day) (30-days average)	Permitted Frequency of Exceeding Dust Fall Rate
Residential area	D < 600	Two within a year, not sequential months.
Non-residential area	600 < D < 1200	Two within a year, not sequential months.

4 LATERAL LANDFILL GAS MIGRATION RISK

4.1 Background Information

One of the major hazard potentials associated with landfill sites is the LFG migration, whereas the LFG migrates to neighbouring buildings and premises, it could cause a fire or an explosion. A typical LFG migration is illustrated in Figure 4-1 below.

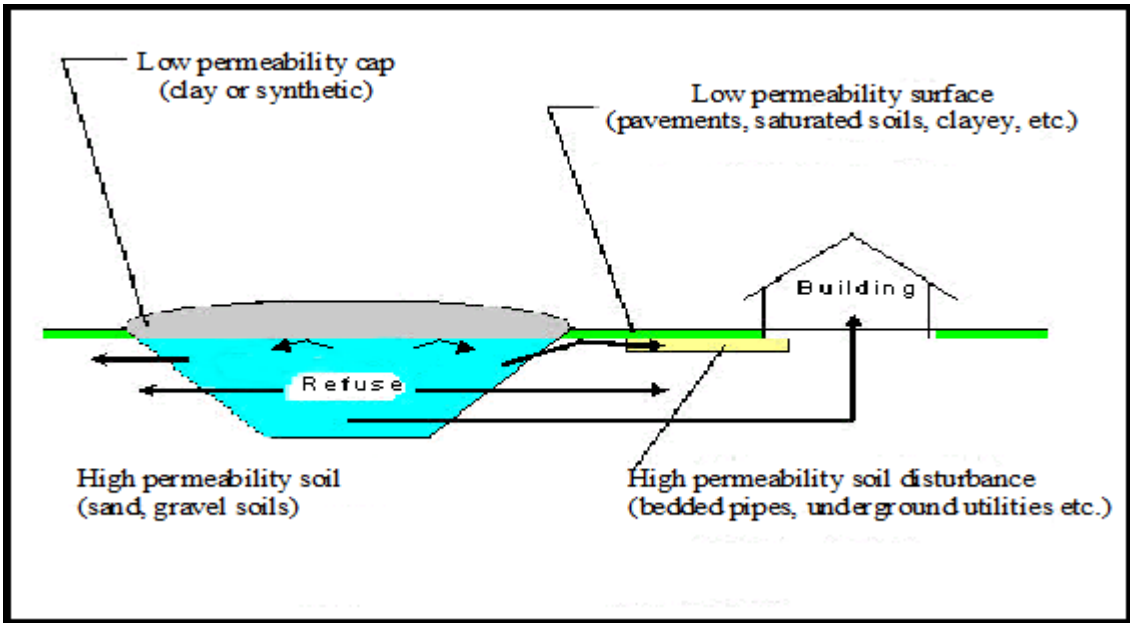

Figure 4-1. Typical LFG Lateral Migration

The two mechanisms governing the dynamics of gas migration are diffusion and convection. Diffusion is driven by the gas concentration gradient according to Fick's law, and convection by the pressure gradient. Both of the mechanisms tend to move LFG out of the refuse since pressures of 2.5 cm to 25 cm of the water column are commonly produced in a landfill.

The rate of gas movement through the refuse and adjacent soil is influenced by a number of factors. One of these is build-up pressure within the refuse mass. Subsurface migration is promoted by increased pressure. The more compacted the refuse during its placement, the less permeable it is, thus resulting in increased pressure build-up.

Another factor is the permeability of the soil surrounding the landfill. The rate of movement is slower through fine-grained soils, such as silts and clays. Coarse soils containing sand and gravel are permeable. Convective and diffusion flow depends directly on the pressure and concentration gradients respectively.

The site geometry, as well as the permeability of the landfill cover, also influences the lateral movement of LFG. Landfill caps with permeability less than $1x10^{-6}$ cm/s tend to restrict LFG from venting into the atmosphere.

The danger caused by LFG migration is primarily due to its methane content. Methane is odourless and potentially explosive in concentrations between 5% and 15% by volume of air. Within the refuse mass itself, methane will not explode since there is no sufficient oxygen available for instantaneous combustion.

However, in the absence of LFG migration control measures, LFG can migrate and accumulate in basements and nearby buildings. It is a potential fire and explosion hazard and can cause damage, injury or loss of life.

According to the Minimum Requirements, methane concentrations should not exceed 10% of the LEL (1% by volume air) in landfill facility structures and 100% of the LEL (5% by volume air) at the landfill property boundary. When these levels are exceeded, the installation of an LFG migration control system may be required. Once this has been installed, gas monitoring should be performed routinely, to determine the effectiveness of the gas control system. Other potential hazards associated with LFG migration are asphyxiation and eco-toxicity.

4.2 Landfill Gas Migration Monitoring and Management

Currently, there is no landfill gas migration management system in place at the Landfill Site.

In addition, there is no infrastructure installed for the monitoring of subterranean landfill gas migration around the Bonnievale Site. Therefore, there is no available historical monitoring data that may provide an indication whether there is existing gas migration around the site.

5 EMISSIONS INVENTORY

An emissions inventory for the Bonnievale Waste Disposal Facility was developed by quantifying the waste deposited at the site and determining the annual landfill gas emission rates. The pollutants of concern were the various VOCs, odorous compounds and hazardous air pollutants contained within the LFG.

Emissions from solid waste landfills cause or contribute significantly to air pollution that may reasonably be anticipated to endanger public health or welfare around landfill sites. Certain non-methane organic compounds (NMOC) are known or suspected carcinogens or cause other non-carcinogenic health effects. Public welfare concerns include odour nuisance from the LFG and the waste deposition operations on site, as well as the potential of explosions and fires due to methane migration, both on-site and off-site. The methane emitted from landfills is also of concern because it is a potent greenhouse gas that contributes to global climate change.

5.1 Landfill Gas Emissions Model

The LFG generated in the landfill site was estimated using the LandGEM. The LandGEM is a first-order decay model, which is used for the estimation of LFG emissions from municipal solid waste landfills, both during and after the landfill's operational lifetime. The first order decay equation used in the model for the estimations of the LFG emissions is as follows:

$$Q_{CH_4} = \sum_{i=1}^{n} \sum_{j=0.1}^{1} kL_o \left(\frac{M_i}{10}\right) e^{-kt_{ij}}$$

Where:

Q_{CH} = annual methane (CH_4) generation in the year of the calculation (m^3/year)

i = 1 year time increment

n = (year of the calculation) - (initial year of waste acceptance)

j = 0.1 year time increment

k = CH4 generation rate constant, yr^{-1}

Lo = CH4 generation potential, m^3 CH_4/mega gram (Mg) of waste

M_i = mass of waste accepted in the i-th year (Mg)

t_{ij} = age of the j-th section of waste mass M_i accepted in the i-th year (decimal years)

- Methane Percentage in Landfill Gas

The primary gaseous products of waste decomposition are methane (50% to 55%) and carbon dioxide (45% to 50%), but other constituents are present in trace amounts. For the modelling

purposes, the default value of 50% methane content in the landfill was used, since a site specific value was not available.

- Methane Generation Rate (k)

The projected methane generation rate (K) determines the rate of methane production for each sub-mass of waste in the landfill. The value of K is a function of waste moisture content, the abundance of nutrients for the anaerobic microbes, the pH value of the waste and the temperature of the waste. The higher the value of K, the faster the methane rate increases and then decreases over time. The model assumes that the value of K is the same before and after peak production of methane occurs. The USEPA conventional K value of 0.04 was adopted for this assessment.

- Potential Methane Generation Capacity (L_o)

The Potential Methane Generation Capacity, L_o, depends only on the type and composition of waste placed in the landfill (USEPA). The higher the cellulose content of the waste, the higher the value of L_o. The L_o value is measured in metric units of m^3/Mg.

The site-specific L_o value was calculated based on the following equations (IPCC, 2006):

$$L_o = 1503 \times DDOCm \times F \times 16/12$$

$$DDOCm = DOC \times DOCf$$

$$DOC = 0.4(A)+0.17(B)+(0.15)C+0.3(D)$$

Where

- Lo: the CH4 generation capacity in m3 CH4 per tonne waste.
- 1503: conversion factor to convert tonnes CH4 to m3 CH4 at 20°C and 101325 Pa.
- DDOCm: the mass of decomposable DOC/mass of waste.
- DOC: degradable organic carbon in the year of deposition, fraction, tonne C/tonne waste.
- DOCf: fraction of DOC expected to decompose (fraction).
- F: fraction of CH4 of the LFG generated, by volume.
- 16/12: the molecular weight ratio between CH_4 and carbon
- A: % papers and textiles.
- B: % garden waste.
- C: % food waste.
- D: % wood and straws.

Two L_o values were calculated: one for the domestic and business waste, which was deposited from the commencement of the site until 2002, and the second value was for the period when only garden waste was deposited at the site, between 2003 and 2013.

The first L_o was estimated on the assumption that the composition of biodegradable content in domestic waste was paper 17.2%, garden waste 20.2%, food waste 17.6% and wood waste 1.0%. The calculated L_o value was 80 m^3/tonne of waste. As a worst-case scenario and due

to the fact that business waste was also deposited at the site during that period, which has an unknown biodegrabable fraction, the L_o value of 100 m^3/tonne was used in the LFG generation calculations.

The second L_o value was estimated based on the fact that only garden waste, together with builders' rubble was deposited at the site between the years 2003 and 2013. This L_o value was estimated to be 85 m^3/tonne.

From the year 2014 onwards, the domestic waste has been diverted to the Ashton Waste Disposal Facility and the green waste is being recycled. As such, only inert materials are depositied at the Bonnievale WDF, which are not expected to contribute to the generation of additional landfill gas.

- Waste Deposition Quantities

The waste deposition at the Bonnievale WDF started on 31 July 1998. The estimated historical waste deposition was approximately 20 tonnes per day. Until 2001/2002, the domestic waste, business waste, builders rubble and green waste has been deposited at the Bonnievale site. From 2001/2002 onwards, the domestic waste has been diverted to the Ashton Waste Disposal Facility, and since 2013/2014 the green waste is being recycled.

Between the years 2003 and 2013, the deposited garden waste quantities were estimated based on the following assumptions. The 2003 garden waste quantity was 20% of the 2003 total and the annual increase thereafter, until the year 2013, was 1.79%.

Currently, according to the landfill manager, an average of 23 tonnes per month is deposited at the site, and this waste does not contain any biodegradable material.

The estimated historic and future annual waste deposition quantities for the site can be seen in Table 5-1.

Table 5-1. Annual Waste Deposition

Year	Deposition (tonne/year)	Year	Deposition (tonne/year)
1998	5000	2018	281
1999	5090	2019	286
2000	5181	2020	291
2001	5273	2021	296
2002	5368	2022	302
2003	1289	2023	307
2004	1312	2024	312
2005	1335	2025	318
2006	1359	2026	324
2007	1384	2027	330
2008	1408	2028	335
2009	1434	2029	341
2010	1459	2030	348

Year	Deposition (tonne/year)	Year	Deposition (tonne/year)
2011	1485	2031	354
2012	1512	2032	360
2013	1539	2033	367
2014	262	2034	373
2015	266	2035	380
2016	271	2036	387
2017	276		

5.2 LFG Generation Estimation

Based on the estimated annual waste deposition, the total annual LFG generation at the site was calculated with the use of the LandGEM model. The maximum LFG emissions occurred one year after the waste was diverted to Ashton Landfill and to start declining thereafter. It can be seen that the LFG generation in 2003 was approximately 2.4E+05 m^3. Figure 5-1 below shows the historical and future estimated annual LFG quantities. As a worst-case scenario, the year 2017 emissions were utilised in the dispersion modelling and impact assessment.

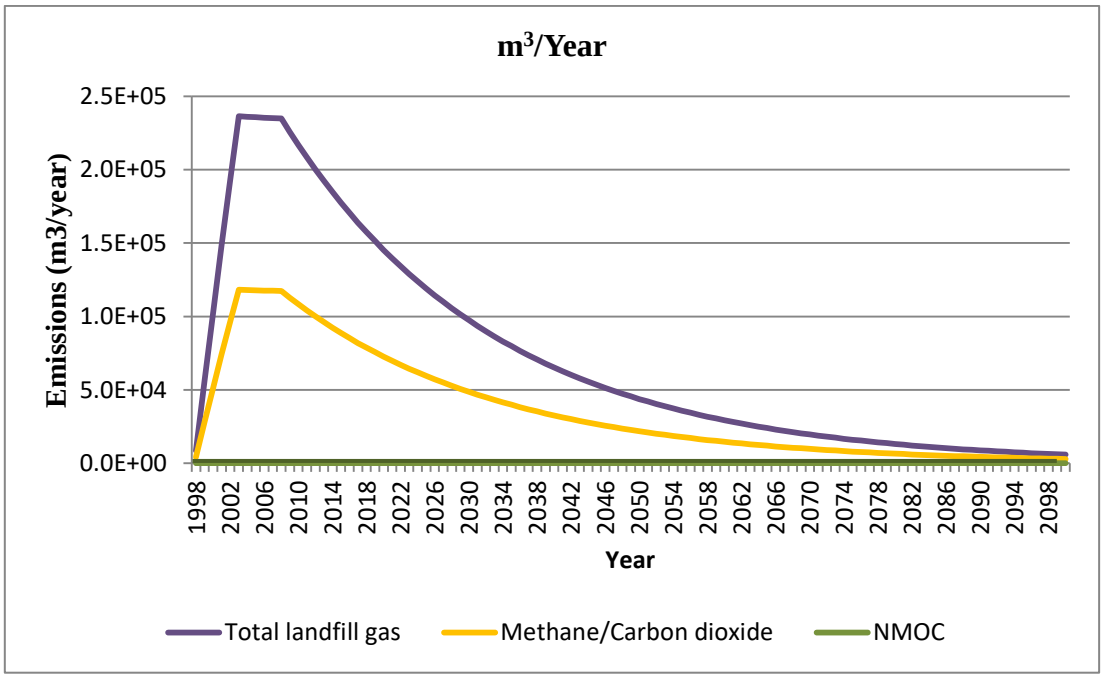

Figure 5-1. Annual LFG Generation

LFG contains low concentrations of air pollutants from the leaching and decomposition of waste. Air pollutant emissions are based on concentrations of air pollutants in the LFG. The default concentrations for municipal waste in the LandGEM model were utilised. The resulting emissions inventory for the year 2017 is presented in Table 5-2.

Table 5-2. Air Pollutant Emissions

Gas / Pollutants	Emission Rates	
	(Mg/year)	g/s
Total landfill gas	223.71	7.1
Methane	59.76	1.9
Carbon dioxide	163.95	5.2
NMOC	0.39	1.22E-02
1,1,1-Trichloroethane (methyl chloroform) - HAP	4.77E-04	1.51E-05
1,1,2,2-Tetrachloroethane - HAP/VOC	1.38E-03	4.36E-05
1,1-Dichloroethane (ethylidene dichloride) - HAP/VOC	1.77E-03	5.61E-05
1,1-Dichloroethene (vinylidene chloride) - HAP/VOC	1.44E-04	4.58E-06
1,2-Dichloroethane (ethylene dichloride) - HAP/VOC	3.02E-04	9.59E-06
1,2-Dichloropropane (propylene dichloride) - HAP/VOC	1.52E-04	4.81E-06
2-Propanol (isopropyl alcohol) - VOC	2.24E-02	7.10E-04
Acetone	3.03E-03	9.61E-05
Acrylonitrile - HAP/VOC	2.49E-03	7.90E-05
Benzene - No or Unknown Co-disposal - HAP/VOC	1.11E-03	3.51E-05
Benzene - Co-disposal - HAP/VOC	6.40E-03	2.03E-04
Bromodichloromethane - VOC	3.78E-03	1.20E-04
Butane - VOC	2.17E-03	6.87E-05
Carbon disulfide - HAP/VOC	3.29E-04	1.04E-05
Carbon monoxide	2.92E-02	9.26E-04
Carbon tetrachloride - HAP/VOC	4.58E-06	1.45E-07
Carbonyl sulfide - HAP/VOC	2.19E-04	6.95E-06
Chlorobenzene - HAP/VOC	2.10E-04	6.65E-06
Chlorodifluoromethane	8.38E-04	2.66E-05
Chloroethane (ethyl chloride) - HAP/VOC	6.25E-04	1.98E-05
Chloroform - HAP/VOC	2.67E-05	8.46E-07
Chloromethane - VOC	4.51E-04	1.43E-05
Dichlorobenzene - (HAP for para isomer/VOC)	2.30E-04	7.29E-06
Dichlorodifluoromethane	1.44E-02	4.57E-04
Dichlorofluoromethane - VOC	1.99E-03	6.32E-05
Dichloromethane (methylene chloride) - HAP	8.86E-03	2.81E-04
Dimethyl sulfide (methyl sulfide) - VOC	3.61E-03	1.14E-04
Ethane	1.99E-01	6.32E-03
Ethanol - VOC	9.27E-03	2.94E-04
Ethyl mercaptan (ethanethiol) - VOC	1.06E-03	3.38E-05
Ethylbenzene - HAP/VOC	3.64E-03	1.15E-04
Ethylene dibromide - HAP/VOC	1.40E-06	4.44E-08
Fluorotrichloromethane - VOC	7.78E-04	2.47E-05
Hexane - HAP/VOC	4.24E-03	1.34E-04
Hydrogen sulfide	9.14E-03	2.90E-04
Mercury (total) - HAP	4.33E-07	1.37E-08
Methyl ethyl ketone - HAP/VOC	3.81E-03	1.21E-04
Methyl isobutyl ketone - HAP/VOC	1.42E-03	4.50E-05
Methyl mercaptan - VOC	8.96E-04	2.84E-05
Pentane - VOC	1.77E-03	5.63E-05
Perchloroethylene (tetrachloroethylene) - HAP	4.57E-03	1.45E-04
Propane - VOC	3.61E-03	1.15E-04
t-1,2-Dichloroethene - VOC	2.02E-03	6.41E-05
Toluene - No or Unknown Co-disposal - HAP/VOC	2.68E-02	8.49E-04
Toluene - Co-disposal - HAP/VOC	1.17E-01	3.70E-03
Trichloroethylene (trichloroethene) - HAP/VOC	2.74E-03	8.69E-05
Vinyl chloride - HAP/VOC	3.40E-03	1.08E-04
Xylenes - HAP/VOC	9.49E-03	3.01E-04

5.3 Fugitive Dust Emissions

Fugitive dust emissions at the landfill site may occur as dust entrainment from vehicle movements on unpaved roads, earthmoving and handling activities and wind erosion of disturbed waste deposition areas.

- Vehicle Entrainment Emissions

When a vehicle travels on a paved/unpaved road, the force of the wheels on the road surface causes particles to be lifted and dropped from the rolling wheels. The road surface is exposed to strong air currents in turbulent shear with the surface, as well as the air wake behind the vehicle. The quantity of dust emissions from a given segment of the road varies linearly with the volume of traffic.

- Active Working Face Emissions

Waste material handling and truck unloading are sources of dust emissions.

- Wind Erosion of Open Areas without Permanent Cover

In open areas without permanent cover, wind erosion is a source of additional dust emissions.

According to the site manager, there is no equipment at the site, and approximately 20 tonnes of builders' rubble is deposited at the site per month. Taking the chipping operations into consideration, the resulting dust emissions from these operations are unlikely to have a significant impact beyond the site boundaries. Therefore, the dust emissions were only assessed quantitatively and were not included in the dispersion modelling.

6 AIR POLLUTION DISPERSION MODELLING

To assess the air quality impacts from the Bonnievale WDF, dispersion modelling calculations were carried out based on the emissions inventory presented in the section above.

6.1 Level of Assessment

A tiered approach is recommended in the Regulations Regarding Air Dispersion Modelling (DEA, 2014). The level of assessment depends on the technical factors such as geophysical, emissions and meteorological conditions; as well as the level of risk associated with the emissions. Three levels of assessment are specified in the regulations:

Level 1 assessment provides an estimate of the worst-case air quality impacts. Screening models are sufficient for this level.

Level 2 assessment is used for air quality impact assessment in standard licence or amendment processes. AERMOD is the recommended model for near-source (less than 50 km from source) applications in all terrain types. The model is used for Level 2 assessments.

Level 3 assessment is used in situations where:

- The purpose of the assessment requires a detailed understanding of the air quality impacts (time and space variation of the concentrations).
- It is important to account for causality effects, calms, non-linear plume trajectories, spatial variations in turbulent mixing, multiple source types and chemical transformations.

The CALPUFF model is recommended for Level assessments for distances greater than 50 km.

The Level 2 assessment was considered appropriate for the present study since it is used for air quality impact assessment in standard licence or amendment processes where:

- The distribution of pollutant concentrations and depositions are required in time and space.
- Pollutant dispersion can be reasonably treated by a straight-line, steady-state, Gaussian plume model with first-order chemical transformation.
- Emissions are from sources where the greatest impacts are in the order of a few kilometres (less than 50 km) downwind.

6.2 Atmospheric Dispersion Model

The AERMOD View from Lakes Environmental, Version 9.5.0, was utilised for the air pollution dispersion modelling. The AERMOD View is an air dispersion modelling system, which incorporates the popular US EPA models AERMOD, ISCST3 and ISC-PRIME into one interface.

The AERMOD model is a steady-state Gaussian plume air dispersion model. It is based on the planetary boundary layer turbulence structure and scaling concepts, including treatment of both surface and elevated sources, and both simple and complex terrain. It is used to model air pollution dispersions up to 50 km from the source.

Special features of AERMOD include its ability to treat the vertical non-homogeneity of the planetary boundary layer, special treatment of surface releases, irregularly-shaped area sources, a three-plume model for the convective boundary layer and limitation of vertical mixing in the stable boundary layer.

Additional details on the AERMOD dispersion algorithms, model characteristics, as well on the AERMET, the meteorological pre-processor, can be found in the description of model formulation and the model's user guide respectively (USEPA, 2004a and USEPA, 2004b).

6.2.1 Model Set-up and Data Input

The dispersion modelling was carried out based on the following:

- Three years of WRF modelled hourly meteorological data for the study area.
- Terrain effects were included in the modelling.
- It was assumed that the air pollutants' emission rates from the landfill site were constant.
- The modelling domain was set to 6 km by 6 km, with the landfill site located approximately at the centre.
- The individual odour units and the health risk indexes of all relevant air pollutants were added to express the cumulative odour and health impacts.

The modelling options utilised for the model setup included the:

- Default regulatory options;
- The terrain effects were taken into consideration.
- Rural dispersion coefficients;
- Constant emissions.
- A 100m grid spacing was utilised for the modelling domain.

6.2.2 Topographical Data

The digital terrain elevations utilised for the dispersion modelling were based on Shuttle Radar Topography Mission (SRTM) (30 m, 1 arc-sec) data. The SRTM elevation dataset is the most complete high-resolution digital topographic database of earth's elevations to date. This data is divided into one by one degree latitude and longitude tiles in "geographic" projection. The heights are provided in meters referenced to the WGS84/EGM96 geoid. The appropriate tiles for the extended project area were selected for the AERMAP, the elevations pre-processor for the AERMOD model.

6.3 Discrete Receptors

In addition to the gridded receptors, discrete receptors were placed at communities close to the site. These were included in the dispersion modelling for the determination of the air pollutant concentrations at these locations. These receptors are depicted in Figure 6-1 and their descriptions are shown in Table 6-1.

Table 6-1. Discrete Receptors

Receptors	UTM Coordinates		Description
	X (m)	Y (m)	
R01	415112.6	6245816	Informal settlement
R02	414958.5	6245877	Informal settlement
R03	415180	6245942	Informal settlement
R04	414544.7	6245356	Happy Valley residence
R05	414549.6	6245190	Happy Valley residence
R06	414891.9	6245044	Happy Valley residence
R07	415748.6	6245644	Farmstead, ~ 660m east of the site

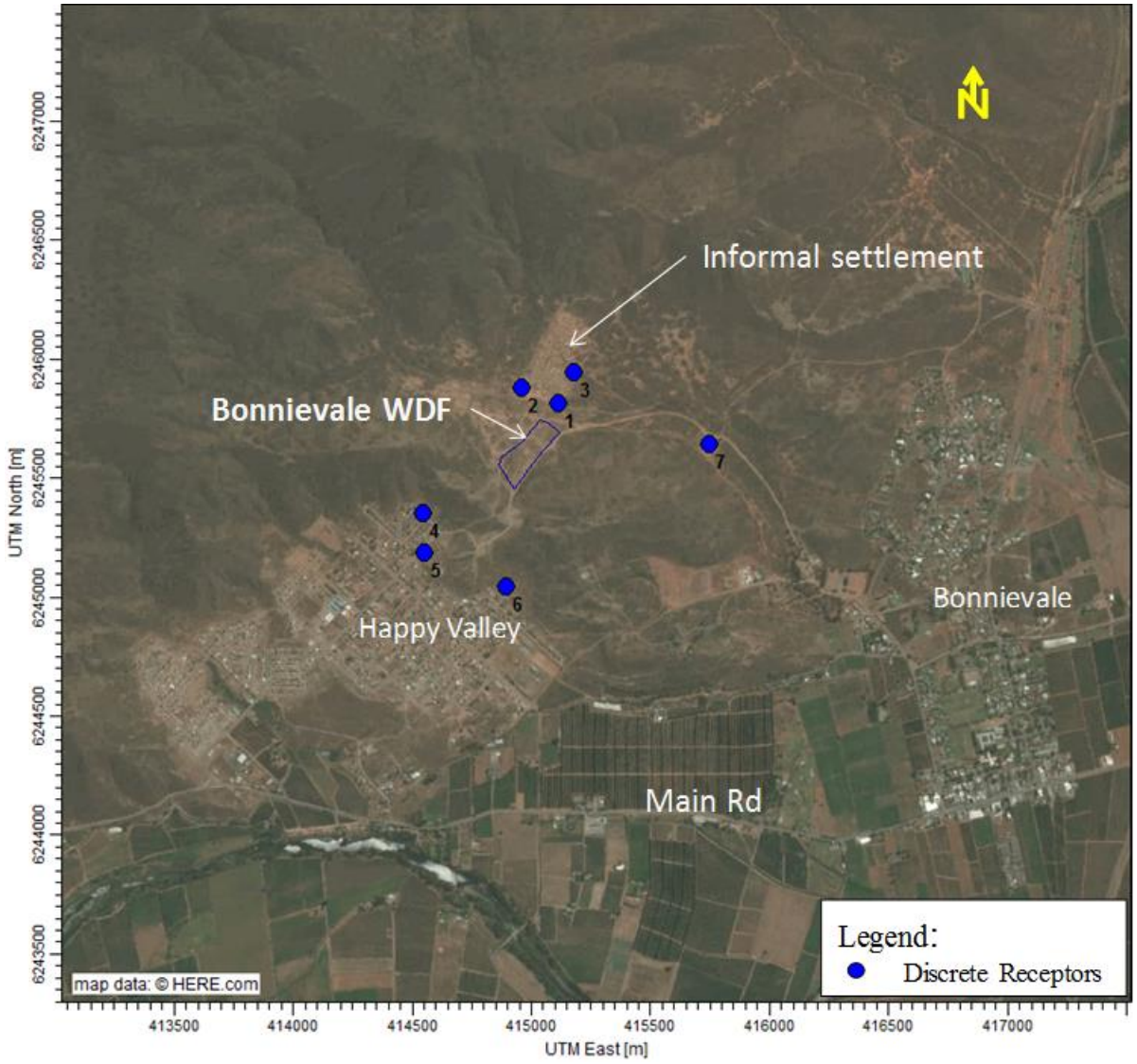

Figure 6-1. Discrete Receptor Locations

The dispersion modelling was carried out based on the recommendation of the Regulations Regarding Air Dispersion Modelling (DEA, 2014). The 99th percentiles of maximum 1-hour and maximum annual ground-level concentrations were calculated. With the ground-level concentrations, the resulting cumulative odour unit concentrations, as well as the cumulative carcinogenic and non-carcinogenic health risk indexes were generated. These results are presented in the following sections.

6.4 Odour

For the odorous compounds ambient concentrations, the 99th percentile of hourly maximum values were used, and the OUs for each compound were added at each grid point to determine the cumulative OUs at each location. The calculated cumulative OU contours are shown in Figure 6-2 below.

As can be seen, the maximum cumulative odour was less than 1 OU at the Bonnievale WDF. The cumulative odour unit was less than 0.4 outside the site, which is below the odour guideline of 2 OU for residential areas. The odour at the informal settlement north of the site was below 0.2 OU. Therefore, odour impact due to the landfill gas emission is expected to be low.

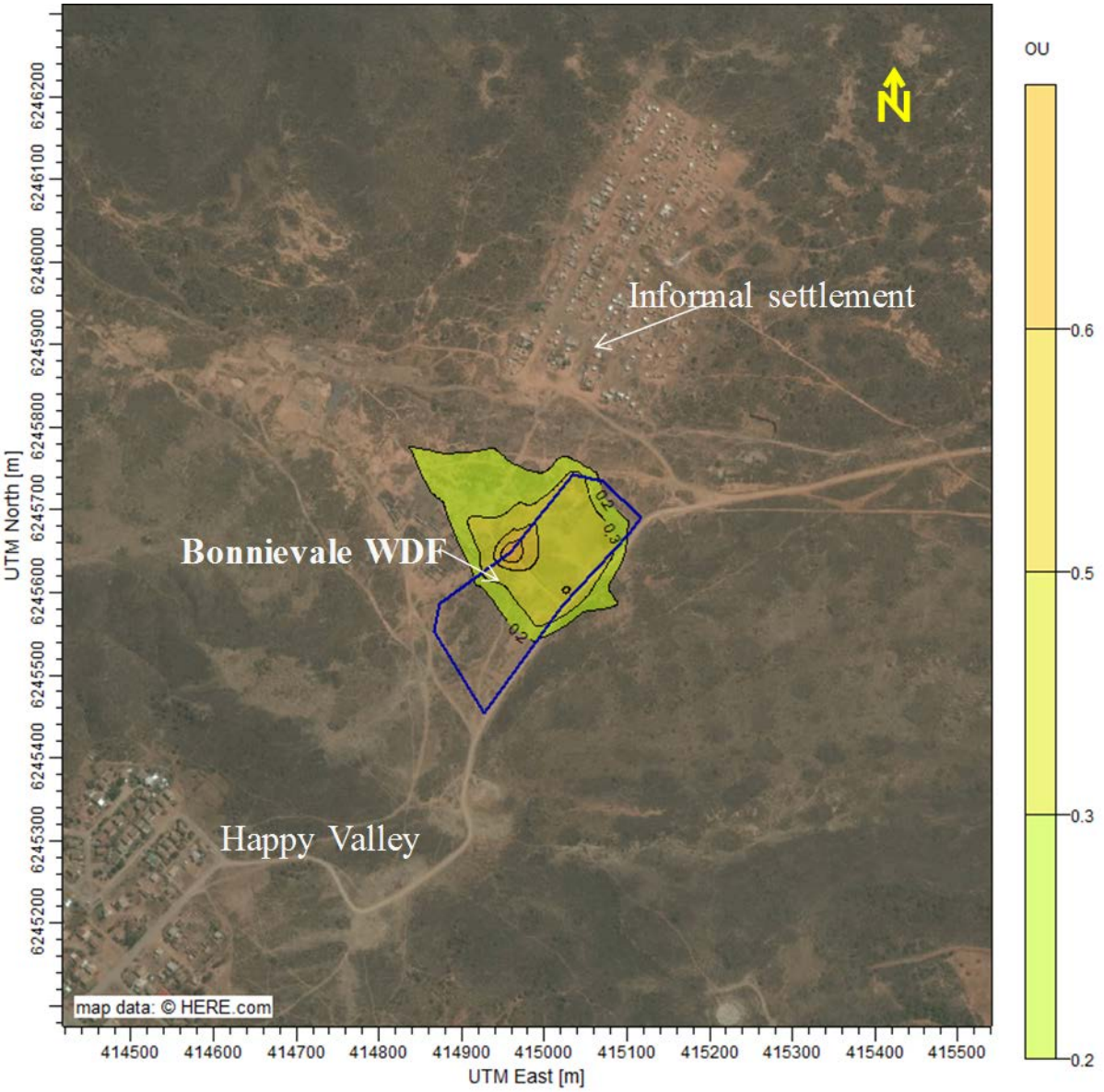

Figure 6-2. Odour Contours (Guideline: 2)

6.5 Non-Carcinogenic Health Risk

Figure 6-3 and Figure 6-4 show the short- and long-term non-carcinogenic endpoints based on the maximum 1-hour (99th percentile) and annual concentrations. It should be noted that the different compounds' respective index fractions were added, to determine the impact of all compounds cumulatively.

It can be seen that the short- and long-term hazard indexes were well below 1 at and outside the Bonnievale WDF perimeter. That means the ambient concentrations of various air pollutants predicted were well below their respective guideline concentrations. The short-term non-carcinogenic health risk index outside the site was approximately 0.01, and the long-term risk was approximately 0.1. As such, the expected non-carcinogenic health impacts are considered to be very low.

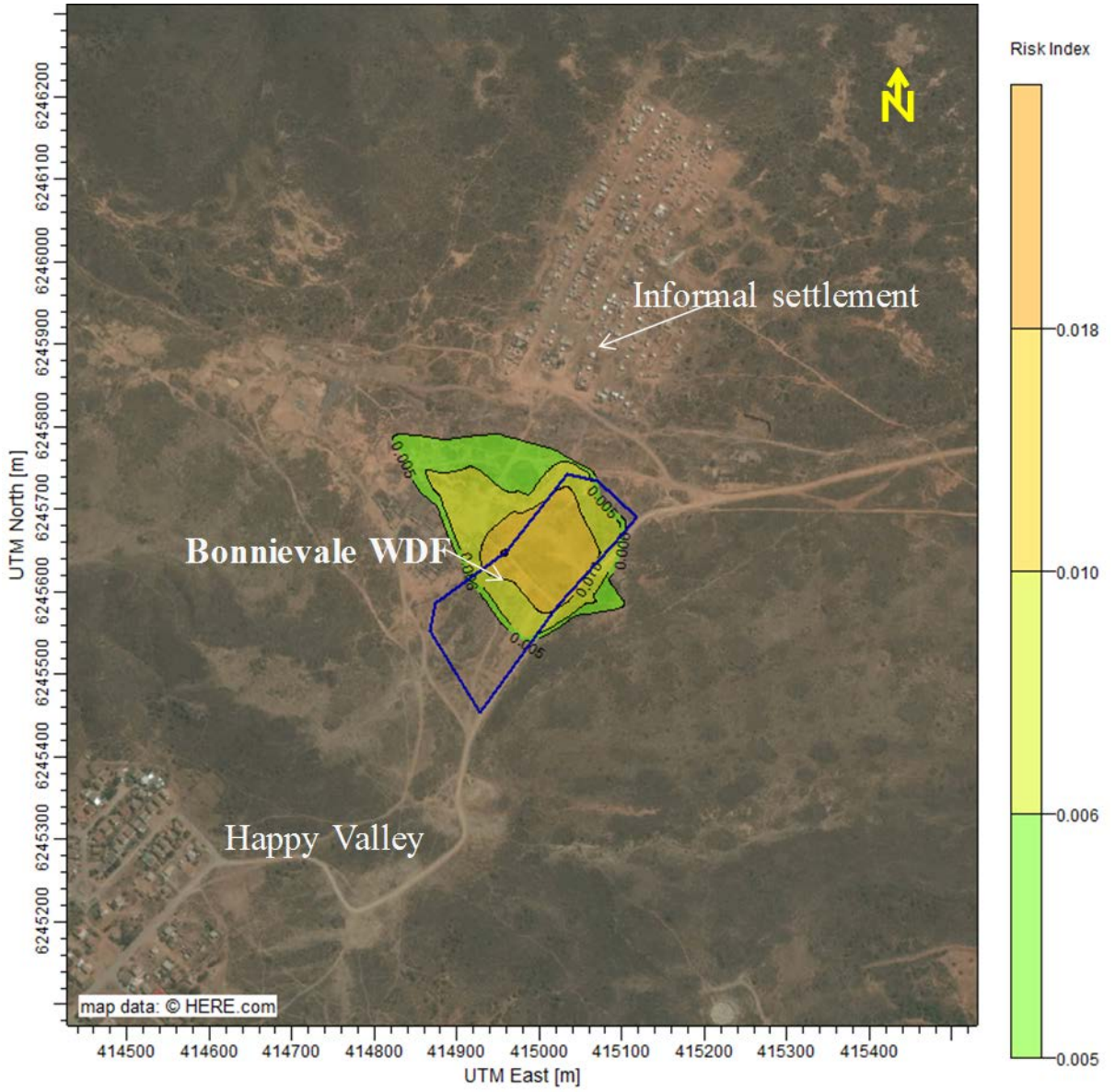

Figure 6-3. Short-term Non-Carcinogenic Health Risk Contours (Guideline: 1)

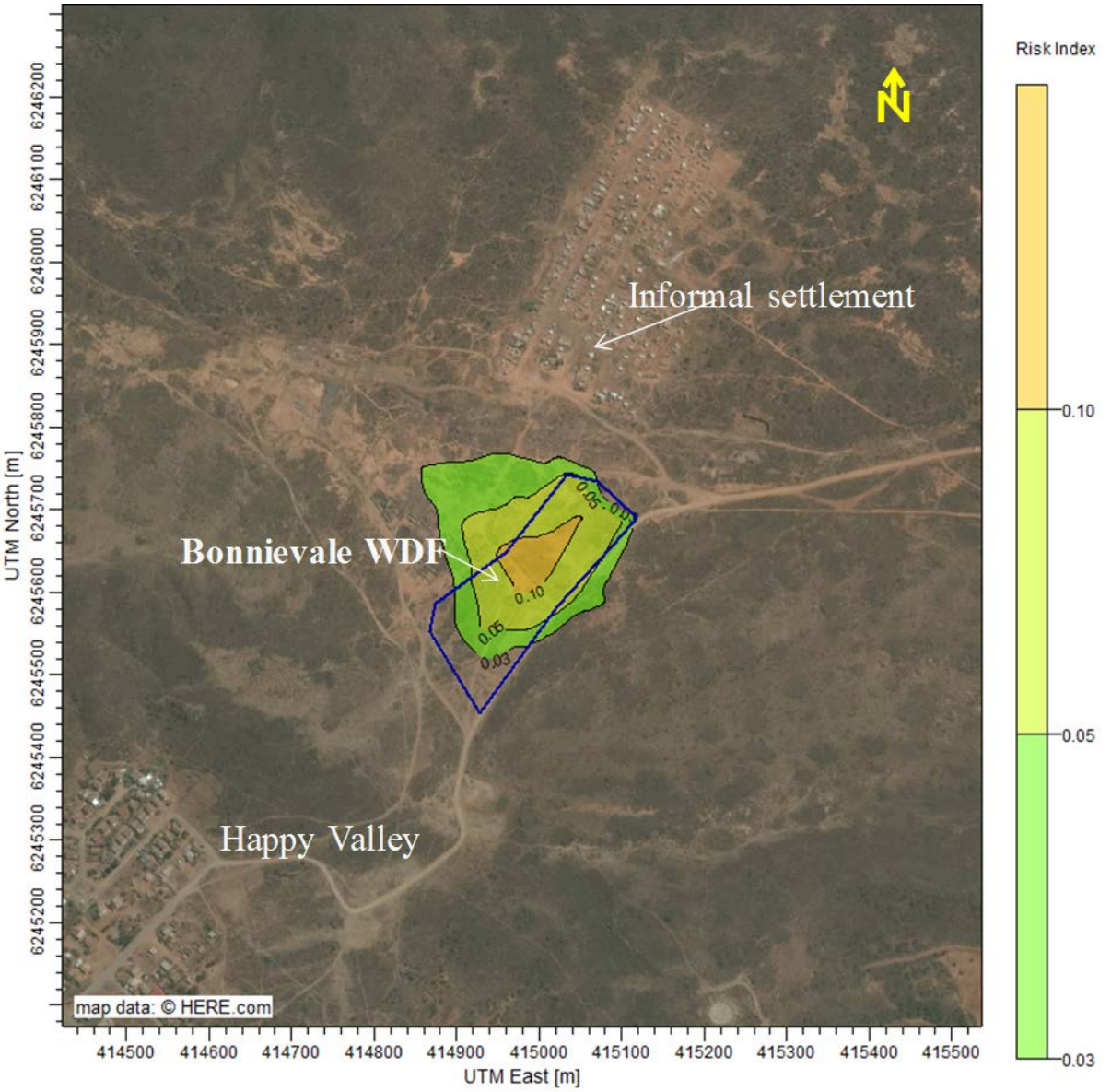

Figure 6-4. Long-term Non-Carcinogenic Health Risk Contours (Guideline: 1)

6.6 Carcinogenic Risk

The compounds that are classified by the USEPA as carcinogenic to humans and likely to be carcinogenic to humans were utilised in the calculations of the carcinogenic risk. These compounds are benzene, carbon tetrachloride, chloroform, trichloroethylene and vinyl chloride. Based on the unit risk factors from Table 3-2, the carcinogenic risk for each compound was calculated and added to determine the cumulative risk. The calculated carcinogenic risks are shown in Figure 6-5 below.

It can be seen that the carcinogenic risk reached $0.5x10^{-6}$ at the site and approximately $0.2x10^{-6}$ outside the site boundaries. The carcinogenic risks at nearby residences were well below $1x10^{-6}$. This means that any person in these areas would have an increased risk of less than 0.2 in 1,000,000 chance of getting cancer due to a lifetime exposure (70 years). This risk is considered very low.

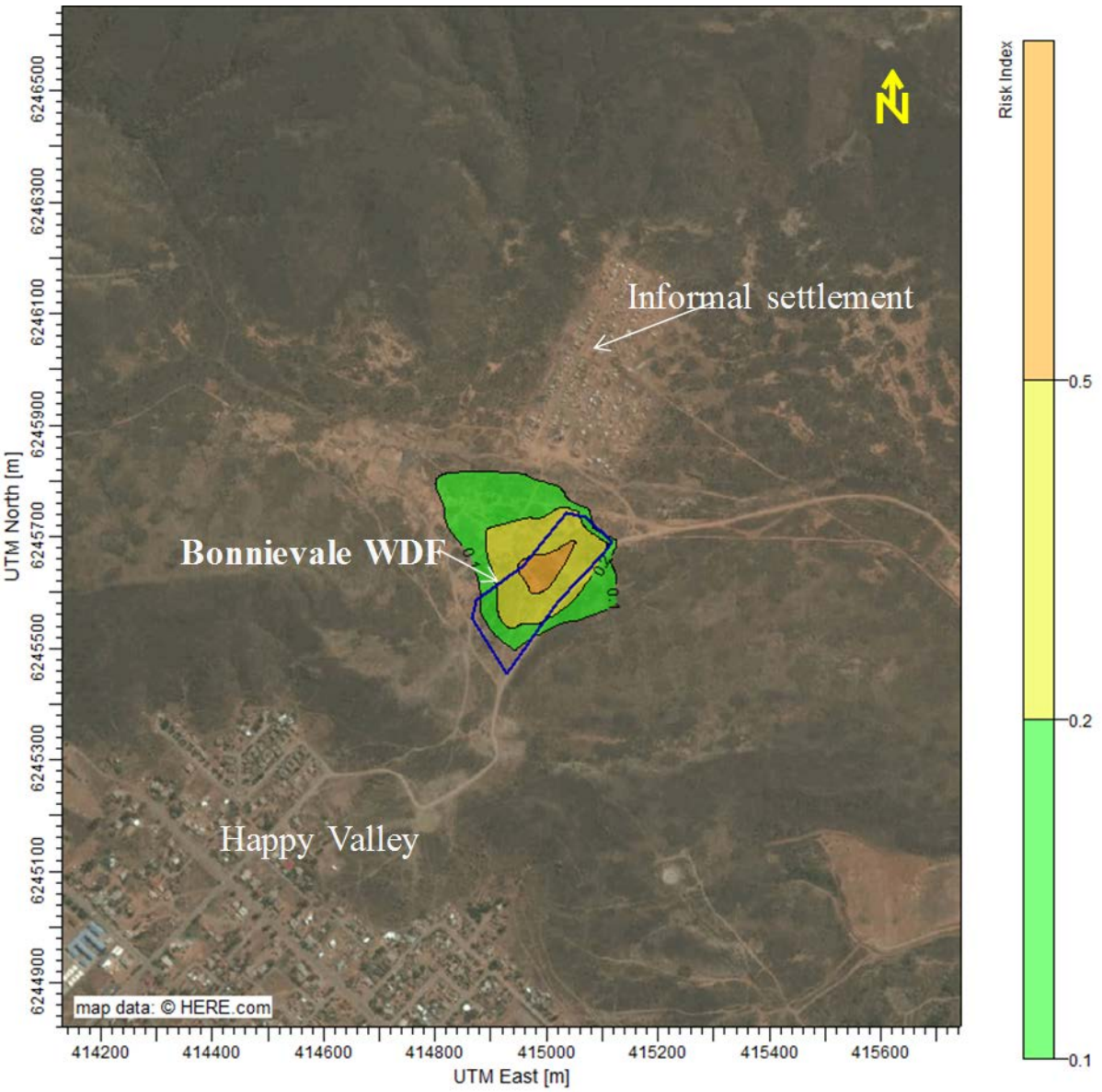

Figure 6-5. Carcinogenic Health Risk Contours (x 10^{-6}) (Guideline: 1 x 10^{-6})

6.7 Modelled Concentrations at Discrete Receptors

The following Table 6-2 shows the odour concentrations and health risks at the discrete receptors in the study area. As can be seen, the odour concentrations and health risks at all discrete receptors were well below their respective guidelines.

Table 6-2. Modelled Concentrations at Discrete Receptors

Receptor	Odour (OU)	Non-carcinogenic Risk Index		Carcinogenic Risk Index ($x10^{-6}$)
		Short-term	Long-term	
R01	0.01	0.00	0.00	0.02
R02	0.10	0.00	0.01	0.06
R03	0.00	0.00	0.00	0.01
R04	0.00	0.00	0.00	0.01
R05	0.00	0.00	0.00	0.01
R06	0.00	0.00	0.00	0.01
R07	0.00	0.00	0.00	0.00
Guideline	**2**	**1**	**1**	**1**

7 CONCLUSIONS

The Bonnievale Waste Disposal Facility is currently used for the deposition of builders' rubble only. The domestic waste is being diverted to the Ashton WDF and the green waste is chipped and recycled.

The air quality impact assessment for the Bonnievale WDF was carried out utilising the year 2017's landfill gas emissions, which is considered the worst-case scenario. The air quality impacts due to these emissions were determined regarding odour, non-carcinogenic and carcinogenic health risks. Based on the above-mentioned impacts and the lateral gas migration potential of the site, the appropriate butter zones around the site boundaries were determined.

7.1 Odour Impact

As can be seen from the dispersion modelling, the maximum cumulative odour was less than 1 OU at the site. The odour impact at the nearby residences is expected to be low.

7.2 Non-carcinogenic Health Risks

Based on the short- and long-term non-carcinogenic health risk, it was found that the maximum short- and long-term hazard indexes were well below 1. Therefore, the maximum 1-hour (99^{th} percentile) and maximum annual concentrations of the air pollutants were well below their respective guidelines in and around the site.

The short-term non-carcinogenic health risk index outside the site was approximately 0.01, and the long-term risk was approximately 0.1. As such, the expected non-carcinogenic health impacts are considered to be very low.

7.3 Carcinogenic Risk

The compounds that are classified by the USEPA as carcinogenic to humans and likely to be carcinogenic to humans were utilised for the calculation of the carcinogenic risk. Based on the annual maximum concentrations of these compounds, the carcinogenic risk reached $0.5x10^{-6}$ at the site and approximately $0.2x10^{-6}$ off site. The carcinogenic risks at nearby residences were below $1x10^{-6}$. This means that any person in these areas would have a less than 1 in 1,000,000 chance of getting cancer due to a lifetime exposure (70 years). This risk is considered very low or negligible.

7.4 Dust Fallout

Fugitive dust emissions at the Bonnievale WDF may occur as dust entrainment from vehicle movements on unpaved roads, waste handling activities and wind erosion of disturbed areas. Due to the very low quantities that the site receives per day, the resulting dust emissions will not have any significant impact beyond the site boundary. The overall impact is considered very low.

8 BUFFER ZONE DETERMINATION

The buffer zone requirements are indicated as distances from each side of the site's perimeter in Figure 8-1 and Table 8-1.

Based on the resulting low odour concentrations and the very low non-carcinogenic and carcinogenic risks, the buffer zone requirements for the Bonnievale WDF are expected to be contained by the site's boundaries. As such, the odour nuisance and health end points' buffer zone requirements were not required outside the site's boundaries.

However, considering that the Bonnievale WDF does not have any active or passive LFG extraction system, nor any lateral LFG migration monitoring probes, and taking into account the potential LFG migration risk, the minimum buffer requirement was set to 100 m from the site's boundaries (see Table 8-1).

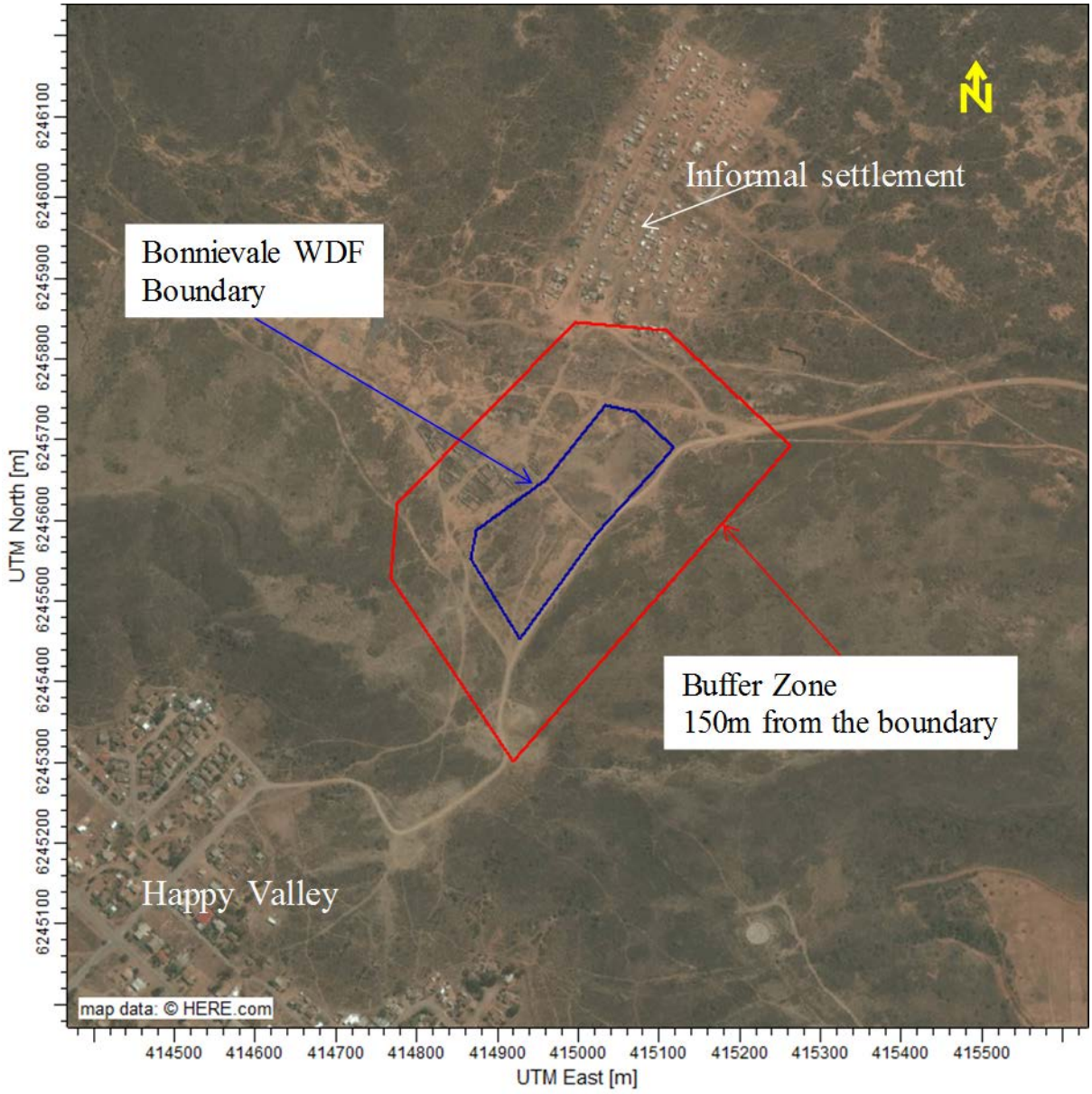

Figure 8-1. Buffer Zone Requirements for the Bonnievale WDF

Table 8-1. Buffer Zone Criteria for the Bonnievale WDF

Zone Criteria	Distance From Site's Boundaries [b] (m)			
	North	South	East	West
Odour: 2 OU	None required [c]			
Non-carcinogenic risk 1-hour: risk index 1	None required [c]			
Non-carcinogenic risk annual: risk index 1	None required [c]			
Carcinogenic risk: risk index $1x10^{-6}$	None required [c]			
Dust fallout	None required [c]			
LFG Migration [a]	100	100	100	100

[a] Recommended minimum buffer distance in terms of potential LFG migration risk.
[b] Distances measured from the relevant boundary.
[c] Buffer zone requirement contained within the site boundary.

Since only a small amount of general waste has been deposited at the site and only inert material is currently deposited, landfill gas migration monitoring is not deem necessary and no probes need to be installed at the site.

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