

DRAFT

Air Quality Monitoring
and Risk Assessment
at the
Dispose-Tech (Pty) Ltd
Shongweni Waste Disposal Site

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GLOSSARY:

Airborne contaminant: An airborne contaminant is a potentially harmful substance that is either naturally absent from air or is present in an unnaturally high concentration, and to which workers may be exposed in their working environment.

Conceptual Model: An understanding of the landfill (including the design and operational fundamentals) in its environmental setting. The conceptual model must identify the sources, pathways and receptors at a landfill. A conceptual model represents the understanding of the problem and is used as the basis on which to develop a site specific risk assessment. The level of detail required of the model will depend upon the complexity of the risk assessment.

Emission: The direct or indirect release of substances, vibrations, heat or noise from individual or diffuse sources in an installation into the air, water or land.

Environmental Benchmark: A standard or criterion against which the level of an emitted substance can be compared at a receptor. For a quantified risk assessment the potential impact of an emission is evaluated through comparison against these appropriate standards in order to assess the significance of the impact and allow a decision to be made on whether the impact of the landfill on air or water quality may be acceptable.

Hazard: A property or situation that particular circumstances could lead to harm.

Odourants:	Odorous substances emitted from a landfill, or other associated operations.
Pathways:	The mechanism by which the receptor and source can come into contact (e.g. by a hazardous event or action on site giving rise to a release of the hazardous substance or material to atmosphere or to ground).
Receptors:	The entity (e.g. human, water body, ecosystem, building, etc.) that is sensitive or vulnerable to the adverse effects of the hazardous substance or material.
Risk:	A combination of the probability, or frequency, of occurrence of a defined hazard and the magnitude of the consequences of the occurrence.
Risk Assessment:	The qualitative/quantitative estimation and characterisation of risks.
Risk management:	The process of making and implementing decisions about accepting or altering risks.
Source:	The hazardous substance or material. The 'source' for waste management facilities is defined by the hazardous properties of the waste types, operations and/or operational byproducts e.g. landfill gas, leachate, particulate matter (dust), gas utilization or flaring emissions

ABBREVIATIONS:

AAS:	Atomic Absorption Spectroscopy
AQMS:	Air Quality Management Plan
ATD:	Automated Thermal Desorption
BS En:	British Standards - Environment
CAS:	Chemical Abstracts System number
CV-AAS:	Cold Vapour Atomic Absorption Spectroscopy
EC:	Exposure Concentration
FID:	Flame Ionisation Detection
GC:	Gas Chromatography
GC-FID:	Gas Chromatography with Flame Ionisation Detection
GC-HRMS:	Gas Chromatography with detection by High Resolution Mass Spectrometry
GC-MS:	Gas Chromatography with detection by Mass Spectrometry
GPSI:	Generic Priority Substance Inventory
HPLC:	High Pressure Liquid Chromatography
ICP-MS:	Inductively Coupled Plasma-Mass Spectrometry
MS:	Mass Spectrometry
NIOSH:	National Institute of Occupational Safety and Health
NMOC:	non-methane organic compounds
OfSEI:	Off-site Source Emissions Inventory
OnSEI:	On-site Source Emissions Inventory
OSHA:	Occupational Safety & Health Administration (U.S. Department of Labor)
PAH:	Polycyclic Aromatic Hydrocarbons
PCDD:	Polychlorinated dibenzo- <i>p</i> -dioxin
PCDF:	Polychlorinated dibenzo furan
PM10:	Particulate matter with an aerodynamic diameter of less than 10 micron.
PSI:	Priority Substance Inventory
USEPA:	United States Environmental Protection Agency

UV: Ultraviolet
VOC: Volatile Organic Compound

UNITS OF MEASUREMENT

I-TEQ: International Toxicity Equivalent, a normalised expression of concentration for PCDDs and PCDFs

ppbv: Parts per billion by volume, an expression of concentration.
ppb is a thousandth of a ppm.

ppmv : Parts per million by volume, an expression of concentration.
10,000ppm v/v equates to 1% gas at STP by volume.

µg/m³: Micrograms of gaseous substance in one cubic metre of total gas. The temperature, pressure and percentage moisture saturation of the total gas must be stated to permit intercomparison from different sources.

EXECUTIVE SUMMARY

Ambient Air Quality is a function of the Dispose-Tech (Pty) Ltd, Shongweni Waste Disposal Site Air Quality Monitoring Plan, embodied within the Air Quality Management Plan. The Ambient Air Quality Test Results and Cancer and Non-Cancer Risk Assessment are issued on a six monthly basis. The results will be presented at the Shongweni Monitoring Committee Meeting on the 7 April 2005. This report presents results obtained from July 2004 to January 2005.

The Shongweni Waste Disposal Site, is a Class H:h waste disposal site (co-disposal landfills). It is equipped with a multibarrier liner system that included a leak-detection layer. The construction included graded stones (leak-detection layer), a 150 mm layer of compacted clay, a 1.5 mm PP liner and 150 mm clay layer, and a drainage and protection layer. The leachate containment and collection discharged biologically treated leachate to a municipal sewerage treatment plant. Landfill Gas is not collected or treated.

The “Source-Pathway-Receptor” concept is used in Air Quality Risk Assessment. An understanding of the source of the hazard, the characteristics of the receptor that may be at risk from the hazard, and the means, or pathway by which the receptor may be affected by the hazard is determined. Therefore within the risk assessment the following answers are sought:

- What are the hazards?
- What are the properties of the hazards?
- How may the receptor become exposed to the hazards?
- What is the probability of exposure?
- What is the scale of the exposure?

- How significant is the risk?
- What are the uncertainties?

The test results are attached in Tables 1 to 4.

Six Air Sampling Stations were established, three on the site and three off the site (Map 2):

Station A – ON-SITE, Boundary Adjacent to Paul's office, Northern Boundary of Waste Disposal Site.

Station B – ON-SITE, Boundary Adjacent to Leachate Dam, Eastern Boundary of Waste Disposal Site relocated in the last two sampling periods to the North Eastern Boundary of the Waste Disposal Site.

Station C – ON-SITE, Located next to Weather Station in the waste disposal site valley towards the Western Boundary.

Station D – OFF-SITE, Located on the premises of the Mushroom Farm.

Station E – OFF-SITE, Located approximately 600 meters from the Eastern Boundary of the Waste Disposal Site.

Station F – OFF-SITE, Located approximately 700 meters from the Western Boundary of the Waste Disposal Site.

PLEASE NOTE: SAMPLING STATIONS E AND F (OFF-SITE STATIONS) WERE VANDALIZED DURING THE FIRST THREE SAMPLING PERIODS. IT DID NOT SEEM TO MATTER WHERE THEY WERE LOCATED THE SAMPLING PROBES AND STATION WERE BROKEN OR TAKEN. THEREFORE THEY WERE NOT REPLACED IN THE DECEMBER 2004 / JANUARY 2005 SAMPLING PERIOD,

SINCE THIS LOSS OF EQUIPMENT AND DATA IS OF NO BENEFIT TO THE PROJECT.

The test results in Tables 1 to 4 are represented in the column headed EC (Exposure Concentration) and are expressed in micrograms per cubic meter ($\mu\text{g}/\text{m}^3$) of air. The environmental benchmark or exposure limit of choice was derived from the ENVIRONMENT AGENCY (2003a) *IPPC HI Horizontal Guidance: Environmental Assessment and Appraisal of BAT*. Environment Agency Bristol. The long-term environmental benchmarked called Environmental Assessment Levels (EAL's) have been used in this case. Environmental benchmarks for both long-term and short-term effects in the receiving environment are available. Long-term effects may relate to those substances that are released continuously, frequently or over relatively long time periods. Short-term effects may relate to peak concentrations, intermittent or periodic emissions that occur over short time periods. The Odour Thresholds, in the last column, are derived from the ILO / NIOSH list of Odour Threshold Values (OTLV), *COMPILER'S GUIDE FOR THE PREPARATION INTERNATIONAL CHEMICAL SAFETY CARDS Odour Safety Factor (O.S.F.)* The non-cancer risk has been calculated and is tabulated in a summary table in Table 5.

The cancer-risk has been calculated and is tabulated in Tables 6 to 9. An estimated increased excess lifetime cancer risk is not a specific estimate of expected cancers. Rather, it is a plausible upper bound estimate of the probability that a person may develop cancer sometime in his or her lifetime following exposure to that contaminant. There is insufficient knowledge of cancer mechanisms to decide if there exists a level of exposure to a cancer-causing agent below which there is no risk of getting cancer, namely, a threshold level. Therefore, every exposure, no matter how low, to a cancer-causing compound is assumed to be associated with some increased risk. The highest or "worst-case" Unit Risk Factor (URF) or Inhalation Unit Factor (IUF) was chosen from those listed by California EPA, WHO or USEPA IRIS and the excess lifetime cancer risk was calculated. To ensure that additive risk would be taken into account the excess lifetime

cancer risk calculated for each carcinogen (cancer-forming substance) were summed. The cancer risk has been calculated and summarized in Table 10.

The Shongweni Waste Disposal Site's Priority Substance Inventory (PSI) was compiled from subsurface and surface sampling of trace components conducted since 1998. The Shongweni PSI is tabulated below in Table T-5:

Table T-5: Shongweni Waste Disposal Site Priority Substance Inventory

Priority Trace Component	CAS No.	Potential Impact	Category
Benzene	71-43-2	Health	Aromatic Hydrocarbon
Toluene	108-88-3	Health	Aromatic Hydrocarbon
Ethyl Benzene	100-41-4	Health	Aromatic Hydrocarbon
Xylene (all isomers)	108-38-3, 95-47-6, 106-42-3	Health & Odour	Aromatic Hydrocarbon
Trimethyl benzenes (all isomers)	526-73-8, 108-67-8, 95-63-6	Health & Odour	Aromatic Hydrocarbon
1,3-butadiene	106-99-0	Health	Aliphatic Hydrocarbon
Trichloroethene (trichloroethylene)	79-01-6	Health	Halogenated Hydrocarbon
Tetrachloroethylene	127-18-4	Health	Halogenated Hydrocarbon
Tetrachloromethane (carbon tetrachloride)	56-23-5	Health	Halogenated Hydrocarbon
Dichloromethane (methylene chloride)	75-09-2	Health	Halogenated Hydrocarbon
Ethanal (acetaldehyde)	75-07-0	Health	Organosulphur
Methanal (formaldehyde)	50-00-0	Health	Organosulphur
Hydrogen Sulphide	7783-06-4	Health & Odour	Organosulphur
Carbon disulphide	75-15-0	Health & Odour	Organosulphur
Methanethiol (methyl mercaptan)	74-93-1	Health & Odour	Organosulphur
Ethanethiol (ethyl mercaptan)	75-08-1	Health & Odour	Organosulphur
1-propanethiol (isopropyl mercaptan)	107-03-9	Health & Odour	Organosulphur
1-butanethiol (butyl mercaptan)	109-79-5	Health & Odour	Organosulphur
Dimethyl sulphide	75-18-3	Health & Odour	Organosulphur
Butyric Acid	107-92-6	Health & Odour	Volatile fatty acid
Valeric Acid	109-52-4	Health & Odour	Volatile fatty acid
Caproic Acid	142-62-1	Health & Odour	Volatile fatty acid
Propionic Acid	79-09-4	Health & Odour	Volatile fatty acid
Ethyl butyrate	105-54-4	Health & Odour	Oxygenated Hydrocarbon
Limonene	5989-27-5	Health & Odour	Terpene Hydrocarbon
p-cumene	99-87-6	Health & Odour	Terpene Hydrocarbon
α-pinene	80-56-8	Health & Odour	Terpene Hydrocarbon
Methyl Ethyl Ketones (MEK)	78-93-3	Health	Ketone
Methyl Isobutyl Ketones (MIBK)	108-10-1	Health	Ketone
1,5 diaminopentane	462-94-2	Health & Odour	Amine
1,4 butanediamine	333-93-7	Health & Odour	Amine
Ammonia	1336-21-6	Health	Inorganic compound

The only substance that was found to be above the Environmental Assessment Level (EAL) was formaldehyde. Formaldehyde was found to be in excess of the EAL during the month July 2004. However, it must be borne in mind that there were a number of bush fires and sugar fires during this period and this could account for the increase in the concentration of formaldehyde detected in ambient air.

The hazard quotients (HQ) were calculated by dividing each exposure concentration (EC) measured by the EAL. These HQ were then added together to calculate the Hazard Index (HI) which is used to assess additive non cancer risk. Table 5 depicts the summary of all four sampling stations from which exposure concentrations were measured. The results indicate that there was a minimal non cancer risk in the August/September 2004 sampling period and a low non cancer risk in the July 2004, October/November 2004 and December 2004/January 2005 sampling periods.

The excess lifetime cancer risk calculated, not only takes into account the highest of the agencies (California EPA, USEPA-IRIS and WHO) unit risk factors (URF), but also considers that a person would be exposed, at the sampling station location, for seventy years and for twenty four hours everyday. Therefore “worst-case” scenario has been considered in this study. In July 2004 there was a moderate to low excess lifetime cancer risk at all sampling stations. This was mainly due to the increase in concentrations of Formaldehyde at all four sampling stations. During the other three sampling periods there was a low excess lifetime cancer risk. However, it is interesting to note that carbon tetrachloride concentration detected at the Mushroom Farm in the August/September 2004, October/November 2004 and the December 2004/January 2005 sampling period created the highest risk at the Mushroom Farm, with lower risk at the on-site Shongweni Waste Disposal Site sampling stations.

It is recommended that in light of the promulgation of the Air Quality Management Act and the revision of the DWAF, Minimum Requirements for Waste Disposal by landfill, that the Air Quality Management Plan (AQMP), that includes the Air Quality Monitoring Plan be reviewed for the Shongweni Waste Disposal Site. This AQMP should only include air pollutants that may cause risk to human health and the environment and odour, but must also include noise assessment on the boundaries of the site. The key elements of the framework are:

- Risk assessment
- Control measures
- Operational procedures
- Monitoring Plan
- Action Plan
- Closure and completion plan.

It is suggested that Lifetime Actual Daily Dose be considered on this site as the next step in the risk assessment, as this takes into account the actual dose to person and incorporates modifying factors, uncertainties and other pathways, e.g. ingestion.

1. Introduction

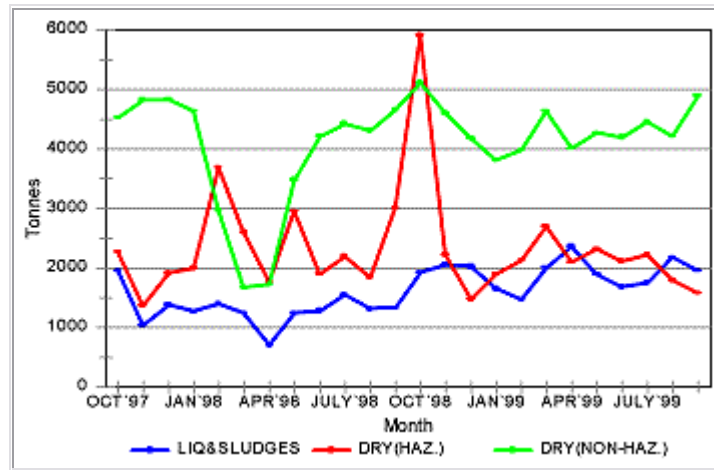
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2. Background

2.1 Site Description

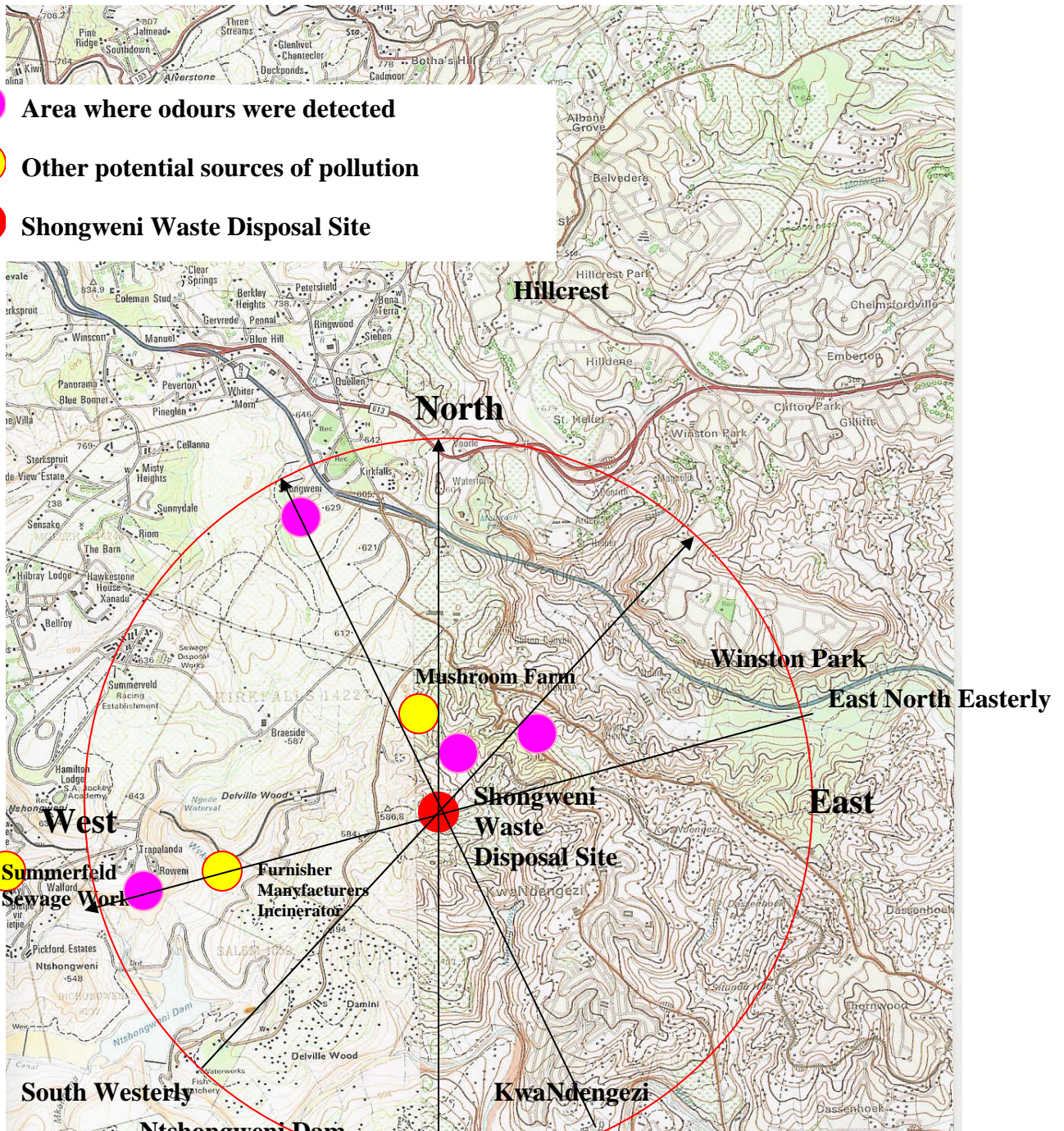
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**Tonnes of waste Landfilled at Shongweni Hh (Low Hazardous) Landfill Site
(October 1997 - September 1999)**

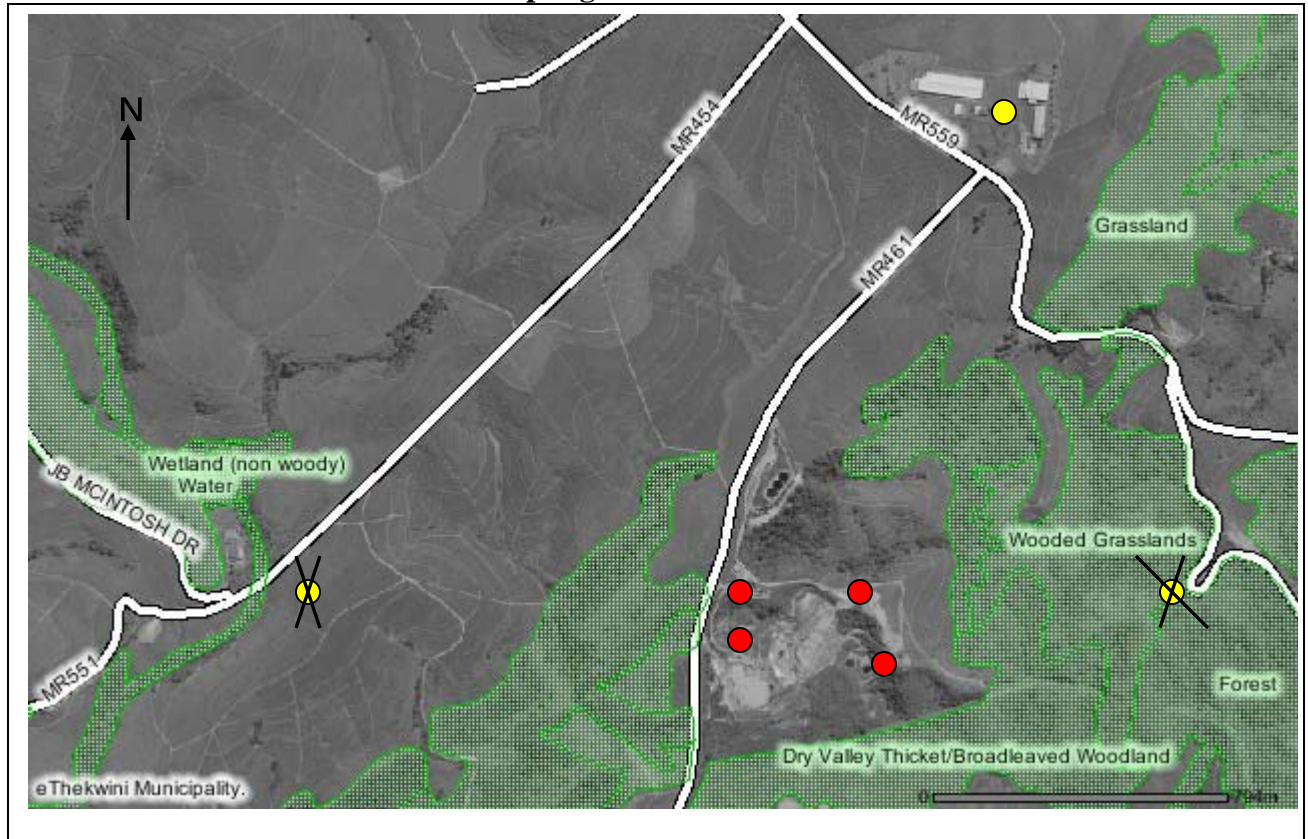


2.2 Relative Location of Site

- Area where odours were detected
- Other potential sources of pollution
- Shongweni Waste Disposal Site



2.3 Relative Location of Air Sampling Stations



Map 2: Shongweni Waste Disposal Site Ambient Air Sampling Station Locations

- On - site Air Sampling Stations – data collected
- Off - site Air Sampling Stations – data collected
- ⊗ Off - site Air Sampling Stations - vandalized – no data collected

2.4 Climate

The average ambient temperature is 21 °C with a typical range of 8 °C. The highest temperatures occur in February with the lowest temperatures in July. The average annual rainfall is 1009 mm, and the average humidity is 80%. The prevailing wind directions of the KwaZulu-Natal coastal belt are predominately from the north east and south west. Winds from these broad sectors occur with frequencies in excess of 255 days a year. South westerly winds are generally stronger and may be accompanied by rain. Mean monthly wind speeds are lowest in May and June. Highest mean wind speeds occur in September and October, a transitional period at the end of winter. Maximum wind speeds occur in the early afternoon (14:00) and minimum wind speeds between 06:00 and 08:00. Local land/sea breezes and topographically-induced circulations are also significant wind systems in view of their effect on human climatic comfort and the dispersion or accumulation of air pollutants. Sea breezes, which are onshore north-easterly winds, blow for most of the day along the KwaZulu-Natal coast, particularly during the summer months. They strengthen the prevailing north-easterly gradient winds which are associated with typical anticyclonic circulation. They ventilate the coastal belt, and because they are associated with unstable atmospheric conditions, they favour the dispersion of pollutants. Sea breezes are known to extend inland as far as Cato Ridge and could thus move pollutants generated at the coast inland.

Land breezes develop at night and blow offshore as a north-westerly wind. They are light winds (1-2 ms⁻¹) and develop in a stable atmosphere. They combine with topographically induced winds to produce mountain-plain winds. At night, cooling leads to the development of mountain winds which blow down the longitudinal axes of the valleys. Under suitable conditions, these winds deepen during the night and overflow their interflaves, so that a sheet of cold, stable air now moves across KwaZulu-Natal towards the coast. This regional wind is known as the mountain-plain wind. It combines with the land breeze near the coast and so the offshore nocturnal wind at Durban may be a very deep stable layer.

The implications for air pollution dispersion are very important. Pollutants released in the interior of KwaZulu-Natal may travel vast distances towards the coast and because the air is stable, they are transported as thin fanning plumes for considerable distances without dispersion. By day, the circulation reverses and plain-mountain winds develop which blow from the coast to the interior. They are frequently not as well developed as their nocturnal counterparts.

Valley winds are important when considering air quality at the Shongweni Waste Disposal Site. Valley winds are diurnal winds that flow up-valley by day and down-valley at night (east to west in the morning and west to east at night at the Shongweni Waste Disposal Site). They are the result of local pressure gradients caused by differences in temperature between air in the valley and air at the same elevation over the adjacent plain or larger valley. This temperature difference, and the resulting pressure difference and airflow, reverses from day to night. During the day, the air in the mountain valleys and canyons tends to become warmer than air at the same elevation over adjacent plains or larger valleys.

One reason for the more intensive heating of the mountain valley air is the smaller volume of air in the valley than over the same horizontal surface area of the plain. The rest of the volume is taken up by landmass beneath the slopes. A valley may have only from one-half to three-fourths the volume of air as that above the same horizontal surface area of the plain.

Another reason is the fact that the mountain valley air is somewhat protected by the surrounding ridges from the general wind flow. The valley air is heated by contact with the slopes, and the resulting slope-wind circulation is effective in distributing the heat through the entire mass of valley air. As the valley air becomes warmer and less dense than the air over the plain, a local pressure gradient is established from the plain to the valley, and an up-valley wind begins.

Whereas upslope winds begin within minutes after the sun strikes the slope, the up-valley wind does not start until the whole mass of air within the valley becomes warmed. Usually this is middle or late forenoon, depending largely on the size of the valley.

The up-valley wind reaches its maximum speed in early afternoon and continues into the evening. Up-valley wind speeds in larger valleys are ordinarily from 20 to 30 kilometers per hour. The depth of the up-valley wind over the center of the valley is usually about the same as the average ridge height.

Strong up-valley winds may be quite turbulent because of the unstable air and the roughness of the terrain. Eddies may form at canyon bends and at tributary junctions. Along upper ridges particularly, the flow tends to be quite erratic. Wind speed and direction may change quickly, thus drastically affecting fire behavior.

Slopes along the valley sides begin to cool in late afternoon and, shortly after they come into shadow, cool air starts flowing downslope. Cool air accumulates in the valley bottom as more air from above comes in contact with the slopes and is cooled. Pressure builds up in the valley, causing the up-valley wind to cease. With continued cooling, the surface pressure within the valley becomes higher than the pressure at the same elevation over the plain, and a down-valley flow begins.

The transition from up-valley to down-valley flow takes place in the early night--the time depending on the size of the valley or canyon and on factors favoring cooling and the establishment of a temperature differential. The transition takes place gradually. First, a down-slope wind develops along the valley floor, deepens during the early night, and becomes the down-valley wind. The down-valley wind may be thought of as the exodus or release of the dense air pool created by cooling along the slopes. It is somewhat shallower than the up-valley wind, with little or no turbulence because of the stable temperature structure of the air. Its speed is ordinarily somewhat less than the up-valley wind, but there are exceptions in which the down-valley wind may be quite strong. The down-valley wind continues through the night and diminishes after sunrise.

Valley winds and slope winds are not independent. A sloping valley or canyon bottom also has slope winds along its length, although these winds may not be easy to distinguish from valley winds. Proceeding upstream during the daytime, the combined flow continually divides at each tributary inlet into many upslope components to the ridgetops. As the valley-wind system strengthens during the day, the direction of the upslope wind is affected.

The first movement in the morning is directly up the slopes with minor draws to the ridgetop. Then, as the speed of the valley wind picks up, the upslope winds are changed to a more up-valley direction. By the time the valley wind reaches its maximum, the slope winds, on the lower slopes at least, may be completely dominated by the up-valley wind. Along the upper slopes, the direction may continue to be upslope, because the up-valley wind does not always completely fill the valley.

Night-time down-slope winds are similarly affected. When the down-valley wind is fully developed, it dominates the flow along the slopes, particularly the lower portion, so that the observed wind direction is down-valley

3. Methodology

3.1 Risk Assessment Methodology for Waste Disposal Sites

The “Source-Pathway-Receptor” concept is used in Air Quality Risk Assessment. An understanding of the source of the hazard, the characteristics of the receptor that may be at risk from the hazard, and the means, or pathway by which the receptor may be affected by the hazard is determined.

Therefore within the risk assessment the following answers are sought:

- What are the hazards?
- What are the properties of the hazards?
- How may the receptor become exposed to the hazards?
- What is the probability of exposure?
- What is the scale of the exposure?
- How significant is the risk?
- What are the uncertainties?

The Minimum Requirements will adopt a tiered approach to finding answers to these questions. A generic tiered approach is outlined in Figure 2 (DETR et. Al, 2000). The tiered approach ensures that the level of effort is proportionate, with risk elimination and minimization being maximized.

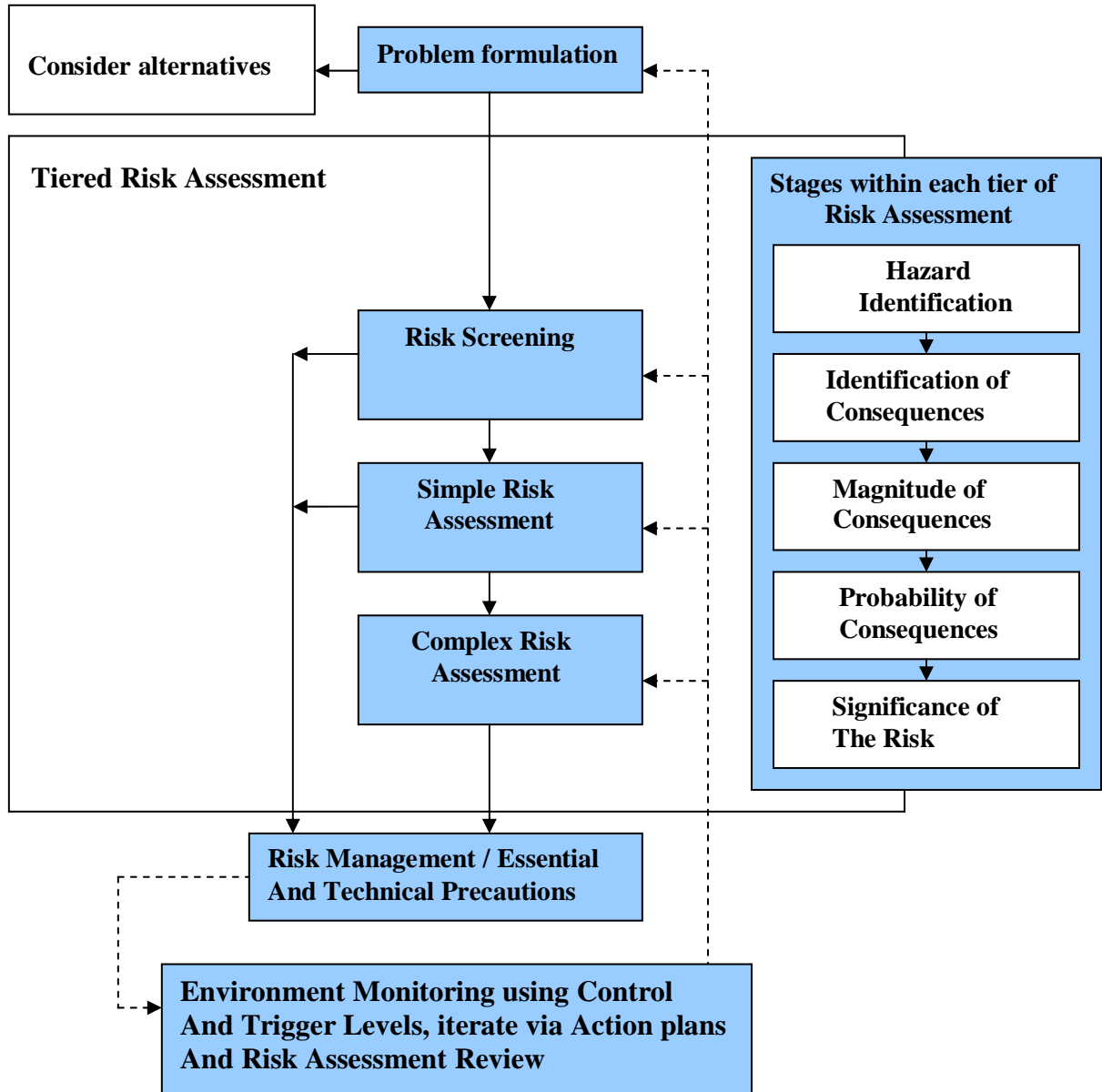


Figure 2: Conceptual approach to risk screening (from DETR et al., 2000)

The “Source-Pathway-Receptor” Concept

The “Source-Pathway-Receptor” concept is the basis for air quality risk assessment. Risk only exists if there is a plausible or identified relationship between the three individual components:

- source – i.e. the hazardous substance or material
- pathway – i.e. the mechanism by which the receptor and source can come into contact (e.g. by a hazardous event or action on site giving rise to a release of the hazardous substance or material to atmosphere or to ground)
- receptor – i.e. the entity (e.g. human, water body, ecosystem, building, etc.) that is vulnerable to the adverse effects of the hazardous substance or material

The ‘source’ for landfill is defined by the hazardous properties of the waste types and operations to which they will be subjected on an existing or proposed site. The potential air emissions sources at a landfill include:

- 1) the landfill (WDS) itself, from which airborne contaminants may be generated. Airborne contaminants on the landfill may be generated from leachate and landfill gas.
- 2) freshly disposed domestic waste that at the time of disposal is usually seven days old and aerobic decomposition has started to produce odorants or odorous pollutants and may be termed “refuse gas”,
- 3) particulate matter or dust generated from the waste itself and/or during burial and cover of the waste,
- 4) hazardous waste streams.

‘Pathways’ are the means by which the identified hazards are transferred from the source into the environment and from there to any defined ‘receptors’. For the purpose of this study the air pathway or releases to atmosphere is the only pathway being considered, i.e. releases to atmosphere such as landfill gas and particulate matter (atmospheric pathway).

Other pathways include, but not necessarily restricted to are:

- releases to the sub-surface environment such as leachate and landfill gas (sub-surface pathway)
- releases to surface water such as a leachate breakout (surface water pathway)

If humans (or animals) are exposed to hazardous substances or emissions via one or more of the above pathways, harm to their health may occur through a number of “**exposure pathways**”. For example, in the case of releases to atmosphere, exposure may be via inhalation or ingestion.

Receptors are the entities that are liable to be adversely affected by the identified hazards.

These include:

- workers on the landfill e.g. landfill equipment operators, traffic controllers, salvagers, supervisors etc.
- people or communities outside the site boundary
- properties inside the site boundary, inclusive of but not restricted to buildings.
- properties outside the site boundary, inclusive of but not restricted to buildings, livestock and crops
- ecosystems
- surface water in the vicinity of the site
- atmosphere, a receptor in regard to the risk of climate change.

If for example there is no probable connection or pathway between potential releases from a specific landfill and an environmental receptor (e.g. people outside the boundary of the site), then the situation cannot be considered to present a risk. Therefore it is said that there is no probable source-pathway-receptor relationship.

Problem Formulation (Conceptual Model)

The understanding of the problem or the hazard to which the risk assessment must be applied is the foundation of any risk assessment. A method of identifying the hazard that the air quality risk assessment is address through the development of a conceptual model of the landfill. The term conceptual model, in this case, means an understanding of the landfill, including the design and the operational principals, in its environmental setting. This understanding (conceptual model) is then used as the basis for conducting the air quality risk assessment. If there is a misunderstanding of the basic design and operations of the site the air quality risk assessment may be flawed. The conceptual model will change with time. For example, monitoring is likely to increase the knowledge of the site. Therefore, there is a need for the conceptual model to be updated as new data is gathered and interpreted. The conceptual model identifies possible sources, pathways and receptors and the processes that are likely to occur along each of the pollutant linkages. A broad range of information should be incorporated into the conceptual model:

- the site location and size
- land use, vegetation and development
- human habitation
- the landfill classification
- the landfill design
- the landfill liner design
- the age of the site
- the type of waste
- sub-surface features: the geology, geohydrology, soils, initial groundwater quality results, groundwater usage and seismic events
- water borehole / well locations
- regional and local meteorological data
- topographical information and drainage
- containment measures adopted

- proximity of buildings and developments to sites
- location of services
- future development proposals
- permeability of the waste
- methods of treatment of waste
- rate of deposition of waste
- list of chemicals used on site for the purpose of leachate and waste treatment, disinfection, laboratory analysis and pest control
- identification potential off-site airborne contaminant emission sources
- DWAF permit requirements (on existing sites)
- the results of previous and current monitoring -, i.e. leachate, surface and borehole water, methane/carbon dioxide
- control measures that have been installed or are installed, e.g. leachate treatment

A conceptual model is should be presented in a diagram indicating the various source-pathway-receptor linkages and in writing, or table-form giving the same information as in the diagram.

Air Quality Risk Assessment Framework

Risk-based Strategy

A tiered approach will be used in this strategy, where the level of detail in the risk assessment will be proportionate to the nature and complexity of the risk to be addressed.

The three tiers are:

- Risk Screening
- Simple Risk Assessment
- Complex Risk Assessment

The air quality strategy requires an understanding through risk assessment air quality through risk assessment and the development of a conceptual model for the site, i.e.:

- Assessment of potential impacts on the local environment, health and amenity; and
- The development of an Air Quality Management Plan

The Air Quality Management Plan includes:

- Management options and procedures in the case of airborne contaminants and noise
- Emissions modeling, emissions monitoring and assessment, if indicated by the Initial Conceptual Model and then the Risk Screening stage of the risk assessment.

The process stresses the:

- Importance of developing an accurate conceptual site model at the risk screening stage: based on a source-pathway-receptor approach that is continually updated as new information is collected;
- Need to screen and prioritize all actual and potential risks before quantification;

- Need to match effort and resources in evaluating potential risks to the magnitude of the environmental damage that may result from each hazard.
- Need for an appropriate level of control to manage the risk;
- Iterative nature of the process, with regular reviews being an integral part of the process.

For new landfills these issues will be dealt with in the permitting application, where it is likely that an Environmental Impact Assessment (EIA) will be required to be submitted with the application and the air quality impact assessment will be addressed within the EIA.

For an existing site, the extent of the assessment will be dependent on the Class of the Site (Section 3 of the Minimum Requirements). For those site that require assessment the sources, pathways and receptors should be identified and the location of the site must take into consideration requirements related to:

- the distances from the boundary of the site to residential and recreational areas, waterways, water bodies and other agricultural or urban sites;
- the existence of groundwater, coastal water or nature protection zones in the area;
- the topographical and meteorological conditions in the area;
- the geological conditions in the area;
- the risk of flooding, landslides or subsidence on the site; and
- the protection of the natural or cultural heritage in the area.

Tier 1 – Risk Screening

The goals of the risk screening stage:

- develop an understanding of the proposed or existing landfill in its environmental setting (the conceptual model), including the identification of possible sources of risk, pathways and potential receptors;
- Consideration of receptor sensitivity and an initial selection of the appropriate environment benchmarks (e.g. Ambient Air Quality Guidelines (DEAT) or Minimum Risk Levels (US EPA) or WHO Ambient Air Quality Guidelines);
- Consideration of the potential impact on each receptor. This can be achieved by a simple quantification or qualification process that systematically examines each source-pathway-receptor linkage and determine the potential impact. This analysis, would for each receptor, prioritize the risks and the requirements for further high priority risks to be evaluated.

The specific output from the risk screening stage should be the conceptual model identifying the nature of the site and its development. In respect of the air quality and noise the information will include:

- Nature of the waste and the source, including an initial indication of emission sources i.e. landfill gas production and emission estimates, other emission sources and emission estimates e.g. surface impoundment (leachate lagoons, vehicular emissions, fugitive emissions (dust).
- Environmental setting in which the site is located including identification of all receptors, including the global atmosphere, as a receptor of greenhouse gases;
- Initial selection of environmental benchmarks;
- Design of landfill;
- Identification of pathways to the receptor including release (emission) points/areas of landfill gas or any other airborne contaminant, e.g. “refuse gas”, dust, vehicular emissions, including emissions from flares or gas treatment systems on existing sites;

- Initial prioritization and assessment of the potential impacts at the receptors (groups of receptors);
- Estimate of emissions (e.g. particulates (dust), methane, carbon dioxide and trace components of landfill gas and “refuse gas”) and dispersion, with simple modeling or quantitative calculations;
- Recommendation for the level of risk assessment required, if any.

It must be remembered that the conceptual site model is an iterative process, the model must be updated as new information becomes available. The process should be reviewed at intervals determined by the regulator and this will depend on the proportion of the risk associated with the site. It is important that the life-time of the site be considered, i.e. pre-operational phase, operational phase and closure/completion).

Tier 2 – Simple Risk Assessment

The simple risk assessment should consist of quantitative calculations, typically solved empirically using conservative input parameters, assumptions and methods. Simple Risk Assessments will only be undertaken if the risk screening phase has indicated that further assessment is required, i.e. when the risk screening phase is insufficient to make an informed decision as to the risks associated with a particular landfill. Simple Risk Assessments can be undertaken when the potential source, pathway and receptor linkage can be defined with sufficient certainty that conservative inputs, models and assumptions may be deemed representative.

Simple Risk Assessments will generally be undertaken in less sensitive locations, where the risk screening has not identified any receptors that may be particularly susceptible to the consequence of airborne contamination arising from a site. If there is uncertainty regarding any of the source, pathway and receptor terms and an informed decision cannot be made using generic information or conservative inputs, methods and assumptions, then a complex risk assessment must be done.

The Tier 2 risk assessment examines the source-pathway-receptor linkage using quantitative data with a mixture of site specific data and predictions of a sites performance. A generic source of information is used in which landfill gas, “refuse gas”, dust generation may be predicted using more complex mathematical models with generic field data and experience being used as input. The goals of the Tier 2 risk assessments are:

- Further quantify the hazards, were composition and concentrations of airborne contaminants are quantitative calculated and generic data is used to assess surface emissions that may pose a potential risk to human health, the environment and property. The risk to human health would include not only the physiological well-being of a person, but the social and psychological well-being of the person. Therefore toxic substances and malodorous substances would be identified and quantified;
- Consideration of time scales of airborne contaminant emissions;
- Re-evaluation of air quality benchmarks;
- A site specific buffer zones (Appendix 4.3, Buffer Zones) can be established using quantitative calculation and generic data: 1) a Health Buffer Zone may be established, 2) an Odour or Nuisance Buffer Zone or Zone of Influence. The buffer zone determination may established using simple predictive dispersion modeling systems or may be determined from generic experience and data.

Tier 3 - Complex Risk Assessment

Complex risk assessment is conducted when the site details are sufficiently sensitive to warrant more detailed assessment. Site which require a high level of confidence to ensure that rational and justified decisions are made and that compliance with legal requirements are ensured. Complex risk assessment is conducted in a quantitative manner using probabilistic techniques, analytical and/or mathematical solutions.

The use of generic data is replaced by specific information gained from site specific monitoring and analysis, site investigations and operational experience of the site. The type of risk assessment tools that will be used include:

- Fault and event trees analysis
- Determination of a site specific **Priority Substance Inventory (PSI)** in which subsurface, surface and ambient sampling is conducted in order to determine the composition and concentration of airborne contaminants generated by a specific site.
- Determination of an On-Site Source Emissions Inventory (OnSSEI) in which the various sources of airborne contaminants on a particular landfill site are listed, e.g. working face, leachate dam, washbay, closed or covered areas of the site.
- Determination of an Off-Site Source Emissions Inventory (OfSSEI) in which the various off-site sources of airborne contaminants are located and listed so that impact from the specific landfill site on the airshed may be determined against impacts from other emissions sources in the area. This allows for cumulative impact to be assessed. For proposed and existing sites where little is known of other sources background emission concentrations can be determined of target compounds found in the **PSI** or may be obtained from the local authorities air monitoring database.
- On-site meteorological data is collected from a dedicated on-site Weather Station.
- Geographical Information Systems (GIS) are used to accurately map the topography of the area, for example, “simple” and “complex terrain” models are too generic and are generally only used in Simple Risk Assessments.

Sophisticated models may then be “locked” by site specific analytical data from the 3 site specific inventories (PSI, OnSSEI, OfSSEI), site specific meteorological data, topography and ambient air sampling. In the case of proposed or new sites generic data from the same class of landfill e.g. Class GLB or H:H or H:h (Section 3, Document 2, Minimum Requirements for Waste Disposal by Landfill) may be used.

This generic data is used, for the new site, to “lock” the mathematical models and must originate from a site or sites located in the same geographical area. However, local meteorological data (collected on the proposed site or within a few kilometers of the site) must be used as input. GIS must be used to accurately map the local topography of the new site. It is likely that specialist assistance would be required for complex risk assessment. Many uncertainties are associated with airborne contaminants at landfills and the emphasis must be placed on best practice standards to ensure that the uncertainty of the risk is eliminated or minimized. The goals of the Tier 3 risk assessments are:

- Further quantify the hazards, where composition and concentrations of airborne contaminants are quantitatively assessed and surface emissions that may pose a potential risk to human health, the environment and property are measured. The risk to human health would include not only the physiological well-being of a person, but the social and psychological well-being of the person. Therefore toxic substances and odorants would be identified and quantified;
- Consideration of time scales of airborne contaminant emissions;
- Re-evaluation of air quality benchmarks;
- Exposure assessment – which refines the understanding of the receptor, the characteristics of the exposed population, verifies the models’ emission and dispersion predictions, verifies the models’ pathways to the population and verifies the concentration or dose to which the population may be exposed.
- Air Quality Risk evaluation – an assessment of the significance of the risk and the acceptability, which will provide a sound foundation for decision in the management of the risk of the site.
- A site specific buffer zones (Appendix 4.3, Buffer zones, DWAF, Minimum Requirements) can be established: 1) a Health Buffer Zone may be established, 2) an Odour or Nuisance Buffer Zone or Zone of Influence.

The air quality risk assessment is iterative. Therefore it is repeated at regular intervals defined within the Air Quality Management Plan. Therefore the air quality risk assessment becomes a tool whereby the regulator can monitor the site's air quality management plan and the operator can use the process as a sound foundation for the implementation of mitigation measures required in the sites risk management plan.

An Air Quality Monitoring Plan embodied in the Air Quality Risk Management Plan may be established which monitors the actual ambient emissions from the landfill. These sampling stations would be appropriately located on the toe of the landfill and on the perimeter of the buffer zones. This will allow the regulator, the operator, the public and other stakeholders (the Monitoring Committee) to monitor the adequacy of the established site-specific buffer zones and/or the zone of influence. Therefore if the risk assessment process is soundly executed from the beginning, and therefore buffer zones and zones of influence are accurately established, the monitoring plan will effectively assess compliance with the management plan.

A fourth phase of the risk assessment may be introduced on closure of the and is often term “**Tier 4 – Closure to Completion**”, in which the potential of emissions of airborne contaminants from the site has been mitigated or removed; or the site has been restored and is not of detriment to the locality and can be further developed.

Air Contaminant Monitoring at a Waste Disposal site

By volume, landfill gas typically contains 40% to 60% methane and 40% to 60% carbon dioxide. Landfill gas also includes small amounts of nitrogen, oxygen, ammonia, sulphides, hydrogen, carbon monoxide and non-methane organic compounds (NMOCs) such as trichloroethylene, benzene and vinyl chloride. If not properly controlled, landfill gas can give rise to flammability, asphyxiation and toxicity hazards as well as vegetation dieback. The sampling of the major components of landfill gas, viz. methane and carbon dioxide do not fall in the scope of this section of this document, they are dealt with in Section 11.5.5, Gas Monitoring of the Minimum Requirements.

More than 200 trace components have been reported in landfill gas, which is anaerobically produced. However, other airborne contaminants may be released from a landfill depending on the class of the landfill site and therefore the waste streams disposed of. For example, freshly deposited domestic or general waste will give rise aerobically produced “refuse gas” that may be largely responsible for odorous emissions from a landfill that accepts general waste.

Priority Gaseous Trace Components

The composition of the gases found in “refuse gas” are different to those found in landfill gas. The gases found in landfill gas and “refuse gas” include higher alkanes and alkenes, cycloalkanes and cycloalkenes, cyclic aromatic and polycyclic aromatic hydrocarbons and their derivatives, alcohols, aldehydes, ketones, esters, organic acids, organosulphur compounds, organohalogens and oxygenated compounds. However, many of these substances detected are at such low concentrations and/or have low toxicity and/or are not odour producing substances (odorants), therefore they will have very little impact on human health, the environment or amenity. Landfill gas will collect volatile substances from the waste, e.g. chlorinated solvents. Hydrogen sulphide will be produced by anaerobic microbial action if the waste contains significant amounts of sulphate and vinyl chloride may be produced by anaerobic microbial action on chloroethanes in the waste. Therefore for the purpose of the Risk Screening (Tier 1) and Simple Risk Assessment (Tier 2) stages of the air quality risk assessment Generic Priority Substance Inventory (GPSI) may be used. These GPSI is reviewed from time to time and a new listing may be published, as new, more representative information becomes available in South Africa and as new and as more accurate testing techniques are developed. Within the first two tiers of risk assessment, models such as the full GasSim model (Environmental Agency, 2002a) may be used that includes default values for trace components of landfill gas in the UK. It hoped that within the next four years that a range of values of trace components in landfill gas will become available and the model used for this purpose may be “locked” by default values for South Africa.

In the case of Tier 3, Complex Risk Assessment, on existing sites, the model by be “locked” with values from a site specific Priority Substance Inventory (PSI), as trace components are actually measured in the landfill gas and on the surface of the site.

Other substances may need to be identified and quantified on a site-specific basis. Examples of additional determinands are listed in Table 2. Table 3 indicates the preferred methods of monitoring priority trace components. An approved methodology should be used and have been developed by NIOSH, USEPA, OHSA and BS-EN.

Gaseous emissions will only be considered in the determination of composition and concentration of landfill gas and “refuse gas”. Gaseous emissions from landfill gas are unlikely to be a significant source of heavy metals. The exceptions are mercury that has a significant vapour pressure at ambient temperature and can form volatile derivatives, and arsenic that may form arsine gas (AsH_3) under certain conditions. Under certain circumstances some landfill gas may have large quantities of dust or aerosol. A separate sample should be drawn through a simple filter to estimate the mass of any likely contribution from particulates that may pass through the sorption tube.

Particulate Matter (Dust)

Particulate Matter (Dust) sampling is conducted using direct reading instruments or NIOSH, USEPA or OHSA approved methodology in which the particulates are collected onto filters and gravimetrically analysis with composition being determined to establish heavy metal and free silica (alpha-quartz) concentrations in ambient air. Asbestos sampling may also be necessary on some site were asbestos is actively disposed or when the risk assessment indicates that a potential asbestos hazard exists. These substances are included in the site specific Priority Substance Inventory (PSI) if detected.

Table T- 1: Generic Priority Substance Inventory found in landfill gas and “refuse gas”

Priority Trace Component	CAS No.	Potential Impact	Category
Benzene	71-43-2	Health	Aromatic Hydrocarbon
Toluene	108-88-3	Health	Aromatic Hydrocarbon
Ethyl Benzene	100-41-4	Health	Aromatic Hydrocarbon
Xylene (all isomers)	108-38-3, 95-47-6, 106-42-3	Health & Odour	Aromatic Hydrocarbon
Trimethyl benzenes (all isomers)	526-73-8, 108-67-8, 95-63-6	Health & Odour	Aromatic Hydrocarbon
2-butoxy ethanol	111-76-2	Health	Oxygenated hydrocarbon
1,3-butadiene	106-99-0	Health	Aliphatic Hydrocarbon
1-pentene	109-67-1	Health	Aliphatic Hydrocarbon
Chloroethane (ethyl chloride)	75-00-3	Health	Halogenated Hydrocarbon
Chloroethene (vinyl chloride)	75-01-4	Health	Halogenated Hydrocarbon
1,1 dichloroethane	75-34-3	Health	Halogenated Hydrocarbon
1,1 dichloroethene	75-35-4	Health	Halogenated Hydrocarbon
1,2 dichloroethene	540-59-0	Health	Halogenated Hydrocarbon
Trichloroethene (trichloroethylene)	79-01-6	Health	Halogenated Hydrocarbon
Tetrachloroethylene	127-18-4	Health	Halogenated Hydrocarbon
Tetrachloromethane (carbon tetrachloride)	56-23-5	Health	Halogenated Hydrocarbon
Dichloromethane (methylene chloride)	75-09-2	Health	Halogenated Hydrocarbon
Ethanal (acetaldehyde)	75-07-0	Health	Organosulphur
Methanal (formaldehyde)	50-00-0	Health	Organosulphur
Hydrogen Sulphide	7783-06-4	Health & Odour	Organosulphur
Carbon disulphide	75-15-0	Health & Odour	Organosulphur
Methanethiol (methyl mercaptan)	74-93-1	Health & Odour	Organosulphur
Ethanethiol (ethyl mercaptan)	75-08-1	Health & Odour	Organosulphur
1-propanethiol (isopropyl mercaptan)	107-03-9	Health & Odour	Organosulphur
1-butanethiol (butyl mercaptan)	109-79-5	Health & Odour	Organosulphur
Dimethyl sulphide	75-18-3	Health & Odour	Organosulphur
Butyric Acid	107-92-6	Health & Odour	Volatile fatty acid
Valeric Acid	109-52-4	Health & Odour	Volatile fatty acid
Caproic Acid	142-62-1	Health & Odour	Volatile fatty acid
Propionic Acid	79-09-4	Health & Odour	Volatile fatty acid
Ethyl butyrate	105-54-4	Health & Odour	Oxygenated Hydrocarbon
Limonene	5989-27-5	Health & Odour	Terpene Hydrocarbon
p-cymene	99-87-6	Health & Odour	Terpene Hydrocarbon
a-pinene	80-56-8	Health & Odour	Terpene Hydrocarbon
Methyl Ethyl Ketones (MEK)	78-93-3	Health	Ketone
Methyl Isobutyl Ketones (MIBK)	108-10-1	Health	Ketone
1,5 diaminopentane	462-94-2	Health & Odour	Amine
1.4 butanediamine	333-93-7	Health & Odour	Amine
Mercury (as Hg)	7439-97-6	Health	Inorganic compound
Arsenic (As)	7440-38-2	Health	Inorganic compound
Ammonia	1336-21-6	Health	Inorganic compound

Table T- 2: Additional prioritized trace components

Priority Trace Component	CAS No.	Potential Impact	Category
PCDDs and PCDFs	NA	Health	Oxygenated Hydrocarbon
Carbon Monoxide	630-08-0	Health	Inorganic compound
Ozone	10028-15-6	Health	Inorganic compound
Sulphur Dioxide	7446-09-5	Health	Inorganic Compound

Table T-3: Preferred methods of monitoring priority trace components

Priority Trace Components	Sampling Method	Monitoring Method
Speciated NMOC's (non-methane organic compounds) - Table 1 compounds except those listed below	Dual solid sorbent	ATD-GC-MS
Aldehydes	Reactive Sorbent or dual solid sorbent	HPLC
Ammonia	Reactive Sorbent	Visible/UV Spectrophotometry
Butyric Acid and other volatile fatty acids	Dual solid sorbent	
Hydrogen Sulphide	Reactive solid sorbent or Direct site measurement	Visible/UV Spectrophotometry Hand-held instrument/ Direct-reading Instrument
Arsenic	Reactive solid sorbent	ICP-MS/AAS
Mercury	Reactive Solid Sorbent	ICP-MS/CV-AAS
PCDDs and PCDFs	Solid Sorbent	GCS-HRMS
Carbon dioxide	Gresham Tube	Laboratory GC Direct-reading Instrument
Ozone	Reactive Solid Sorbent	Visible/UV Spectrophotometry
Sulphur Dioxide	Reactive Solid Sorbent	Visible/UV Spectrophotometry

Air Quality Monitoring Plan

An air quality monitoring and sampling plan should be developed as a result of the conceptual model and as part of the Air Quality Management Plan. Air Quality Monitoring includes:

- Source Monitoring
- Surface Emissions Monitoring
- Combustion Emissions Monitoring
- Ambient Air Quality Monitoring
- Meteorology Monitoring

Source Monitoring

Source monitoring is conducted to determine quantity and quality (concentration and composition) of the gas in each cell of the landfill site. The routine monitoring of the gas is done using direct-reading portable hand-held instruments. These instruments measure the bulk components of the gas, e.g. methane and carbon dioxide, and the associated physical parameters (flow rate, atmospheric pressure, temperature etc.). Section 11.5.5, Gas Monitoring, Document 2, Minimum Requirements for Waste Disposal by Landfill outlines the monitoring of bulk gases (methane and carbon dioxide) and associated physical parameters. Source monitoring in the context of Air Quality deals with the bulk and the trace components of landfill gas.

Lateral migration or subsurface migration and bulk component sampling that deals with the movement of landfill gas below the surface (subsurface) is dealt with in Section 11.5.5, Gas Monitoring of the DWAF Minimum Requirements. However, the lateral migration of gas both on-site and off-site can impact on the health and safety of both on-site receptors (workers) and off-site receptors (community), the environment and amenities. Therefore it forms an integral part of the health risk assessment for a particular site and should be referred to in the Air Quality Management Plan.

A large number of trace substances are present in landfill gas. These trace components can contribute significantly to the odour and potential health and/or environmental impacts of the landfill gas. Therefore landfill gas should be appropriately sampled and analyzed as indicated above. The monitoring required is less frequent and from fewer locations than for bulk components of landfill gas and lateral migration. However, the sampling points must be selected so that the gas evaluated is representative of a particular section of the landfill. Sampling should be done when steady state conditions have been reached in the sampling structure. Sampling can be conducted from the main gas line of a gas collection system or from appropriately designed subsurface gas probes placed in the waste body, monitoring wells and boreholes. The components detected in landfill gas will form part of the site specific Priority Substance Inventory (PSI).

Surface Emissions Monitoring

The monitoring of gas emission from the surface of the landfill is undertaken to determine the rate at which the gas is escaping from:

- the capped surface of the site;
- the temporary capped areas;
- the uncapped (e.g. working face) of the site.

The capped and uncapped surface sampling is particularly important when consideration is being given to the global warming potential of a specific site.

The working face surface sampling also provides information of the composition and concentration of gases (sometimes referred to as “refuse gas” in this document) beginning released from areas where freshly deposited waste has been disposed. The substances detected in this sampling are used to compile the Priority Substance Inventory (PSI) for a site. Therefore the surface emissions monitoring is used:

- to establish uncontrolled release airborne contaminants and their impact on human health, the environment and amenities.
- to establish the uncontrolled release of airborne contaminants and their impact on global warming;
- in the establishment of portion of the site specific Priority Substance Inventory;
- to check the integrity of a gas management system, if one exists.

The monitoring of surface emissions may be undertaken using a variety of field techniques, with the isolated flux chamber being the most common technique. A flux chamber is an enclosed chamber that is used to measure gas emissions, over specified intervals, above a specific, small area of landfill surface. However, new techniques have been developed whereby open-path spectrometers are now used to estimate the emission rates from industrial and agricultural sources. Traditional methods are both tedious and costly when a large area is to be monitored, such as the surface of a landfill. Recently, several researchers have conducted field studies using open path spectrometers in

conjunction with dispersion modeling software to estimate the emission rates from point, area and, volume sources.

This technique is particularly useful when considering emissions from capped and uncapped areas on a landfill, as large areas, not small areas as used in flux chamber techniques, can be monitored.

Surface Sweep sampling using PID or FID is currently employed in a “walkover” survey of the site to determine suitable locations for the flux chambers. This again is time consuming and tedious and the open-path instrument which consists of a laser head and a remote retro-reflector can define a path across the landfill (up to several hundred metres, maximum 1000m). This device is capable of measuring such gases as methane concentrations to below ambient levels (i.e.: in the order of 1 ppm) and hydrogen sulphide at concentration below the odour threshold (i.e. in the order of 1 ppb).

Combustion Emissions Monitoring

Landfill gas is collected and treated on some sites in South Africa. The gas is utilized where possible and if not, it may be flared. An operation standard and emission standard needs to be developed for such combustion systems in accordance with the DEAT, Air Quality Management Bill. These operation standards and emission standards will be determined by the Department of Environmental Affairs and Tourism and will be outlined in the permit/license issued for such a combustion system.

Ambient Air Quality

The monitoring of ambient air quality within and around landfill sites is important not only to evaluate actual exposure but also to determine the adequacy of the buffer zone of a site and the zone of influence. The Priority Substance Inventory (PSI) is used to determine what substances should be monitored in ambient air and the following aspects are considered:

- human health
- environment (flora, fauna, surface water, soil, crops etc.)
- amenities

The emphasis being placed on the sampling of:

- toxic gaseous substances (carcinogens and non-carcinogens)
- odorants (odour-forming substances)
- particulates (dust)
- hazardous biological agents

Toxic Gaseous Substances

Toxic gaseous substances are monitored in ambient air as outlined in (Table 2) of this section. The substances are identified in the Generic Priority Substance Inventory (GPSI) (Table 1) or in a site specific Priority Substance Inventory (PSI) derived from site specific sampling and analysis of landfill gas, leachate emissions sampled, for example, in leachate wells, surface emissions (working face or uncapped and capped area emissions).

Odorants

Odorants are also defined in the GPSI (Table 1) or derived from a site specific PSI. An odour may be defined as (Environmental Agency 2002i) as:

- that characteristic property of a substance which makes it perceptible to the sense of smell; and
- a smell whether pleasant or unpleasant; fragrant or stench.

The perceptibility of an odour depends on the concentration of that substance in the atmosphere and for each substance there is a limiting concentration in air, below which the odour is not perceptible. This is known as the *odour threshold* of that substance.

Odour nuisance comprises two factors:

- odour concentration; and
- the length of time the receptor may have been subjected to this concentration.

The offensiveness of an odour is highly subjective. The judgement on the offensiveness of an odour dependent upon factors such as race, sex, age, occupation, health and previous history of odour experiences. Odours are often expressed in odour units (ou/m³), with one odour unit being the concentration at which 50% of an odour panel detects the odour. The monitoring of odour is undertaken to fulfill a number of differing objectives including:

- the development of input data for risk assessment and predictive dispersion modelling;
- development of ambient air and gas monitoring plan;
- prioritization of odour sources for mitigation or abatement;
- selection of odour abatement measures; and
- assessment of the effectiveness of odour abatement and mitigation measures e.g. buffer zones and zones of influence.

Odour assessments should be carried out, as far as possible, in a distal to proximal direction i.e. from the furthest point away from the site relative to the wind direction towards the site boundary or onto the site itself, and in a proximal to distal direction up wind of the site. The persistence of the odour, together with its location from the site boundary, should be noted. Subjective monitoring can be supported by techniques such as olfactometry, gas chromatography and mass spectrometry. Collected samples of air are assessed for the strength of an odour and the potential source. Olfactometry involves the presentation of the samples of air at various levels of dilution to an odour panel. As an alternative to olfactometric techniques, measurement of a selected “marker” compound in the atmosphere, such as hydrogen sulphide, may be used as a surrogate measure for odour. Portable monitoring instruments are available that can measure hydrogen sulphide down to parts per billion concentrations and a large area can be covered in a relatively short time. This technique has been used successfully to pinpoint odour and landfill gas escapes on a number of UK landfills.

It is also possible to select specific organic components to be monitored, e.g. VOCs, organosulphur compounds and aromatic hydrocarbons. (For example, measuring the concentration of the carrier gas (methane) may be an effective way of identifying the extent of the odour plume).

Odour action plans or odour abatement programmes should be developed to engage a series of specific actions or odour mitigation measures in response to a particular event or anticipated result.

Particulate Matter (Dust)

Particulate Matter (Dust) sampling is conducted using direct reading instruments or NIOSH, USEPA or OHSA approved methodology in which the particulates are collected onto filters and gravimetrically analysed with composition being determined to establish heavy metal and free silica (alpha-quartz) concentrations in ambient air. Asbestos sampling may also be necessary if some site where asbestos is actively disposed or when the risk assessment indicates that a potential asbestos hazard exists. It should be noted that PM10 sampling is conducted. PM10 is particulate matter with an aerodynamic diameter of less than 10 microns. PM10 sampling is conducted because it is these particles that penetrate deep into the lungs and may cause the most harmful effects on human health. It must be remembered that PM10 sampling, onto filters, is not used for heavy metal analysis. In most cases total suspended particulate sampling must be conducted if heavy metal analysis is required, the exception being cadmium.

Hazardous Biological Agents

Hazardous Biological Agents (HBAs) means a micro-organism, cell culture, or human endoparasite, whether or not genetically modified, which may cause infection, allergy, toxicity or otherwise create a hazard to human health. Therefore when referring to airborne contaminants, HBAs are included.

The potential for exposure to HBAs exist on landfill sites. Exposure to HBAs may result from direct exposure (e.g. site worker) or may be carried on particulate matter (dust) generated from the site. These HBAs can be monitored using various OHS and NIOSH approved methodologies and include such techniques as plate culture and polymerase chain reaction analysis.

Worker Personal Sampling

The monitoring of workers on landfill sites is important and The Priority Substance Inventory (PSI) is used to determine what airborne contaminants should be monitored. Personal sampling is conducted and the sampling device is placed in the “breathing zone” of the employee for an entire work shift. The Occupational Hygiene Programme which forms part of the Air Quality Management Plan and the Occupational Health and Safety Programme serves to inform the Occupational Medicine Programme what medical surveillance should be done on the landfill site workers. These Programmes serve to ensure compliance with the Occupational Health and Safety Act (Act No.85 of 1993).

The Occupational Hygiene programme recognizes, evaluates and controls the occupational health hazards associated with land filling. Therefore other aspects of occupational hygiene are considered:

- Recognition of Worker Health Hazards: Initial Worker Health Risk Assessment
- Evaluation/Measurement of Health Hazards identified in the Initial Worker Health Risk Assessment, for example:
 - Airborne Contaminants arising from waste streams or operation activities and by-products
 - Noise
 - Thermal stress
 - Ergonomic stress including visual and dermal stress
 - Hazardous Biological Agents.
- Control of Worker Hazards

This Worker Health Risk is iterative and must be updated as new information becomes available. This risk assessment should form part of the Air Quality Risk Assessment and should be identified within the Conceptual Model of the site.

Meteorological Monitoring

If an air quality management plan, odour abatement programme or odour action plan is required on a specific landfill site the following parameters should be recorded:

- Volume of precipitation (rainfall)
- Maximum and minimum temperature
- Wind speed and direction
- Barometric
- Atmospheric Pressure

Meteorological data should ideally be collected using an on-site weather station which has an automated logging capability. In some circumstances it may be appropriate to obtain some or all of this data from a local meteorological station commissioned by the SA Weather Bureau.

Monitoring and Risk Assessment of Amenity Topics

There are a number of other aspects that need to be dealt with in the overall consideration of risk on a landfill:

- noise and vibration
- litter
- birds, vermin and insects

However it is worth highlighting that:

- the overall principles of risk assessment given in this section apply
- the same single conceptual model should be used for these assessments
- the same receptors and any relevant additional receptors should be considered

The following document will assist in the assessment and monitoring of these amenity topics:

SANS 10103 / SABS 0103:2003 - The measurement and rating of environmental noise with respect to land use, health, annoyance and to speech communication.

Noise Guidance - Internal Guidance for the Regulation of Noise at Waste Management Facilities, Environment Agency, (2002d)

IPPC H3 – Horizontal Noise Guidance Part 1 ‘Regulation and Permitting’, Environment Agency (2002e),

IPPC H3 – Horizontal Noise Guidance Part 2 ‘Noise assessment and Control’, Environment Agency (2002f).

Odour Guidance - Guidance for the Regulation of Odour at Waste Management Facilities, Environment Agency, (2002g)

IPPC H4 - Horizontal Guidance for odour Part 1: Regulation and Permitting ,Environment Agency, (2002h) Assessment of Risks from Landfill Sites External Consultation April 2004 Version 1.0.

On-site Source Emissions Inventory (OnSEI) and Off-site Source Emissions Inventory (OfSEI)

On-site sources may include:

- freshly deposited wastes;
- uncapped wastes;
- caps or temporary cover materials;
- intrusive engineering work and excavation;
- leachate and leachate collection and treatment infrastructure;
- cracks, gaps, fissures and along the edges of the site capping;
- lateral migration through surrounding geology;
- landfill gas flares and engines (utilisation plant);
- landfill gas engine crank cases; and
- emissions through leakages in gas collection and distribution pipework

The site conceptual model and/or a “walkover” survey will inform the process of the development of the On-site Source Emissions Inventory (OnSEI). This is particularly important to the development of the Air Quality Management Plan. Determination of specific sources of airborne contaminants provides for control at source, which is often the most effective measure of control.

It is often important to establish an Off-site Source Emissions Inventory. The reason being is that there may be a number of other sources in an area surrounding the landfill that generate the same or similar emissions. It is necessary to determine the cumulative impact of all the sources in the area on the airshed and therefore the receptors. This cumulative impact should not be confused with **cumulative risk** associated with particular chemical substances. The **cumulative risk** is the risk of a common toxic effect associated with concurrent exposure by all relevant pathways and routes of exposure to a group of chemicals that share a common mechanism of toxicity.

Management Zones - Buffer Zones and Zones of Influence

Three distinct definitions pertaining to buffers or zones of influence (separation distances) have been included in the revised Minimum Requirements:

- 1) **Amorphous Zones of Influence:** An area of land with no identifiable shape (as opposed to for instance a concentric zone with predetermined radius). These zones are delineated as the product of the mapping of all the various zones of influence associated with a proposed land fill activity by the denoting of the worst case outer limit of each zone of influence when all such zones of influence have been superimposed. These amorphous buffer zones will be influenced by the nature of topography in the area of a landfill site and the existence of manmade features such as canals, roads, railway lines.
- 2) **Area of influence:** The area denoted on an appropriate map associated with the anticipated influence of any particular category of impact associated with a proposed landfill project. Factors such as wind dispersion modelling, plumes associated with subterranean ground water pollution and noise pollution contours will each have their own very specific areas of influence.

- 3) **Buffer zones** are areas of land separating the registered surveyed boundaries of registered landfill sites from the registered surveyed boundaries of identified sensitive land use categories (both existing or proposed) such as residential, educational, health and social activities. Buffer zones may vary in size, depending on the classification of the landfill and the nature and extent of anticipated environmental impacts associated therewith. The outer perimeters of the areas of influence of the landfill site may result in an amorphous buffer zone form. This outer perimeter will define the maximum extent of the buffer zone to be surveyed and registered in the office of the Surveyor General and Registrar of Deeds by way of servitudes or subdivided portions of land. No identified sensitive development may occur within the defined buffer zone: Provided that, at the discretion of the relevant local authority and in conjunction with the relevant state departments, non-sensitive development such as industrial or commercial activities may be permitted within the buffer zone, subject to such conditions as the relevant authorities may impose.

Buffer zones and/or zones of influence are determined by the air quality and noise impact associated with a landfill site. The air quality and noise impact are those impacts that remain largely unattenuable, unless buffer zones/zones of influence are delineated in which restricted development may be allowed around a landfill site. Two zones will be considered:

- **Buffer Zone (health buffer zone)**, an amorphous zone determined by the defined the Air Quality Risk Assessment. The outer perimeter of the zone is so determined, by use of the risk assessment tools. At this outer perimeter of the zone there will be minimal impact on or risk to human health by definition of physiological (body system) chemical stressors. The extent of the zone is defined as from the toe of the landfill to the qualitatively and/or quantitatively determined outer perimeter of the amorphous zone.

- **Zone of Influence (amenity buffer zones (odour and noise))**, an amorphous zone in which the outer perimeter ensure minimal nuisance from odour and noise to occupants of an area. This zone will be determined in the Air Quality Risk Assessment or may be predetermined within Table 11 of the Minimum Requirements.

These zones of influence will be determined by the defined Air Quality Risk Assessment and may use such tools as air dispersion modelling or Health/Odour Analysis Surveys. On new sites where buffer zones and zones of influence can be determined within the development stage, little challenge is posed, as these zones can be clearly defined within the development phase of the landfill. However, historically, there are landfill sites in South Africa which have restricted land available for the purpose of demarcation of buffer zones and zones of influence. Therefore if air dispersion modelling is used to determine these zones, the operator/owner of the landfill would have to acquire the surrounding land, and this is not always an economically viable option.

However, if Health and Odour Impact Assessments are conducted on these sensitive/existing sites then adequate zones can be demarcated. If necessary these amorphous zones can be created on the landfill site itself by, for example, rehabilitation of portion of the site or the implementation of other mitigation measures that will restrict impact. The adequacy of the amorphous zones can then be monitored within the Air Quality Management Plan (Monitoring Plan) discussed in section 6 of this section. Once the buffer zone and zone of influence have been established and demarcated on both new and existing sites then the monitoring of its adequacy may then be incorporated into the Air Quality Monitoring Plan for the site to ensure adequacy of the extent of the zones and control of emissions of airborne contaminants and noise.

3.2 Sampling and Analysis Methodology and Instrumentation used in this study

References:

1. ENVIRONMENT AGENCY (2004g) *Guidance on the Management of Landfill Gas*. Environment Agency, Bristol.
2. ENVIRONMENT AGENCY (2004c) *Guidance for monitoring of trace components in landfill gas*. Environment Agency, Bristol.

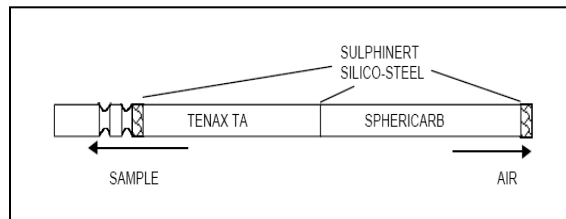
The Site-specific Air Quality Monitoring Plan included:

- Subsurface Sampling
- Near Surface Sampling
- Ambient Air Quality Sampling
- Meteorological Data Collection

3.2.1 Source or Subsurface Sampling

Subsurface Speciated Non-Methane Organic Compounds (NMOC)

Subsurface gas sampling was conducted in existing landfill gas collection wells. Speciated NMOC's were pre-concentrated by adsorption onto sequentially packed beds of two sorbents – Tenax TA and Unicarb TM (formerly known as Spherocarb) supplied by Markes International. These sorbents are held in tubes that are suitable for automated thermal desorption (ATD) and have an inert coating (e.g. Silicosteel) that prevents loss of labile species. Moisture is eliminated by purging with dry nitrogen. The concentrated compounds are thermally desorbed in the laboratory and analysed by gas chromatography–mass spectrometry (GC–MS). The 100 ml sample was drawn over the tube using a Markes International 100 ml syringe, specifically designed for the collection and analysis of landfill gas trace components. The method used for laboratory analysis was NIOSH Method Number: 2549, as recommended by the manufacturers of the sampling tubes (Markes International).



The detection limits for all substances, issued by the laboratory, is 0.001 micrograms per cubic meter ($\mu\text{g}/\text{m}^3$).

Subsurface Formaldehyde

Simple aldehydes polymerise when heated, making gas chromatography inappropriate to quantify this category of components. The recommended method is in-situ derivatization of the aldehydes with dinitrophenylhydrazine (DNPH) and laboratory analysis by high performance liquid chromatography (HPLC) based on the US Environmental Protection Agency (USEPA) Method TO-5 (USEPA), online. This method has been validated for use in environmental monitoring. Radiello sampling components, stainless steel net cartridge filled with 2,4-dinitrophenylhydrazine (2,4-DNPH) (Code 165) were placed in Markes International Silcosteel Tubes. The analysis was conducted using the Radiello prescribed methodology outlined in Annexure 1, Radiello Manual. The detection limits for formaldehyde and issued by the laboratory, is 0.05 micrograms per cubic meter ($\mu\text{g}/\text{m}^3$).

Subsurface Ammonia, Hydrogen Sulphide and Hydrogen Cyanide

An Oldham MX21000 Multigas Detector was used for the determination of concentrations of ammonia, hydrogen sulphide and hydrogen cyanide. This is a direct-reading instrument and measurements are recorded in the field. The technology employed

is electrochemical sensor technology. The instrument does not require calibration but is issue to the supplier for service, annually.

In essence, the target gas undergoes a chemical reaction, producing a current that is directly proportional to the concentration of the gas present. The sensors use very little power and display good responses to various gas concentrations over a wide range of ambient conditions. The instrument had a detection limit of 0.3 parts per million (ppm) for hydrogen sulphide, 0.5 ppm for hydrogen sulphide and 5 ppm for ammonia.

Blanks

To provide adequate quality assurance/quality control (QA/QC), a blank was issued to the laboratory together with the test samples. To ensure the tubes are not contaminated and have not been affected by environmental factors during the journey, one trip-blank per method per site is transported, unopened, from the beginning to the end of the sampling programme and subsequently analysed. If the blank for a particular trip is higher than routinely found, re-sampling may be required.

Sample handling and storage

Once the sampling was completed, the sampling (sorbent) tubes were transported in specifically designed cooler canisters to ensure that the tubes were kept at approximately 4⁰C. Once the samples were issued to the laboratory they were refrigerated pending analysis. The samples were analysed within a week of receipt of the sample. The tubes stored under refrigerated conditions were allowed to re-equilibrate at room temperature before the seals were removed for analysis. This prevents water from the laboratory atmosphere condensing inside the cold tube and interfering with the subsequent analysis. The samples were issue to Protechniks Laboratories, a SANAS Accredited Laboratory.

3.2.2 Ambient Air Sampling and Analysis

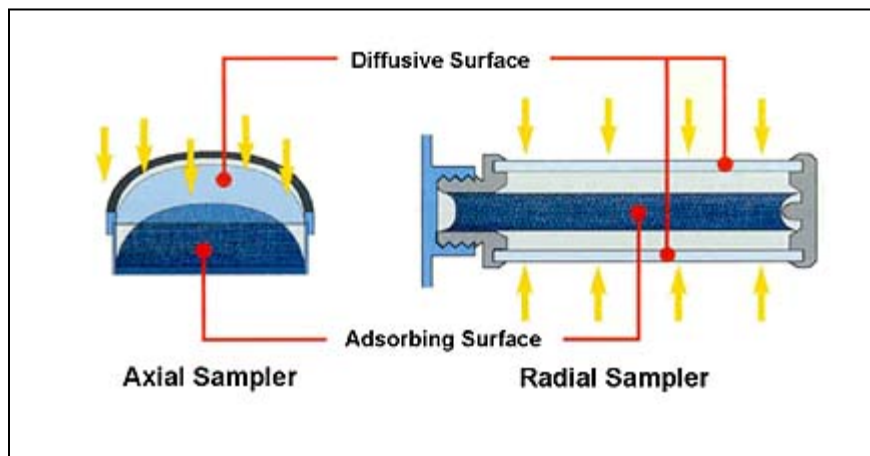
The Radiello System was the ambient sampling method of choice for non-methane organic compounds, hydrogen sulphide, ozone, formaldehyde and ammonia. The details

of the sampling and analysis methodology are attached. Composite samples were taken over a two period in accordance with sampling recommendations issued by Radiello.

Applications, Regulatory Status

The radial geometry of the Radiello samplers allows for gas sampling rates that are high and constant. The radial design allows a special diffusive surface with a large area to be located very close to a small sorbent volume, resulting in high sensitivity and a consistent sampling rate. Typical fields of use include industrial hygiene, indoor air quality, personal sampling, and environmental monitoring in urban and background areas. The analytes include benzene, toluene, xylenes (BTX), volatile organic compounds (VOCs), ammonia (NH₃), nitrogen dioxide (NO₂), sulfur dioxide (SO₂), ozone (O₃), hydrogen

fluoride (HF),
hydrogen chloride (HCl),
hydrogen sulfide (H₂S),
aldehydes and
anaesthetic gases. The
system is included in
ISO 16200-2:2000
(*Workplace air quality
- Sampling and*



analysis of volatile organic compounds by solvent desorption/gas chromatography -- Part 2: Diffusive sampling method) and conforms with CEN/TC 264 WG 11 (Ambient air quality - Diffusive samplers for the determination of gases and vapours).

Theory of a Coaxial Sampling System

The radiello unit does not rely upon any moving parts to collect a sample from indoor or outdoor ambient air. Selected atmospheric gases either adsorb or react on chemically treated material contained in a collection cartridge located behind a diffusive barrier.

After the collection cartridge is installed in the system and exposed in the field for the desired length of time, it is transported to the laboratory sealed in its glass storage tube.

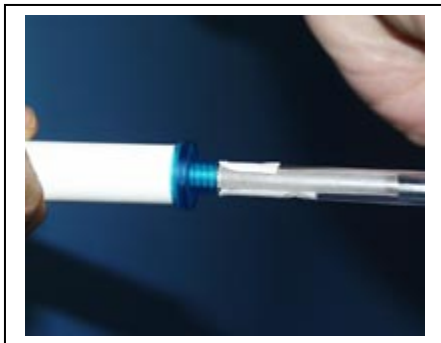
System Components

* **Supporting plate** - connects the sampler's parts and is mounted in the industrial, outdoor or indoor environment, or in an individual's breathing zone. The adapter changes the orientation of the sampler from horizontal to vertical. The horizontal sampling configuration is used for outdoor sampling.



horizontal position

- **Collection cartridge** - the type of the cartridge varies by the gases being sampled, and is housed before and after sample collection in a sealed glass storage tube.



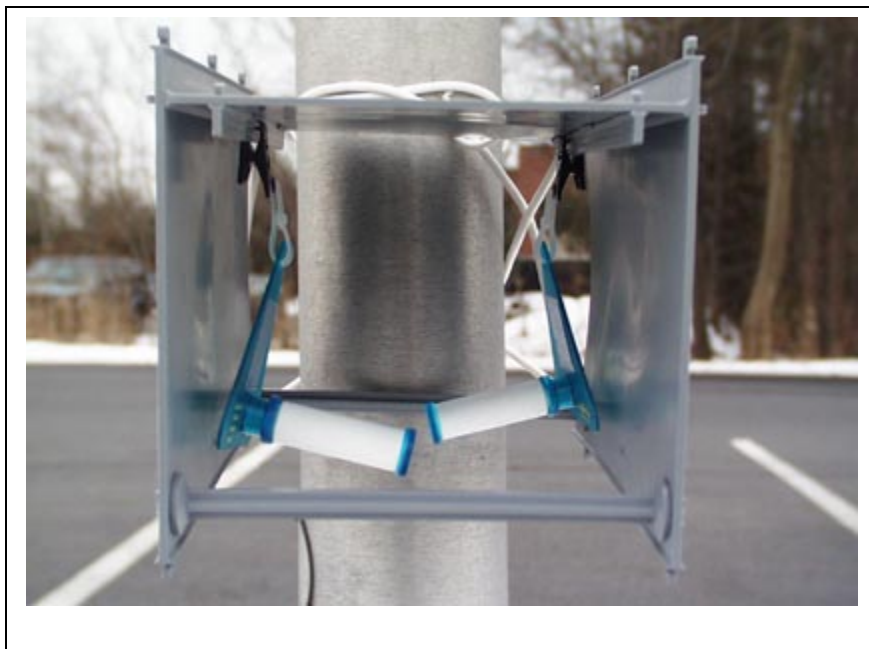
Insertion of cartridge into the
Diffusion body



Installation of sampler onto
support plate

* **Diffusive body** - restricts the type of molecules that make their way to the collection cartridge, and minimizes the sensitivity of the system to wind speed and turbulence. The

diffusive body used varies by the gases to be sampled, and is reusable.



* **Outdoor shelter** - it has been designed to be mounted easily and without any tool onto lamp-posts. Once assembled, it ensures the best compromise

between protection against bad weather and ventilation.

Blanks

To provide adequate quality assurance/quality control (QA/QC), a blank was issued to the laboratory together with the test samples. To ensure the tubes are not contaminated and have not been affected by environmental factors during the journey, one trip-blank per method per site is transported, unopened, from the beginning to the end of the sampling programme and subsequently analysed. If the blank for a particular trip is higher than routinely found, re-sampling may be required.

Sample handling and storage

Once the sampling was completed, the sampling (sorbent) tubes were transported in specifically designed cooler canisters to ensure that the tubes were kept at approximately 4°C.

Once the samples were issued to the laboratory they were refrigerated pending analysis. The samples were analysed within a week of receipt of the sample. The tubes stored under refrigerated conditions were allowed to re-equilibrate at room temperature before the seals were removed for analysis. This prevents water from the laboratory atmosphere condensing inside the cold tube and interfering with the subsequent analysis. The samples were issue to Protechniks Laboratories a SANAS Accredited Laboratory.

Particulate Matter Sampling

The instrument of choice for particulate matter sampling was a TOPAS (Turnkey Optical Particle Analysis System), which is a fixed station monitor designed to continuously record environmental PM10, PM2.5 and PM1 particles.

- Continuous on-site air quality measurement
- Reference filter for gravimetric calibration

The instrument is calibrated by the manufacturer on a six monthly basis. The last date of manufacturer calibration was the November 2003.



Meteorological Data Collection



On-site weather data was collected from April 2004 to September 2004 using a 6153 Davis Wireless Vantage Pro2 with Fan-Aspirated Radiation Shield.

3.3 Air Quality Criteria

The test results were used to determine the non-cancer and cancer risk associated with the exposure to BTEX's. The 4-step Risk Assessment Process was used:



Risk assessment is one tool used in risk management. It is the process that scientists and government officials use to estimate the increased risk of health problems in people who are exposed to different amounts of toxic substances.

Risk characterization integrates the information from the first three steps of risk assessment to develop a qualitative or quantitative estimate of the likelihood that any of the hazards associated with a chemical will be realized in exposed people.

For chemicals that cause non-cancer health effects, risks are typically characterized using a measure called the hazard index (HI). The hazard index is calculated by dividing the dose received as a result of some exposure scenario by the reference dose for a chemical:

$$HI = \text{Dose from Exposure/Reference Dose}$$

or

$$HI = \text{Exposure Concentration/Reference Concentration}$$

If the HI is greater than 1, an individual is at some risk of adverse health effects, because their dose exceeds a regulatory agency's estimate of the allowable daily intake. To characterize population risks, the number of people receiving doses greater than the reference dose is often calculated to obtain an exceedance count. Note that noncancer risk characterization does not generally involve quantitative predictions of how much someone's risk of adverse effects are increased when their exposures exceed a reference dose.

For carcinogens, individual risks are typically characterized by estimating the increased risk of cancer associated with an exposure. Risks to an exposed population are characterized by estimating the additional number of additional cancer cases that may occur.

Individual's Increased Cancer Risk = Exposure Concentration (EC) X Unit Risk Factor (URF) or Inhalation Unit Risk (IUR)

Unit Risk: The upper-bound excess lifetime cancer risk estimated to result from continuous exposure to an agent at a concentration of 1 µg/L in water, or 1 µg/m³ in air. The interpretation of unit risk would be as follows: if unit risk = 1.5 x 10⁻⁶ µg/L, 1.5 excess tumors are expected to develop per 1,000,000 people if exposed daily for a lifetime to 1 µg of the chemical in 1 liter of drinking water.

Inhalation Cancer Risk

How do you usually calculate it?

The basic equation for calculating risk from breathing a carcinogenic air toxic is:

$$\text{Risk} = \text{EC} \times \text{IUR}$$

Where:

EC = concentration of the chemical in air at the point of exposure (ug/m^3)

IUR = Inhalation Unit Risk ($\text{risk}/\text{ug}/\text{m}^3$)



16

NonCancer Hazard

What happens when multiple noncarcinogens are present?

The equation is the same – however, you usually sum over all the different noncarcinogens present in the air (note the new name for the sum)

$$\text{Hazard Index} = (\text{EC}_1)/(\text{RfC}_1) + (\text{EC}_2)/(\text{RfC}_2) + \dots + (\text{EC}_i)/(\text{RfC}_i)$$

Where:

EC_i = concentration of the i^{th} chemical in the air at the point of exposure (mg/m^3)

RfC_i = reference concentration of the i^{th} chemical in the air (mg/m^3)



16.1

Air Quality Evaluation Criteria

Air Quality Guidelines and Standards were adopted from the Air Quality Guideline published by the World Health Organization (WHO), United Kingdom – Environmental Agency (UK-EU) and the United States of America – Environmental Protection Agency (US-EPA). The ambient air quality guideline values indicate safe daily exposure levels for the majority of the population, including the very young, the elderly and susceptible individuals throughout an individuals' lifetime. South Africa's air quality guidelines are currently being revised. Reference is therefore made to air quality limits currently being proposed for adoption locally and to international 'best practice' standards. Air quality guidelines are only given for criteria pollutants. No such thresholds exist for some toxic pollutants. In the absence of such guidance reference needs to be made to other health impact criteria such as effect or environmental screening levels (EALs), reference exposure levels (RELs), inhalation reference concentrations (RfC) and unit cancer risk factors.

Table T-4: Unit risk factors from the California EPA, the US-EPA Integrated Risk Information System (IRIS) (as at December 2004) and WHO risk factors (2000)

Chemical	California EPA Unit Risk Factor ($\mu\text{g}/\text{m}^3$)	WHO Inhalation Unit Risk ($\mu\text{g}/\text{m}^3$)	US-EPA IRIS Unit Risk Factor ($\mu\text{g}/\text{m}^3$)	IARC Cancer Class	US-EPA Cancer Class ^(a)
1,1,2,2-Tetrachloroethane		$(0.6-3.0) \times 10^{-6}$	5.8×10^{-5}	3	C
1,1,2-Trichloroethane			1.6×10^{-5}	3	C
1,1-Dichloroethane	1.6×10^{-6}				C
1,2-Dichloroethane	2.1×10^{-5}	$(0.5-2.8) \times 10^{-6}$		2B	C
1,3-Butadiene	1.7×10^{-4}		3×10^{-5}	2A	B2
Acetaldehyde	2.7×10^{-6}	$(1.5-9) \times 10^{-7}$	2.2×10^{-5}	2B	B2
Acrylonitrile	2.9×10^{-4}	2.0×10^{-5}	6.8×10^{-5}	2A	B1
Arsenic, Inorganic ^(a)	3.3×10^{-3}	1.5×10^{-3}	4.3×10^{-3}	1	A
Benzene	2.9×10^{-5}	4.4×10^{-6} to 7.8×10^{-6}	2.2×10^{-6} to 7.8×10^{-6}	1	A
Bromodichloromethane	3.7×10^{-5}				B2
Carbon Tetrachloride	4.2×10^{-5}		1.5×10^{-5}	2B	B2
Chloroform	5.3×10^{-6}	4.2×10^{-7}	2.3×10^{-5}	2B	B2
Chromium VI (particulates)	1.5×10^{-1}	1.1×10^{-2} to 13×10^{-2}	1.2×10^{-2}	1	A
Formaldehyde	6.0×10^{-6}		1.3×10^{-5}	2A	B1
Methylene chloride	1.0×10^{-6}		4.7×10^{-7}	2B	B2
Tetrachloroethylene	5.9×10^{-6}			2B	
Trichloroethylene	2.0×10^{-6}	4.3×10^{-7}		2A	
Vinyl chloride	7.8×10^{-5}	1×10^{-6}	$(4.4-8.8) \times 10^{-5}$	1	A

^(a) EPA Cancer Classifications:

A – Human carcinogen.

B – Probable human carcinogen. There are two sub-classifications:

B1 – agents for which there is limited human data from epidemiological studies

B2 – an agent for which there is sufficient evidence from animal studies and for which there is inadequate or no evidence from human epidemiological studies.

C – Possible human carcinogen

D – Not classifiable to human carcinogenicity

E – Evidence of non-carcinogenicity for humans

An estimated increased excess lifetime cancer risk is not a specific estimate of expected cancers. Rather, it is a plausible upper bound estimate of the probability that a person may develop cancer sometime in his or her lifetime following exposure to that contaminant.

There is insufficient knowledge of cancer mechanisms to decide if there exists a level of exposure to a cancer-causing agent below which there is no risk of getting cancer, namely, a threshold level. Therefore, every exposure, no matter how low, to a cancer-causing compound is assumed to be associated with some increased risk. As the dose of a carcinogen decreases, the chance of developing cancer decreases, but each exposure is accompanied by some increased risk. There is general consensus among the scientific and regulatory communities on what level of estimated excess cancer risk is acceptable. An increased lifetime cancer risk of one in one million or less is generally not considered a significant public health concern. Health comparison values for cancer health effects are set at this level of risk. Cancer risks greater than one per ten thousand usually trigger actions to lower exposures. For non-carcinogenic health risks, the contaminant intake was estimated using exposure assumptions for the site conditions. This dose was then compared to a risk reference dose (estimated daily intake of a chemical that is likely to be without an appreciable risk of health effects) developed by the US EPA, ATSDR and/or NYS DOH. The resulting ratio was then compared to the following qualitative scale of health risk:

Excess Lifetime Cancer Risk

Risk Ratio	Qualitative Descriptor
equal to or less than one per million	very low
greater than one per million to less than one per ten thousand	low
one per ten thousand to less than one per thousand	moderate
one per thousand to less than one per ten	high
equal to or greater than one per ten	very high

Noncarcinogenic effects unlike carcinogenic effects are believed to have a threshold, that is, a dose below which adverse effects will not occur. As a result, the current practice is to identify, usually from animal toxicology experiments, a no-observed-effect-level (NOEL). This is the experimental exposure level in animals at which no adverse toxic effect is observed. The NOEL is then divided by an uncertainty factor to yield the risk reference dose. The uncertainty factor is a number which reflects the degree of uncertainty that exists when experimental animal data are extrapolated to the general human population. The magnitude of the uncertainty factor takes into consideration various factors such as sensitive subpopulations (for example, children or the elderly), extrapolation from animals to humans, and the incompleteness of available data. Thus, the risk reference dose is not expected to cause health effects because it is selected to be much lower than dosages that do not cause adverse health effects in laboratory animals. The measure used to describe the potential for noncancer health effects to occur in an individual is expressed as a ratio of estimated contaminant intake to the risk reference dose. A ratio equal to or less than one is generally not considered a significant public health concern. Health comparison values for noncancer health effects are set at this level. If exposure to the contaminant exceeds the risk reference dose, there may be concern for potential noncancer health effects because the margin of protection is less than that afforded by the reference dose. As a rule, the greater the ratio of the estimated contaminant intake to the risk reference dose, the greater the level of concern. This level of concern depends upon an evaluation of a number of factors such as the actual potential for exposure, background exposure, and the strength of the toxicological data.

Qualitative Descriptions for Non carcinogenic Health Risks	
Ratio of Estimated Contaminant Intake to Risk Reference Dose	Qualitative Descriptor
equal to or less than the risk reference dose	minimal
greater than one to five times the risk reference dose	low
greater than five to ten times the risk reference dose	moderate
greater than ten times the risk reference dose	high

4. Statutory Requirements

Legislation applicable to this incidence of release to the environment is embodied in:

- Environmental Conservation Act (Act 73 of 1989)
- National Environmental Management Act (Act 107 of 1998)
- National Water Act (Act 36 of 1998)
- Occupational Health and Safety Act (Act 85 of 1993)
- Health Act (Act 63 of 1977)
- Atmospheric Pollution Prevention Act (Act 45 of 1965)

The South African Department of Environmental Affairs and Tourism (DEAT) promulgated an Air Quality Act (NEMA) to introduce a comprehensive air quality management regime to the country in February 2005. The Act will supercede the current air law, the Atmospheric Pollution Prevention Act of 1965, which focuses primarily on the control industrial air emissions. The new Air Quality Act describes various regulatory tools or measures which will be made available to government to implement and enforce the air quality management plans and to achieve acceptable ambient air quality. These include:

- priority areas - air pollution "hot spots" may be identified for focused attention including, specific air quality management actions and the provision of specific regulations relating to the area;
- listed activities - the identification of "problem" processes means that they will require an atmospheric emission license before they can operate.
- Provision has been made in the Air Quality Bill for the setting of minimum standards for emissions from listed activities;
- controlled emitters - the setting of emission standards for identified "classes" of emitters (for example, motor vehicles and hazardous waste incinerators);

- control of noise - measures may be prescribed for the control of noise; and
- control of odours and dust - measures may be prescribed for the control of offensive odours meaning any smell which is considered to be malodorous or a nuisance to the reasonable person.

All pathways of potential exposure are of concern on a landfill, including groundwater, surface water, direct contact and air. While most pathways require extended periods of exposure-based risk to occur and can be minimized or eliminated by limiting site access or discontinuing the use of contaminated resources, the air pathway can have a major downwind impact where local residents and on-site workers have little choice but to breathe the air. The World Health Organizations definition of health is “Health is a state of complete physical, mental and social well-being and not merely the absence of disease or infirmity”. Therefore when considering human health the physical well-being of and individual is not the only consideration and nuisance from noise, odours and dust will also be considered in the DWAF, Minimum Requirement for Waste Disposal Sites, currently being reviewed, as it is in the National Environmental Management, Air Quality Bill. Shongweni Waste Disposal Site is a permitted by the Department of Water Affairs and Forestry (DWAF) and this requires the action for Air Quality Monitoring.

5. Test Results

The test results are attached in Tables 1 to 4.

Six Air Sampling Stations were established, three on the site and three off the site (Map 2):

Station A – ON-SITE, Boundary Adjacent to Paul’s office, Northern Boundary of Waste Disposal Site.

Station B – ON-SITE, Boundary Adjacent to Leachate Dam, Eastern Boundary of Waste Disposal Site relocated in the last two sampling periods to the North Eastern Boundary of the Waste Disposal Site.

Station C – ON-SITE, Located next to Weather Station in the waste disposal site valley towards the Western Boundary.

Station D – OFF-SITE, Located on the premises of the Mushroom Farm.

Station E – OFF-SITE, Located approximately 600 meters from the Eastern Boundary of the Waste Disposal Site.

Station F – OFF-SITE, Located approximately 700 meters from the Western Boundary of the Waste Disposal Site.

PLEASE NOTE: SAMPLING STATIONS E AND F (OFF-SITE STATIONS) WERE VANDALIZED DURING THE FIRST THREE SAMPLING PERIODS. IT DID NOT SEEM TO MATTER WHERE THEY WERE LOCATED THE SAMPLING PROBES AND STATION WERE BROKEN OR TAKEN. THEREFORE THEY WERE NOT REPLACED IN THE DECEMBER 2004 / JANUARY 2005 SAMPLING PERIOD, SINCE THIS LOSS OF EQUIPMENT AND DATA IS OF NO BENEFIT TO THE PROJECT.

The test results in Tables 1 to 4 are represented in the column headed EC (Exposure Concentration) and are expressed in micrograms per cubic meter ($\mu\text{g}/\text{m}^3$) of air. The environmental benchmark or exposure limit of choice was derived from the ENVIRONMENT AGENCY (2003a) *IPPC HI Horizontal Guidance: Environmental Assessment and Appraisal of BAT*. Environment Agency Bristol. The long-term environmental benchmark called Environmental Assessment Levels (EAL's) have been used in this case. Environmental benchmarks for both long-term and short-term effects in the receiving environment are available. Long-term effects may relate to those substances that are released continuously, frequently or over relatively long time periods. Short-term effects may relate to peak concentrations, intermittent or periodic emissions that occur over short time periods.

The Odour Thresholds, in the last column, are derived from the ILO / NIOSH list of Odour Threshold Values (OTLV), *COMPILER'S GUIDE FOR THE PREPARATION INTERNATIONAL CHEMICAL SAFETY CARDS Odour Safety Factor (O.S.F.)*

The non-cancer risk has been calculated and is tabulated in a summary table in Table 5.

The cancer-risk has been calculated and is tabulated in Tables 6 to 9. An estimated increased excess lifetime cancer risk is not a specific estimate of expected cancers. Rather, it is a plausible upper bound estimate of the probability that a person may develop cancer sometime in his or her lifetime following exposure to that contaminant.

There is insufficient knowledge of cancer mechanisms to decide if there exists a level of exposure to a cancer-causing agent below which there is no risk of getting cancer, namely, a threshold level. Therefore, every exposure, no matter how low, to a cancer-causing compound is assumed to be associated with some increased risk. The highest or "worst-case" Unit Risk Factor (URF) or Inhalation Unit Factor (IUF) was chosen from those listed by California EPA, WHO or USEPA IRIS and the excess lifetime cancer risk was calculated. To ensure that additive risk would be taken into account the excess lifetime cancer risk calculated for each carcinogen (cancer-forming substance) were summed. The cancer risk has been calculated and summarized in Table 10.

6. Evaluation of Results

6.1 Shongweni Priority Substance Inventory

The Shongweni Waste Disposal Site's Priority Substance Inventory (PSI) was compiled from subsurface and surface sampling of trace components conducted since 1998. The Shongweni PSI is tabulated below in Table T-5:

Table T-5: Shongweni Waste Disposal Site Priority Substance Inventory

Priority Trace Component	CAS No.	Potential Impact	Category
Benzene	71-43-2	Health	Aromatic Hydrocarbon
Toluene	108-88-3	Health	Aromatic Hydrocarbon
Ethyl Benzene	100-41-4	Health	Aromatic Hydrocarbon
Xylene (all isomers)	108-38-3, 95-47-6, 106-42-3	Health & Odour	Aromatic Hydrocarbon
Trimethyl benzenes (all isomers)	526-73-8, 108-67-8, 95-63-6	Health & Odour	Aromatic Hydrocarbon
1,3-butadiene	106-99-0	Health	Aliphatic Hydrocarbon
Trichloroethene (trichloroethylene)	79-01-6	Health	Halogenated Hydrocarbon
Tetrachloroethylene	127-18-4	Health	Halogenated Hydrocarbon
Tetrachloromethane (carbon tetrachloride)	56-23-5	Health	Halogenated Hydrocarbon
Dichloromethane (methylene chloride)	75-09-2	Health	Halogenated Hydrocarbon
Ethanal (acetaldehyde)	75-07-0	Health	Organosulphur
Methanal (formaldehyde)	50-00-0	Health	Organosulphur
Hydrogen Sulphide	7783-06-4	Health & Odour	Organosulphur
Carbon disulphide	75-15-0	Health & Odour	Organosulphur
Methanethiol (methyl mercaptan)	74-93-1	Health & Odour	Organosulphur
Ethanethiol (ethyl mercaptan)	75-08-1	Health & Odour	Organosulphur
1-propanethiol (isopropyl mercaptan)	107-03-9	Health & Odour	Organosulphur
1-butanethiol (butyl mercaptan)	109-79-5	Health & Odour	Organosulphur
Dimethyl sulphide	75-18-3	Health & Odour	Organosulphur
Butyric Acid	107-92-6	Health & Odour	Volatile fatty acid
Valeric Acid	109-52-4	Health & Odour	Volatile fatty acid
Caproic Acid	142-62-1	Health & Odour	Volatile fatty acid
Propionic Acid	79-09-4	Health & Odour	Volatile fatty acid
Ethyl butyrate	105-54-4	Health & Odour	Oxygenated Hydrocarbon
Limonene	5989-27-5	Health & Odour	Terpene Hydrocarbon
p-cumene	99-87-6	Health & Odour	Terpene Hydrocarbon
a-pinene	80-56-8	Health & Odour	Terpene Hydrocarbon
Methyl Ethyl Ketones (MEK)	78-93-3	Health	Ketone
Methyl Isobutyl Ketones (MIBK)	108-10-1	Health	Ketone
1,5 diaminopentane	462-94-2	Health & Odour	Amine
1.4 butanediamine	333-93-7	Health & Odour	Amine
Ammonia	1336-21-6	Health	Inorganic compound

6.2 Evaluation of Ambient Air Sampling Results – Tables 1 to 10

6.2.1 Tables 1 to 5 – Exposure Concentrations and Non cancer Risk

The only substance that was found to be above the Environmental Assessment Level (EAL) was formaldehyde. Formaldehyde was found to be in excess of the EAL during the month July 2004. However, it must be borne in mind that there were a number of bush fires and sugar fires during this period and this could account for the increase in the concentration of formaldehyde detected in ambient air. The hazard quotients (HQ) were calculated by dividing each exposure concentration (EC) measured by the EAL. These HQ were then added together to calculate the Hazard Index (HI) which is used to assess additive non cancer risk. Table 5 depicts the summary of all four sampling stations from which exposure concentrations were measured. The results indicate that there was a minimal non cancer risk in the August/September 2004 sampling period and a low non cancer risk in the July 2004, October/November 2004 and December 2004/January 2005 sampling periods.

6.2.2 Tables 6 to 10 Exposure Concentrations and Cancer Risk

The excess lifetime cancer risk calculated, not only takes into account the highest of the agencies (California EPA, USEPA-IRIS and WHO) unit risk factors (URF), but also considers that a person would be exposed, at the sampling station location, for seventy years and for twenty four hours everyday. Therefore “worst-case” scenario has been considered in this study. In July 2004 there was a moderate to low excess lifetime cancer risk at all sampling stations. This was mainly due to the increase in concentrations of Formaldehyde at all four sampling stations. During the other three sampling periods there was a low excess lifetime cancer risk. However, it is interesting to note that carbon tetrachloride concentration detected at the Mushroom Farm in the August/September 2004, October/November 2004 and the December 2004/January 2005 sampling period created the highest risk at the Mushroom Farm, with lower risk at the on-site Shongweni Waste Disposal Site sampling stations.

6.2.3 Putting Risk into Perspective

Ultimate human cancer morbidity (the ratio of sick people in a community) to all causes of the disease is 1 in 3 in America, 1 in 4 Americans of which will suffer cancer mortality (death). These figures are not dissimilar to the South African and other international figures. This in associated terms amounts to 333,333 in 1,000,000 and 250,000 in 1,000,000, respectively. When assessing cancer risk from chemical exposure we consider figures of 1 in 1,000,000 and 1 in 100,000.

This is an example issued by Santa Barbara County Air Pollution Control District. Every day, Santa Barbara County residents are exposed to toxic air contaminants from automobiles, homes, businesses, and natural sources. Many of these substances such as benzene, 1,3-butadiene, diesel soot, and perchloroethylene can cause cancer. The risk posed by these sources is called the "background" cancer risk. This is the chance that anyone living in the area will develop cancer in their lifetime.

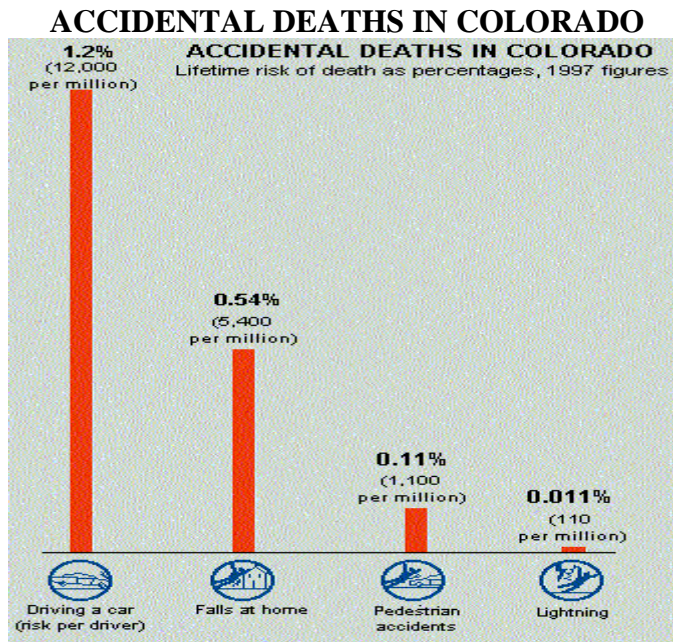
The risk from individual businesses' toxic air emissions is generally less than the background risk. The health risk estimates for these facilities calculate only the additional (above and beyond background) cancer risk caused by their emissions.

Among the largest contributors of air toxics are cars and trucks. A recent study by the South Coast Air Quality Management District reported that diesel particulate, or soot, accounted for 71% of the total cancer risk from toxic air pollution in their region. The study is one of the most comprehensive studies of urban toxic air pollution ever performed.

The estimated background cancer risks due to air pollution for some selected areas of Santa Barbara County are as follows:

Downtown Santa Barbara:	223 cancer cases per million
Santa Maria:	98 cancer cases per million
Gaviota:	47 cancer cases per million
Lompoc:	40 cancer cases per million

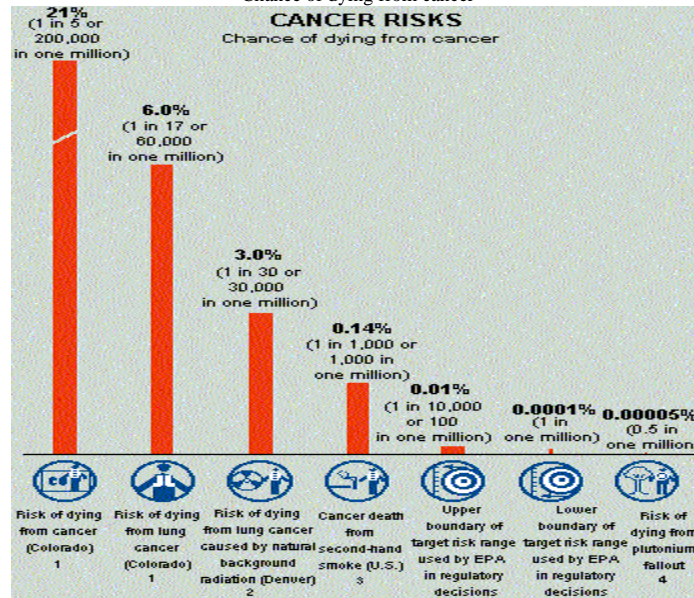
While this puts the risk from individual businesses in perspective, it does not imply that the risk from these individual businesses is acceptable or insignificant. Emissions from a particular business can create a "hot spot" where individuals can be exposed to compound risks.



Source: *Developing Comparisons for Risk Due to Plutonium and Carbon Tetrachloride Exposure*, Institute for Science and International Security, 1999.

CANCER RISKS

Chance of dying from cancer



- 1) Colorado Department of Public Health and Environment Central Cancer Registry.
- 2) *Developing Comparisons for Risk Due to Plutonium and Carbon Tetrachloride Exposure*, Institute for Science and International Security, 1999.
- 3) U.S. Environmental Protection Agency, *Respiratory Health Effects of Passive Smoking: Lung Cancer and Disorders*. Report EPA/600/6-90/006F, USEPA Office of Research and Development, 1993.
- 4) Calculated based on Radiological Assessments Corporation Task 4 Report, Rope et al, 1994 and Plutonium Risk Report, Sinclair, Grogan and Volleque, 1999.

7. Recommendations

It is recommended that in light of the promulgation of the Air Quality Management Act and the revision of the DWAF, Minimum Requirements for Waste Disposal by landfill, that the Air Quality Management Plan (AQMP), that includes the Air Quality Monitoring Plan be reviewed for the Shongweni Waste Disposal Site. This AQMP should only include air pollutants that may cause cancer risk to human health and the environment and odour, but must also include noise assessment on the boundaries of the site. The key elements of the framework are:

- Risk assessment
- Control measures
- Operational procedures
- Monitoring Plan
- Action Plan
- Closure and completion plan.

It is suggested that Lifetime Actual Daily Dose be considered on this site as the next step in the risk assessment, as this takes into account the actual dose to person and incorporates modifying factors, uncertainties and other pathways, e.g. ingestion.

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Table 5: Shongweni Ambient Air Sampling - July 2004 to January 2005 - Non-Cancer Risk

Sampling Period	Month	Jul-04	Aug/Sep 04	Oct/Nov 04	Dec 04/Jan 05
Sampling Station	Station Location	Hazard Index	Hazard Index	Hazard Index	Hazard Index
A	On-site Pauls Office	3.8	0.8	1.3	1.5
B	On-site Leachate Dam/NE Boundary	5	0.8	0.8	0
C	On-site Weather Station	4.3	0.7	1.1	1.1
D	Off-site - Mushroom Farm	3.4	0.6	0.8	1
Non-cancer Risk	National Exposure Limit (NEL)	1	1	1	1
Non - Cancer Risk	Qualitative Descriptor	LOW	MINIMAL	LOW	LOW

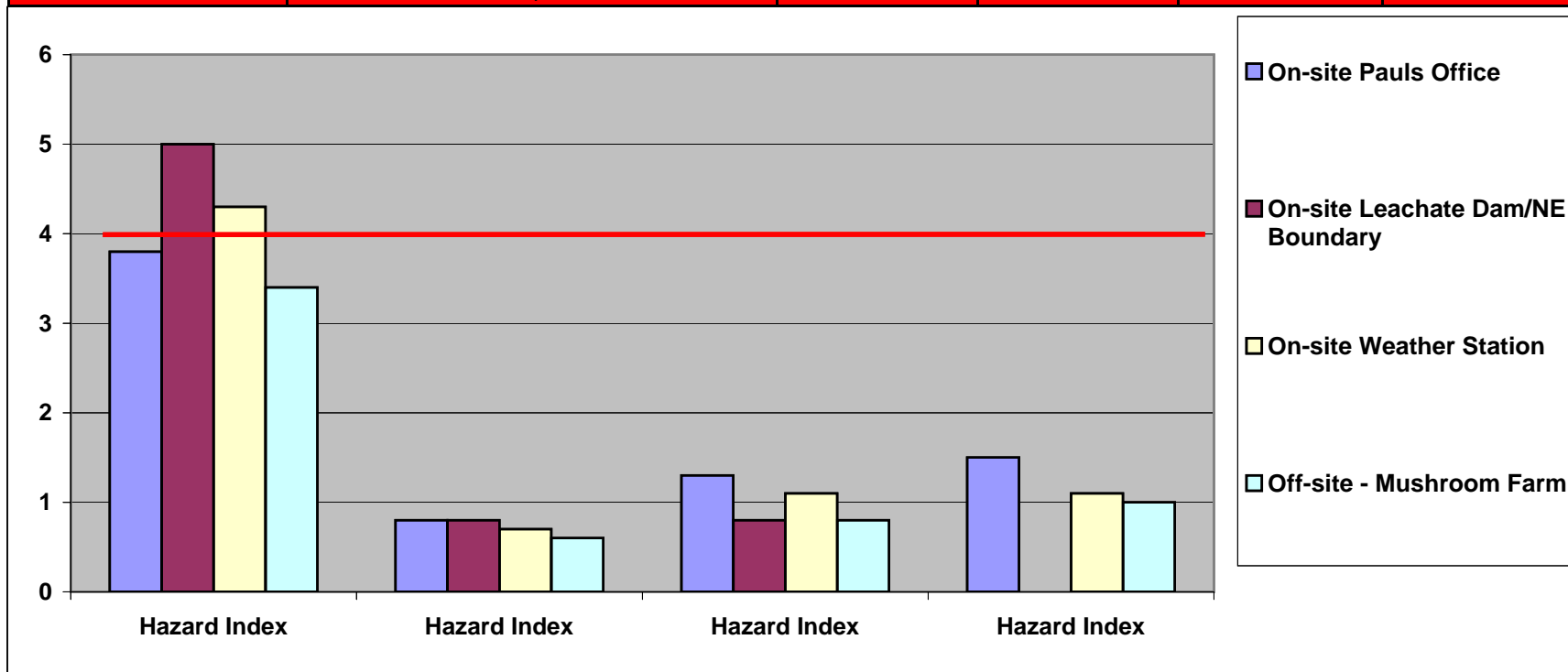


Table 10: Shongweni Ambient Air Sampling - July 2004 to January 2005 - Additive Cancer Risk

Sampling Station	Station Location	PER MILLION	PER MILLION	PER MILLION	PER MILLION
A	On-site Pauls Office	130	21	39	24
B	On-site Leachate Dam/NE Boundary	160	16	25	0
C	On-site Weather Station	190	17	35	26
D	Off-site - Mushroom Farm	170	76	63	45
Cancer Risk	Qualitative Descriptor	moderate	low	low	low

