Project done for

Lidwala Consulting Engineers SA (Pty) Ltd

Proposed Continuous Disposal of Ash at Tutuka Power Station

Air Quality Specialist Study

Environmental Impact Assessment Phase

Report No.: APP/12/LCE03A Rev1

DATE: 2014/06/30

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REPORT DETAILS

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Prepared by	T. Bird PhD (University of the Witwatersrand, Johannesburg) Reneé von Gruenewaldt (Pr. Sci. Nat.), MSc (University of Pretoria)
Notice	Airshed Planning Professionals (Pty) Ltd is a consulting company located in Midrand, South Africa, specialising in all aspects of air quality, ranging from nearby neighbourhood concerns to regional air pollution impacts. The company originated in 1990 as Environmental Management Services, which amalgamated with its sister company, Matrix Environmental Consultants, in 2003.
Declaration	Airshed is an independent consulting firm with no interest in the project other than to fulfil the contract between the client and the consultant for delivery of specialised services as stipulated in the terms of reference.
Copyright Warning	
Acknowledgements	Gerhard de Beer, from Eskom, for provision of the meteorological data.

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List of Acronyms and Symbols

$\mu g.m^{-3}$	Microgram per metre cubed
CE	Control effciency
m	metre
m^2	Metre squared
$m.s^{-1}$	Metre per second
$mg.m^{-2}.day^{-1}$	Milligram per metre squared per day
mamsl	metres above mean sea level
NAAQS	National Ambient Air Quality Standards
PM_{10}	Particulate Matter with an aerodynamic diameter of less than 10μ
$PM_{2.5}$	Particulate Matter with an aerodynamic diameter of less than 2.5μ
SA	South Africa
tpa	Tonnes per annum
TSP	Total Suspended Particles
US	United States
US-EPA	United States Environmental Protection Agency
°C	Degrees Celsius

Glossary

"**air pollution**" means any change in the composition of the air caused by smoke, soot, dust (including coal), cinders, solid particles of any kind, gases, fumes, aerosols and odorous substances.

"**ambient air**" is defined as the near surface air, external to the proposed ash disposal facility, which is not regulated by Occupational Health and Safety regulations.

"atmospheric emission" or **"emission"** means any emission or entrainment process emanating from a point, non-point or mobile source that results in air pollution.

"particulates" comprises a mixture of organic and inorganic substances, ranging in size and shape. These can be divided into coarse and fine particulate matter. The former is called Total Suspended Particulates (TSP), whilst thoracic particles or PM_{10} (particulate matter with an aerodynamic diameter of less than 10 µm) fall in the finer fraction. PM_{10} is associated with health impacts for it represents particles of a size that would be deposited in, and damaging to, the lower airways and gas-exchanging portions of the lung. TSP, on the other hand, is usually of interest in terms of dust deposition (nuisance).

1 INTRODUCTION

1.1 Background

Tutuka Power Station, a coal fired power generation facility commissioned between 1985 and 1990, is located 25 kilometres (km) north-north-east (NNE) of Standerton in the province of Mpumalanga. The power station falls within the Lekwa Local Municipality which falls within the Gert Sibande District Municipality. The study area is within an 8 km radius of the centre point of the Tutuka Power Station Site, and is made up of agricultural, mining and power generation activities.

The project involves the proposed continuous ashing at the existing ash disposal facilities at the Tutuka Power Station in the Mpumalanga Province. Tutuka Power Station currently disposes of ash in a dry (8% - 10% moisture content) form by means of conveyors, spreader and a stacker system from the station terrace to the ash disposal site. The proposed development is for a facility to which dry ashing can continue. According to the Eskom Holdings SOC Limited (Eskom) plans, the complete ash disposal site would eventually cover an area of 2 500 hectares (ha) (existing and remaining ash disposal site, and pollution control canals) and is located within 8 km of the Power Station terrace. Three alternative sites for continuous ash disposal facility have been considered in this assessment ranging in size between 534.41 and 764.94 ha.

1.2 Objectives of the report

Airshed Planning Professionals (Pty) Ltd was appointed by Lidwala Consulting Engineers SA (Pty) Ltd to determine the potential for dust impacts on the surrounding environment and human health from the proposed continuous ashing operations, with specific reference to air quality. Practical mitigation measures were considered for the operational phase of the project, including the initiation of re-vegetation of the ash disposal facility and a watering programme for dust suppression.

1.3 Legislative Framework

The environmental regulations and guidelines governing the impact of the ash disposal operations need to be considered prior to the identification of potential impacts and sensitive receptors are identified.

Air quality guidelines and standards are fundamental to effective air quality management, providing the link between the source of atmospheric emissions and the user of that air at the downstream receptor site. The ambient air quality limits are intended to indicate safe daily exposure levels for the majority of the population, including the very young and the elderly, throughout an individual's life-time. Air quality guidelines and standards are normally given for specific averaging periods. These averaging periods refer to the time-span over which the air concentration of the pollutant was monitored at a location.

Generally, five averaging periods are applicable, namely an instantaneous peak, 1-hour average, 24-hour average, 1-month average, and annual average. The application of these standards varies, with some countries allowing a certain number of exceedances of each of the standards per year.

1.3.1 National Ambient Air Quality Standards

The South African Bureau of Standards (SABS) assisted the Department of Environmental Affairs (DEA) in the development of ambient air quality standards. National Ambient Air Quality Standards (NAAQS) were determined based on international best practice for particulate matter with a diameter less than 10 micrometres (µm) (PM_{10}), sulphur dioxide (SO_2), nitrogen dioxide (NO_2) ozone (O_3), carbon monoxide (CO), lead (Pb) and benzene. The NAAQS were published in the Government Gazette (no. 32816) on 24 December 2009 (**Table 1-1**– only pollutants of concern for this assessment are presented). The particulate matter with an diameter less than 2.5 µm ($PM_{2.5}$) national ambient air quality standards were gazetted (Government Gazette no. 35463, #486) on the 29th June 2012 with lowering concentration limits over three commitment periods.

Table 1-1: South African national ambient air quality standards for particulate matter (Government Gazette numbers: 32816, 2009 and 35463, 2012)

Substance	Molecular formula / notation	Averaging period	Concentration limit ($\mu g.m^{-3}$)*	Frequency of exceedance[1]	Compliance date[2]
Particulate matter	PM_{10}	24 hour	120	4	Immediate – 31 Dec 2014
			75	4	1 Jan 2015
		1 year	50	0	Immediate – 31 Dec 2014
			40	0	1 Jan 2015
Particulate matter	$PM_{2.5}$	24 hour	65	4	Immediate – 31 Dec 2015
			40	4	1 Jan 2016 – 31 Dec 2029
			25	4	1 Jan 2030
		1 year	25	0	Immediate – 31 Dec 2015
			20	0	1 Jan 2016 – 31 Dec 2029
			15	0	1 Jan 2030

* $ug.m^{-3}$ – microgram per metre cubed.
[1]The number of exceedances of the National Ambient Air Quality limit.
[2]Date after which concentration limits become enforceable.

1.3.2 National Regulations for Dust Deposition

No criteria for the evaluation of dust fallout levels are available for the United States Environmental Protection Agency (US-EPA), European Union (EU), World Health Organisation (WHO), or the World Bank (WB). Dust deposition may be gauged according to the criteria published by the South African Department of Environmental Affairs (DEA). In terms of these criteria dust deposition is classified as follows:

SLIGHT	-	less than 250 mg.m^{-1}.day^{-1}
MODERATE	-	250 to 500 mg.m^{-1}.day^{-1}
HEAVY	-	500 to 1 200 mg.m^{-1}.day^{-1}
VERY HEAVY	-	more than 1 200 mg.m^{-1}.day^{-1}y

The South African Department of Mineral Resources (DMR) use the 1 200 milligrams per metre squared per day (mg.m^{-2}.day^{-1}) threshold level as an action level. In the event that on-site dust-fall exceeds this threshold, the specific causes of high dust-fall should be investigated and remedial steps taken.

A perceived weakness in the current dust-fall guidelines is that they are purely descriptive, without giving any guidance for action or remediation (SLIGHT, MEDIUM, HEAVY, and VERY HEAVY). On the basis of the cumulative South African experience of dust-fall measurements, a modified set of dust-fall standards is proposed, within the overall framework of the new Clean Air Legislation. Dust-fall will be evaluated against a four-band scale as presented in **Table 1-2**.

A draft copy of the National Dust Regulation was published for comment on the 27 May 2011 which states no person may conduct any activity in such a way as to give rise to dust in such quantities and concentrations that:

- The dust or dust fall, has a detrimental effect on the environment, including health, social conditions, economic conditions, ecological conditions or cultural heritage, or has contributed to the degradation of ambient air quality beyond the premises where it originates; or
- The dust remains visible in the ambient air beyond the premises where it originates; or
- The dust fall at the boundary or beyond the boundary of the premises where it originates exceeds:
    - 600 mg.m^{-2}.day^{-1} averaged over 30 days in residential and light commercial areas measured using reference method American Society for Testing and Materials (ASTM) 01739; or
    - 1 200 mg.m^{-2}.day^{-1} averaged over 30 days in areas other than residential and light commercial areas measured using reference method ASTM 01739.

A summary of available literature information on the impacts from dust on plants and animals are provided in **Appendix A**.

Table 1-2: Bands of dust-fall rates proposed for adoption

Band number	Band description label	Dust-fall rate (D) ($mg.m^{-2}.day^{-1}$, 30-day average)	Comment
1	Residential	D < 600	Permissible for residential and light commercial
2	Industrial	600 < D < 1 200	Permissible for heavy commercial and industrial
3	Action	1 200 < D < 2 400	Requires investigation and remediation if two sequential months lie in this band, or more than three occur in a year.
4	Alert	2 400 < D	Immediate action and remediation required following the first exceedance. Incident report to be submitted to relevant authority.

1.4 Study approach and methodology

The study has followed a quantitative approach, using available meteorological data and pollutants typically associated with the proposed activities to evaluate the potential for off-site impacts. A quantitative assessment was undertaken based on the evaluation of existing windblown dust from ash dump studies (Burger, 1994), together with the dispersion potential of the site and magnitude of expected impacts from the proposed activities. A more detailed methodology is provided in Section 2.

1.5 Assumptions and Limitations of this study

- An ash sample was acquired from the current Tutuka ash disposal facility. It is assumed that the particle size distribution and elemental composition of ash disposal at the new facility will be similar to that from Tutuka, when operational.
- The closet available meteorological data set, suitable for dispersion modelling, was from the Eskom Grootdraaidam monitoring station, for January 2009 to June 2012. Due to the proximity of the Grootdraaidam monitoring station to the proposed ash disposal facility alternatives and the Power Station, as well as data availability, the data was assumed to be appropriate for this assessment.
- A comprehensive list of sensitive receptors was identified via aerial photography (using Google Earth™), including farmsteads, homesteads, and nearby towns or villages. After dispersion modelling many of the identified sensitive receptors identified were shown to occur outside of the main impact zone and as such were not included in the assessment of impacts at specific sensitive receptors. A sub-set of 11 sensitive receptors were considered to be affected by the proposed ash disposal facility and impacts were assessed at these receptors.
- The dispersion model cannot compute real-time processes. The end-of-life, worst-case, area footprint for each ash disposal facility alternative was used in the model, as a conservative approach. The range of uncertainty of the model predictions could to be -50% to 200%. There will always be some error in any geophysical model, but it is desirable to structure the model in such a way to minimise the total error. A model represents the most likely outcome of an ensemble of experimental results. The total uncertainty can be thought of as the sum of three components: the

uncertainty due to errors in the model physics; the uncertainty due to data errors; and the uncertainty due to stochastic processes (turbulence) in the atmosphere.

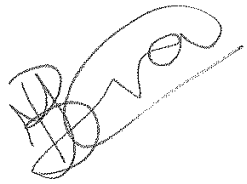
- The assumption was made that the existing Tutuka ash disposal facility would be discontinued when the proposed continuous ashing operations commence and was thus excluded in the consideration of proposed operating conditions.
- Increased life-time cancer risk was calculated at the identified sensitive receptors for arsenic, nickel and chromium.
    - Carcinogenic trivalent arsenic (As^{3+}) was assumed to account for 10% of the total arsenic in the ash sample.
        - The US-EPA unit risk factor (URF), 4.3×10^{-3}, was used to calculate the increased cancer risk, due to the fact that it is more conservative than the WHO unit risk factor.
    - There is much uncertainty in the literature regarding the species and the mechanisms through which nickel is toxic. A conservative estimate of increased life-time cancer risk was calculated assuming:
        - All forms of nickel present in the ash sample are carcinogenic.
        - The US-EPA IRIS unit risk factor (URF) of cancer as a result of exposure to nickel used was 2.4×10^{-4} per microgram per metre cubed [$(\mu g.m^{-3})^{-1}$].
    - The following important assumptions were made with regards to hexavalent chromium (Cr^{6+}) emissions and impacts:
        - All forms of Cr^{6+} were assumed to be carcinogenic. Known carcinogenic Cr^{6+} compounds include chromium trioxide, lead chromate, strontium chromate and zinc chromate. Cr^{6+} was assumed to represent only 1.1% of the total Cr in the PM_{10} fraction, as per literature.
        - Uncertainty regarding the unit risk factor (URF) for Cr^{6+} is evident in the range of 1.1×10^{-2} $(\mu g.m^{-3})^{-1}$ to 13×10^{-2} $(\mu g.m^{-3})^{-1}$ as specified by the WHO. The US-EPA URF of 1.2×10^{-3} $(\mu g.m^{-3})^{-1}$ was used in the estimation of increased life-time cancer risk compensating for conservative approach followed in the estimation of Cr^{6+} emissions and impacts.

1.6 Declaration of independence

I, Theresa Leigh Bird, declare that --

General declaration:

- I act as the independent specialist in this application;
- I will perform the work relating to the application in an objective manner, even if this results in views and findings that are not favourable to the applicant;
- I declare that there are no circumstances that may compromise my objectivity in performing such work;
- I have expertise in conducting the specialist report relevant to this application, including knowledge of the Act, Regulations and any guidelines that have relevance to the proposed activity;
- I will comply with the Act, Regulations and all other applicable legislation;
- I have no, and will not engage in, conflicting interests in the undertaking of the activity;
- I undertake to disclose to the applicant and the competent authority all material information in my possession that reasonably has or may have the potential of influencing - any decision to be taken with respect to the application by the competent authority; and - the objectivity of any report, plan or document to be prepared by myself for submission to the competent authority;
- all the particulars furnished by me in this form are true and correct; and,
- I realise that a false declaration is an offence in terms of regulation 71 and is punishable in terms of section 24F of the Act.



Theresa Leigh Bird
PhD (Wits)

30 June 2014

on behalf of

Airshed Planning Professionals (Pty) Ltd.

2 METHODOLOGY

2.1 Particulate matter impact assessment

2.1.1 Source Identification

The project includes the disposal of ash from the Tutuka Power Station at one of three proposed ash disposal facilities, within 8 km of the power station. The main pollutant of concern associated with the proposed operations is particulate matter. Particulates are divided into different particle size categories with Total Suspended Particulates (TSP) associated with nuisance impacts and the finer fractions of PM_{10} and $PM_{2.5}$ linked with potential health impacts. PM_{10} is primarily associated with mechanically generated dust whereas $PM_{2.5}$ is associated with combustion sources. Gaseous pollutants (such as sulphur dioxide, oxides of nitrogen, carbon monoxide, etc.) derive from vehicle exhausts and other combustions sources. These are however insignificant in relation to the particulate emissions and are not discussed in detail.

The establishment of the ash disposal facility will result in particulate emissions (listed in **Table 2-1**) during the following operations:

- land preparation during establishment and progression of the ash disposal facility;
- freshly exposed topsoil, as a step in rehabilitation of the ash disposal facility, that will be prone to wind erosion before establishment of vegetation; and,
- movement of vehicles across exposed soil or ash, will also be a source of pollution.

The subsequent sections provide a generic description of the parameters influencing dust generation from the various aspects identified.

Table 2-1: Activities and aspects identified for the construction, operational and closure phases of the proposed operations

Pollutant(s)	Aspect	Activity
Construction		
Particulates	Construction of progressing ash disposal facility site	Clearing of groundcover
		Levelling of area
		Wind erosion from topsoil storage piles
		Tipping of topsoil to storage pile
	Vehicle activity on-site	Vehicle and construction equipment activity during construction operations
Gases and particles	Vehicle and construction equipment activity	Tailpipe emissions from vehicles and construction equipment such as graders, scrapers and dozers

Pollutant(s)	Aspect	Activity
Continuous ash disposal		
Particulates	Wind erosion from ash disposal facility	Exposed dried out portions of the ash disposal facility
	Vehicle activity on-site	Vehicle activity at the ash disposal facility
Gases and particles	Vehicle activity	Tailpipe emissions from vehicle activity at the ash disposal facility
Rehabilitation		
Particulates	Rehabilitation of ash disposal facility	Topsoil recovered from stockpiles
		Tipping of topsoil onto ash disposal facility
	Wind erosion	Exposed cleared areas and exposed topsoil during rehabilitation
	Vehicle activity on unpaved roads and on-site	Truck activity at site during rehabilitation
Gases and particles	Vehicle activity	Tailpipe emissions from trucks and equipment used for rehabilitation

2.1.1.1 Construction phase

The construction phase is relevant as the ash disposal facility is established and during continuous ash disposal, as this would normally comprise a series of different operations including land clearing, topsoil removal, road grading, material loading and hauling, stockpiling, compaction, etc. Each of these operations has a distinct duration and potential for dust generation. It is anticipated that the extent of dust emissions would vary substantially from day to day depending on the level of activity, the specific operations, and the prevailing meteorological conditions.

It is not anticipated that the various construction activities will result in higher off-site impacts than the operational activities. The temporary nature of the construction activities, and the likelihood that these activities will be localised and for small areas at a time, will reduce the potential for significant off-site impacts. The Australian Environmental Protection Agency recommends a buffer zone of 300 m from the nearest sensitive receptor when extractive-type materials handling activities occur (AEPA, 2007).

2.1.1.2 Continuous ash disposal

Wind erosion is a complex process, including three different phases of particle entrainment, transport and deposition. It is primarily influenced by atmospheric conditions (e.g. wind, precipitation and temperature), soil properties (e.g. soil texture, composition and aggregation), land-surface characteristics (e.g. topography, moisture, aerodynamic roughness length, vegetation and non-erodible elements) and land-use practice (e.g. farming, grazing and mining) (Shao, 2008).

Windblown dust generates from natural and anthropogenic sources. For wind erosion to occur, the wind speed needs to exceed a certain threshold, called the threshold velocity. This relates to gravity and the inter-particle cohesion that resists removal. Surface properties such as soil texture, soil moisture and vegetation cover influence the removal potential. Conversely, the friction velocity or wind shear at the surface is related to atmospheric flow conditions and surface aerodynamic properties. Thus, for particles to become airborne the wind shear at the surface must exceed the gravitational and cohesive forces acting upon them, called the threshold friction velocity (Shao, 2008).

Estimating the amount of windblown particles to be generated from the proposed ash disposal facility is not a trivial task and requires detailed information on the particle size distribution, moisture content, silt content and bulk density (explained in Appendix B). Dust will only be generated under conditions of high wind speeds and from areas where the material is exposed and has dried out (US-EPA, 1995a). Annual emissions were quantified for four scenarios (Section 2.1.3.3) where mitigation practices were calculated to have control efficiencies (CE) greater than 70% (**Table 2-2**).

Table 2-2: Annual emissions for each site alternative for each of the modelled scenarios

Scenario	Particulate fraction	Annual emissions (tons per annum – tpa)		
		Alt A	Alt B	Alt C
		672.7 ha	764.94 ha	534.41 ha
Unmitigated	TSP	77 331	234 461	109 201
	PM_{10}	28 876	87 549	40 776
	$PM_{2.5}$	8 594	26 055	12 135
Re-vegetation CE = 97%	TSP	2 326	7 052	3 284
	PM_{10}	869	2 633	1 226
	$PM_{2.5}$	258	784	365
Wetting CE = 78%	TSP	17 159	52 025	24 231
	PM_{10}	6 408	19 429	9 049
	$PM_{2.5}$	1 907	5 781	2 693
Both (re-vegetation & wetting) CE = 99%	TSP	516	1 565	729
	PM_{10}	193	584	272
	$PM_{2.5}$	57	174	81

2.1.1.3 Rehabilitation

Rehabilitation is planned to occur continuously throughout the disposal of ash and will include the removal and tipping of topsoil onto the completed ash disposal facility surface areas. Dust may be generated from the dried out exposed ash surfaces before it is covered with topsoil. Once vegetation is established the potential for dust generation will reduce significantly. The tipping of topsoil and vehicle entrainment on associated unpaved roads will also result in dust generation.

It is assumed that all ash disposal activities will have ceased during closure phase, when the power station has reached end of life. Because most of the rehabilitation is undertaken during the operations,

the ash disposal facility should be almost completely rehabilitated by the closure phase. The potential for impacts after closure will depend on the extent of continuous rehabilitation efforts on the ash disposal facility.

The significance of the rehabilitation activities is likely to be linked to impacts from windblown dust from the exposed dried out ash, topsoil and vehicle entrainment during the rehabilitation process. Windblown dust is likely to only impact off-site under conditions of high wind speed with no mitigation in place. If rehabilitation as indicated takes place, i.e. vegetation cover, the impacts should be limited to be within the ash disposal facility fence-line. As vegetation cover increases, the potential for wind erosion will decrease.

2.1.2 Identification of Sensitive Receptors

The National Ambient Air Quality Standards (NAAQS) are based on human exposure to specific criteria pollutants and as such, possible sensitive receptors were identified where the public is likely to be unwittingly exposed. NAAQS are enforceable outside of power station and ash disposal facility boundaries and therefore a number of sensitive receptors were identified (**Figure 2-1**; **Table 2-3**). These sensitive receptors are farmsteads, homesteads and residential areas within the vicinity of the proposed ash disposal facility alternatives. The modelled ground-level concentrations of total suspended particulates (TSP), PM_{10} and $PM_{2.5}$ will be compared to National Standards and Guidelines at these sensitive receptors in the full Air Quality Impact Assessment.

2.1.3 Compliance analysis and impact assessment

The current air quality at the proposed site is discussed in Section 4.2. The ash disposal facility will continue to give rise to dust generation as the ash disposal operations are initiated and continue through the life of the power station. These operations, as discussed under Section 4.1, are low level release sources meaning that the dust gets generated at heights of between 0.5 and 1 metre (m) from the ash disposal facility surface.

The recommendation of a preferred alternative, from an air quality perspective, is based on longer-term predictions and pollutants with health risk (as opposed to nuisance dust-fall). Therefore although some TSP and $PM_{2.5}$ simulation results are presented, the recommendation is based on annual PM_{10} ground-level concentrations over the modelling domain and at the specific sensitive receptors.

Wind erosion, will occur during strong wind conditions when wind speeds exceed the critical threshold required to lift and suspend the ash particles. This threshold is determined by the parameters that resist removal such as the particle size distribution of the bed material, moisture content and vegetation. A typical wind speed threshold is given as 5.4 metres per second ($m.s^{-1}$) for storage piles (US-EPA, 1995a). Wind data for the proposed ash disposal facility site (2009 to 2012) indicate an average wind

speed of 3.39 m.s^{-1} and a maximum of 16.35 m.s^{-1}, where the wind speed threshold is exceeded 21% of the time.

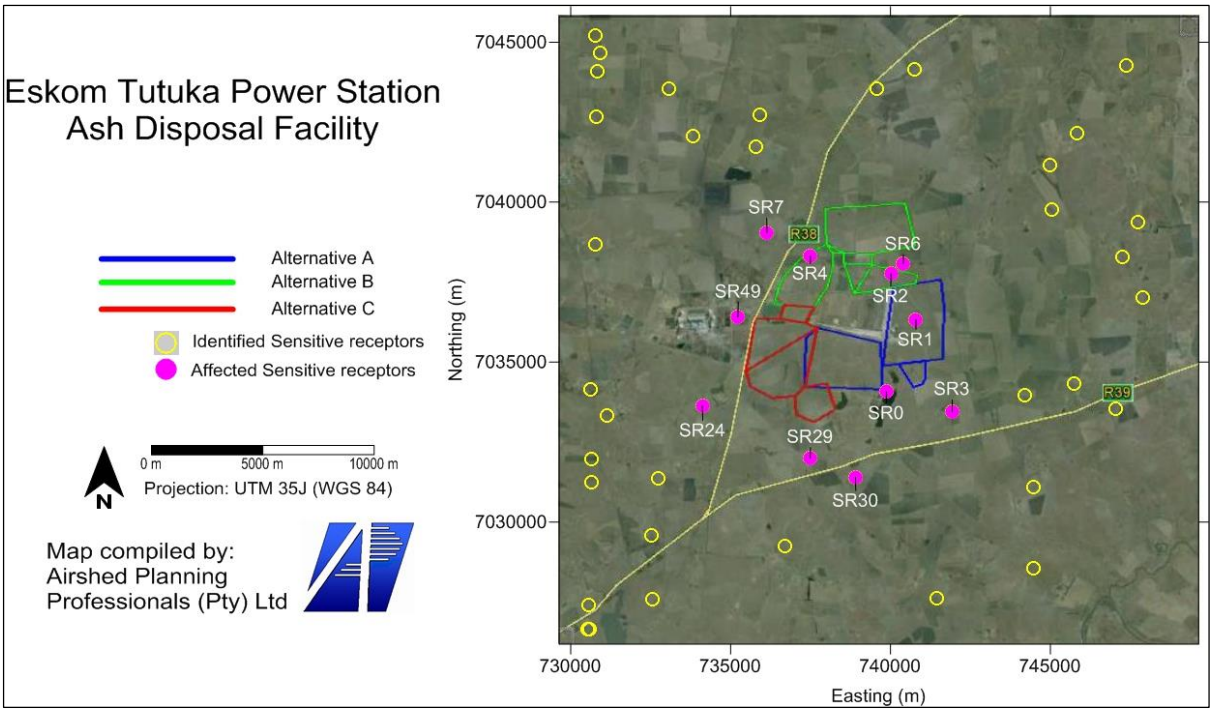


Figure 2-1: Aerial map (from Google Earth™) of the Tutuka Power Station, the proposed alternative sites for continuous ash disposal and the potential sensitive receptors (identified and affected).

Table 2-3: Location of the affected sensitive receptors (Projection: WGS 84, UTM 35J)

Receptor name	Easting (m)	Northing (m)
SR0	739871.5	7034069
SR1	740798.5	7036328
SR2	740018.4	7037760
SR3	741927.3	7033454
SR4	737495.8	7038316
SR6	740404.5	7038069
SR7	736137.7	7039051
SR24	734115.9	7033638
SR29	737486	7031992
SR30	738903	7031397
SR49	735227.8	7036405

2.1.3.1 Dispersion Model Selection and Data Requirements

Dispersion models compute ambient concentrations as a function of source configurations, emission strengths and meteorological characteristics, thus providing a useful tool to ascertain the spatial and temporal patterns in the ground level concentrations arising from the emissions of various sources.

Increasing reliance has been placed on concentration estimates from models as the primary basis for environmental and health impact assessments, risk assessments and emission control requirements. It is therefore important to carefully select a dispersion model for the purpose.

For the purpose of the current study, it was decided to use the Atmospheric Dispersion Modelling System (ADMS) developed by the Cambridge Environmental Research Consultants (CERC). CERC was established in 1986 and developed a number of computer models for pollutant dispersion, including ADMS 5. This model simulates a wide range of buoyant and passive releases to the atmosphere either individually or in combination. It has been the subject of a number of inter-model comparisons (CERC, 2004); one conclusion of which is that it tends to provide conservative values under unstable atmospheric conditions in that it predicts higher concentrations than the older models close to the source.

ADMS 5 is a new generation air dispersion model which differs from the regulatory models traditionally used in a number of aspects. The most important of which are the description of atmospheric stability as a continuum rather than discrete classes (the atmospheric boundary layer properties are described by two parameters; the boundary layer depth and the Monin-Obukhov length, rather than in terms of the single parameter Pasquill Class) and in allowing more realistic asymmetric plume behaviour under unstable atmospheric conditions. Dispersion under convective meteorological conditions uses a skewed Gaussian concentration distribution (shown by validation studies to be a better representation than a symmetric Gaussian expression).

ADMS 5 is currently used in many countries worldwide and users of the model include Environmental Agencies in the UK and Wales, the Scottish Environmental Protection Agency (SEPA) and regulatory authorities including the UK Health and Safety Executive (HSE).

Concentration and deposition distributions for various averaging periods can be calculated by ADMS 5. It has generally been found that the accuracy of off-the-shelf dispersion models improve with increased averaging periods. The accurate prediction of instantaneous peaks are the most difficult and are normally performed with more complicated dispersion models specifically fine-tuned and validated for the location. For the purposes of this report, the shortest time period modelled is one hour.

There will always be some error in any geophysical model, but it is desirable to structure the model in such a way to minimise the total error. The total uncertainty can be thought of as the sum of three components: the uncertainty due to errors in the model description of atmospheric physics; the uncertainty due to data errors; and the uncertainty due to stochastic processes (turbulence) in the atmosphere. Nevertheless, dispersion modelling is generally accepted as a valid tool to quantify and analyse the atmospheric impact of existing installations and for determination of the impact of future installations.

2.1.3.2 Meteorological Data Requirements

Hourly average wind speed, wind direction and temperature data from the Eskom meteorological station at Grootdraaidam (approximately 13.5 km south-south-west of the Tutuka Power Station) were used. Although a weather station is positioned at the current Tutuka ash disposal facility, the data was not available prior to modelling. Due to the proximity of the Grootdraaidam monitoring station to the proposed ash disposal facility alternatives and the Power Station, as well as data availability at the time of dispersion modelling, the data was assumed to be appropriate for this assessment.

2.1.3.3 Source Data Requirements

The ash disposal facility, as the focus of this report, was the only source considered during model simulations; however, the impact of all three alternatives was simulated. Due to the fact that high ambient PM_{10} concentrations (compared to SA NAAQS) were expected, generic mitigation measures were also modelled. These included wetting of the ash by water sprays and re-vegetation. A total of four scenarios were simulated:

- unmitigated (disposal of conditioned ash but allowed to dry out);
- mitigation by means of re-vegetation covering 80% of the ash disposal facility (control efficiency of: 97%);
- mitigation by means of water sprays to maintain ash moisture content at 5% (about half of the moisture content when ash deposited at disposal facility – control efficiency of: 78%); and,
- mitigation by means of re-vegetation of 80% of ash disposal facility and watering to maintain ash moisture content at 5% (control efficiency of: 99%).

All alternative sources were modelled at full size as ADMS is not capable to model real-time changes in ash disposal facility size. In addition, the ADMS model restricts the geometry of area sources (such as the ash disposal facility) to convex shapes. Therefore the footprint of each proposed alternative was sectioned into portions of equivalent total size. An ash sample from the current Tutuka Power Station ash disposal facility was obtained for analysis of particle size distribution (**Table 2-4**) and elemental content (**Table 2-5**).

2.1.3.4 Modelling Domain

The dispersion of pollutants expected to arise from the proposed operations was modelled for an area covering approximately 20 km (east-west) by 20 km (north-south). The area was divided into a grid matrix with a resolution of 200 m by 200 m. ADMS 5 simulates ground-level concentrations for each of the receptor grid points. Sensitive receptors were included in the model as additional receptors points.

Table 2-4: Particle size distribution for the ash material at the Tutuka Power Station

Size (micrometres - µm)	Fraction
2000	0.0548
1000	0.0431
301	0.0060
140	0.1791
103	0.0919
76	0.0797
56	0.0685
48	0.0318
30	0.0929
16	0.1190
10	0.0765
6	0.0591
3	0.0564
2	0.0154
1	0.0259

Table 2-5: Elemental analysis of the ash material at Tutuka Power Station

Element	Parts per million (ppm)
Arsenic (As)	9.8
Selenium (Se)	<2
Molybdenum (Mo)	2.9
Titanium (Ti)	703
Strontium (Sr)	474
Magnesium (Mg)	5509
Aluminium (Al)	16208
Nickel (Ni)	13
Beryllium (Be)	0.7
Mercury (Hg)	6.3
Manganese (Mn)	131
Iron (Fe)	19132
Chromium (Cr)	28
Vanadium (V)	34
Sodium (Na)	4007
Boron (B)	79
Calcium (Cu)	31206
Zinc (Zn)	21
Phosphorus (P)	563
Copper (Cu)	13
Lead (Pb)	5.7
Lithium (Li)	14
Cobalt (Co)	6.7
Cadmium (Cd)	0.1
Potassium (K)	926

2.2 Increased life-time cancer risk

Trace metals, some of which are potentially carcinogenic, occur in coal ash. The increased life-time cancer risk was calculated at the identified sensitive receptors in order to assist in the identification of the preferred ash disposal facility location. The South African National Cancer Registry life-time cancer risk for South African men and women (**Table 2-6**), based on histologically diagnosed cancers in 2004, provide context for the increased risk as a result of exposure to the coal ash from Tutuka Power Station. The risks contextualised in **Table 2-6** are for the types of cancer that may develop as a result of long-term exposure to the coal ash. After metal analysis of an ash sample (from Tutuka Power Station), increased life-time cancer risk was calculated for the three most abundant metals likely to result in increased risk of cancer.

Table 2-6: Life-time risk of three types of cancer for South African men and women (NHLS-NCR, 2004)

Cancer type	All men	All women
Lung cancer	1 in 79	1 in 219
Naso-oropharynx	1 in 358	1 in 1355
Oesophogeal	1 in 107	1 in 206

2.2.1 Trivalent Arsenic

Arsenic and its compounds are ubiquitous in nature, exhibiting both metallic and non-metallic properties. Arsenic is most commonly found in nature with sulfides of ores of lead, copper, nickel, antimony, cobalt and iron. The most prevalent oxidation states of arsenic include the trivalent (As^{3+}) and pentavalent (As^{5+}) forms. The more toxic trivalent arsenic form, i.e. arsenic trioxide, is introduced into nature mainly as a result form industrial activities including the smelting of ores. Pentavalent arsenic compounds are generally considered to be less toxic and are most frequently found naturally.

Arsenic is released to the atmosphere from both natural and anthropogenic sources. The principal natural source is volcanic activity, with man-made emissions mainly arising from the smelting of metals, the combustion of fuels (especially low-grade brown coal) and the use of pesticides. Historically, pesticides have constituted the largest use (~50%) of arsenic compounds. The use of arsenic compounds in agriculture has been reduced in recent years.

Mean levels of ambient arsenic air concentration in the United States range from less than 1 nanograms per metre cubed ($ng.m^{-3}$) to 3 $ng.m^{-3}$ in remote areas, whereas the background levels in urban area have been found to be an order of magnitude higher, i.e. 20 to 30 $ng.m^{-3}$. Concentrations can reach several hundred nanograms per cubic metre in some cities and exceed 1000 $ng.m^{-3}$ (1 $\mu g.m^{-3}$) near nonferrous metal smelters (WHO, 1981) and some power plants, depending on the arsenic content of the coal.

Arsenic is toxic to human health and is considered a carcinogen. The exposure of humans to arsenic affects several organs and may interfere in the immune system (Duker *et al.*, 2005). Inorganic arsenic can have acute, sub-acute and chronic affects which may be either local or systemic. Lung cancer is considered to be the critical effect following inhalation. An increased incidence in lung cancer has been seen in several occupational groups exposed to inorganic arsenic. Some studies show that populations near emissions sources of inorganic arsenic, such as smelters, have a moderately elevated risk of lung cancer (Blot and Fraumeni, 1975). Other studies have failed to detect an effect in such situations (Greaves *et al.,* 1981*;* Rom *et al.*, 1982). The main pathway of arsenic exposure to the general population is through ingestion and inhalation.

The inhalation reference concentration (RfC) of a substance is based on the assumption that thresholds exist for certain toxic effects such as cellular necrosis. This is similar to the treatment of, for example, sulphur dioxide. The inhalation RfC considers toxic effects for both the respiratory system (portal-of-entry) and for effects peripheral to the respiratory system (extra-respiratory effects).In general, the RfC is an estimate of a daily inhalation exposure of the human population (including sensitive subgroups) that is likely to be without an appreciable risk of harmful effects during a life-time, with uncertainty potentially spanning an order of magnitude. Present risk estimates have been derived from studies in exposed human populations in the United States and Sweden. When assuming a linear dose–response relation, a safe level for inhalation exposure cannot be recommended. At an air concentration of 1 $\mu g.m^{-3}$, an estimate of life-time risk is 1.5×10^{-3} (or 1 500 in 1 million). This means that the excess life-time risk level is 1:10 000, 1:100 000 or 1:1 000 000 at an atmospheric concentration of about 66 $ng.m^{-3}$, 6.6 $ng.m^{-3}$ or 0.66 $ng.m^{-3}$, respectively. Arsenic in particulate matter (PM) is considered a pollutant of major concern in the EU and ambient air concentrations have been regulated. WHO (2000) Air Quality Guidelines state that no safe inhalation level could be established and recommended a unit risk factor of 1.5×10^{-3} $(\mu g.m^3)^{-1}$. The US-EPA Integrated Risk Information System (IRIS) recommends a more conservative 4.3×10^{-3} $(\mu g.m^3)^{-1}$ URF for arsenic. It was decided to use the more conservative URF to estimate increased cancer risk through exposure to ash from the Tutuka Power Station.

A coal fly-ash sample from an Australian Power Station was found to contain 10% of the total arsenic as the toxic As^{3+} species (Shah *et al.*, 2008). Increased life-time cancer risk as a result of long-term exposure to As^{3+} in ash from the Tutuka Power Station was calculated from the annual PM_{10} concentrations at the identified sensitive receptors, assuming 10% of total As^{3+} being carcinogenic.

2.2.2 Nickel

Nickel (Ni) is used in many industrial and commercial applications including: in stainless steel, nickel alloys, catalysts, batteries, pigments and ceramics. According to the US-National Toxicology Program of the Department of Health and Human Services, nickel compounds are classed as known human carcinogens, while metallic nickel is classed as '*reasonably anticipated to be a human carcinogen*'. Evidence suggests that the genotoxic agent, and probable carcinogenic agent, is the Ni^{2+} ion although

the potency of nickel compounds is highly variable, based on solubility and chemical speciation. The US-EPA IRIS (Integrated Risk Information System) therefore defines risk profiles for nickel carbonyl, nickel subsulfide and soluble nickel salts. Inhalation, ingestion and dermal contact are the mechanisms via which exposure to Ni occurs. Most people are exposed to low levels of environmental Ni, in air (with ambient concentrations generally less than 2.5 $ng.m^{-3}$ – Sivulka, 2005), water, food and consumer products. Occupational exposure through inhalation of dust particles and fumes has the greatest cancer risk (Sivulka, 2005), potentially results in the development of cancers of the lung and / or nasal passages, with a possibility of extra-pulmonary tumours. The unit risk (URF) for lung cancer based on life-time exposure to 1 $\mu g.m^{-3}$ of Ni compounds ranges between 2.1 x 10^{-4} $(\mu g.m^{-3})^{-1}$ and 37 x 10^{-4} $(\mu g.m^{-3})^{-1}$. The recommended inhalation URF for exposure to Ni refinery dust is 2.4 x 10^{-4} $(\mu g.m^{-3})^{-1}$ and for exposure to Ni subsulfide is 4.8 x 10^{-4} $(\mu g.m^{-3})^{-1}$. Haney *et al.* (2012) recently presented a weighted URF of 1.74 x 10^{-4} $(\mu g.m^{-3})^{-1}$, translating into an ambient Ni concentration of 0.059 $\mu g.m^{-3}$ for the increased lung cancer risk of 1 in 100 000. The revised URF presented by Hanley *et al.* (2012) is, however, most appropriate for the low sulfidic nickel emissions from Texas (USA) refineries.

The increased life-time cancer risk as a result of long-term exposure to Ni in ash from the Tutuka Power Station was calculated from the annual PM_{10} concentrations at the identified sensitive receptors using the URF of 2.4 x 10-4 $(\mu g.m^{-3})^{-1}$, recommended for nickel refinery dust. Due to the uncertainty in the literature of the carcinogenic nickel species and the proportion of carcinogenic species in relation to total nickel, it was conservatively assumed that 100% of nickel present in the ash from the Tutuka Power Station would be carcinogenic.

2.2.3 Hexavalent Chromium

In the hexavalent state, chromium exists as oxo-species such as CrO_3 and CrO_4^{2-} that are strongly oxidizing (Cotton & Wilkinson, 1980). In a solution, hexavalent chromium exists as hydrochromate ($HCrO^{4-}$), chromate (CrO_4^{2-}), and dichromate ($Cr_2O_7^{2-}$) ionic species. The proportion of each ion in a solution is pH dependent. In basic and neutral pH, the chromate form predominates. As the pH is lowered (6.0 to 6.2), the hydrochromate concentration increases. At very low pH, the dichromate species predominate (US-EPA, 1984).

The primary sources of hexavalent chromium in the atmosphere are chromate chemicals used as rust inhibitors in cooling towers and emitted as mists, particulate matter emitted during manufacture and use of metal chromates, and chromic acid mist from the plating industry. Hexavalent chromium in air eventually reacts with dust particles or other pollutants to form trivalent chromium (National Academy of Sciences, 1974); however, the exact nature of such atmospheric reactions has not been extensively studied. Both hexavalent (Cr^{6+}) and trivalent (Cr^{3+}) chromium are removed from air by atmospheric fallout and precipitation (Fishbein, 1981). The atmospheric half-life for the physical removal mechanism is dependent on the particle size and particle density. Chromium particles of small aerodynamic

diameter (<10 µm) will remain airborne for a longer period.

Hexavalent chromium may exist in aquatic media as water-soluble complex anions and may persist in water. Hexavalent chromium is a strong oxidizing agent and may react with organic matter or other reducing agents to form trivalent chromium. The trivalent chromium will eventually be precipitated as $Cr_2O_3 \cdot xH_2O$. Therefore, in surface water rich in organic content, hexavalent chromium will exhibit a much shorter life-time (Callahan, et al., 1979). Any hexavalent chromium in soil is expected to be reduced to trivalent chromium by organic matter. The primary processes by which the converted trivalent chromium is lost from soil are aerial transport through aerosol formation and surface water transport through runoff (US-EPA, 1984). The insolubility of Cr_2O_3 restricts the extent to which chromium is leached from soil (Fishbein, 1981). Chemical *in situ* treatment with ferrous sulfate has been found to stabilize trace metals in coal fly-ash to limit impacts as a result of leaching, especially for unlined disposal facilities (Bhattacharyya *et al.*, 2009).

A number of factors can influence the absorption of chromium following inhalation, including the size, oxidation state, and solubility of the chromium particles; the activity of alveolar macrophages; and the interaction of chromium with bio-molecules following deposition in the lung. A very detailed review on the toxicology of hexavalent chrome was compiled by the US-EPA (US-EPA, 1998).

2.2.3.1 Sub-Chronic Exposure of Hexavalent Chrome

The inhalation reference concentration (RfC) of a substance is based on the assumption that thresholds exist for certain toxic effects such as cellular necrosis. This is similar to the treatment of, for example, sulphur dioxide. The inhalation RfC considers toxic effects for both the respiratory system (portal-of-entry) and for effects peripheral to the respiratory system (extra-respiratory effects).In general, the RfC is an estimate of a daily inhalation exposure of the human population (including sensitive subgroups) that is likely to be without an appreciable risk of harmful effects during a life-time, with uncertainty potentially spanning an order of magnitude.

Nasal mucosal irritation, atrophy, and perforation have been widely reported following occupational exposures to chromic acid mists and dissolved hexavalent chromium aerosols. However, there is uncertainty regarding the relevance of occupational exposures to chromic acid mists and dissolved hexavalent chromium aerosols to exposures to Cr^{6+} dusts in the environment. Lower respiratory effects have been reported in laboratory animals following exposures to Cr^{6+} dusts. However, these studies have not reported on nasal mucosal effects following the exposures. The uncertainties in the US-EPA IRIS database have been addressed through the development of two RfCs; one - 16 $\mu g.m^{-3}$ - based on nasal mucosal atrophy following occupational exposures to chromic acid mists and dissolved hexavalent chromium aerosols, and a second - 0.1 $\mu g.m^{-3}$ - based on lower respiratory effects following inhalation of Cr^{6+} particulates in rats.

For the purposes of the alternative site assessment, sub-chronic exposure to Cr^{6+} was not assessed.

2.2.3.2 Chronic Exposure and Dose-Response Relationships for Hexavalent Chrome

There are many epidemiologic studies demonstrating that hexavalent chromium (Cr^{6+}) is a potential human carcinogen, but few provide adequate exposure data for use in risk estimation. Mancuso (1975) provides limited but adequate information for this purpose, and Mancuso's data are used as the main database for estimating the carcinogenic potency of hexavalent chromium.

Results of occupational epidemiological studies of chromium-exposed workers are consistent across investigators and study populations. Dose-response relationships have been established for chromium exposure and lung cancer. Chromium-exposed workers were exposed to both Cr^{3+} and Cr^{6+} compounds. Because only Cr^{6+} has been found to be carcinogenic in animal studies, however, it was concluded that only Cr^{6+} should be classified as a human carcinogen consistent with the human carcinogenicity data on hexavalent chromium, confirmed by many tumour types in animal bioassays.

In assessing the impacts of constituents a distinction need be made between carcinogenic and non-carcinogenic pollutants. It is plausible that for any dose of a carcinogen there could be some finite increase in cancer risk (i.e. there is no safe dose). In most countries, as is the case in South Africa, non-carcinogens are, however, considered to act via a threshold mechanism, which allows for the identification of a safe dose. Unit Risk Factors (i.e. life-time exposure) were used in the current study to determine the potential for human health impacts associated with Cr^{6+}. Unit risk factors are applied in the calculation of carcinogenic risks. These factors are defined as the estimated probability of a person (60-70 kilogram (kg)) contracting cancer as a result of constant exposure to an ambient concentration of 1 $\mu g.m^{-3}$ over a 70-year life-time. In the generic health risk assessment undertaken as part of the current study, maximum possible exposures (24-hours a day over a 70-year life-time) are assumed for all areas beyond the boundary of the ash disposal facility.

Hexavalent chromium is classified as a Group A, human carcinogen of high carcinogenic hazard by the US-EPA. The US-EPA has calculated the inhalation unit risk factor (US-EPA, 1998) to be 1.2×10^{-2} $(\mu g.m^{-3})^{-1}$. Using the US-EPA cancer unit risk factor, a concentration of 0.0008 µg $Cr^{6+}.m^{-3}$ in air would be associated with an excess cancer risk of one in a hundred thousand. The WHO cancer unit risk factor for hexavalent chromium is stated in the range 1.1 to 13×10^{-2} $(\mu g.m^{3})^{-1}$. Using the lower factor, a concentration of 0.000091 µg $Cr^{6+}.m^{-3}$ in air would be associated with an excess cancer risk of one in a million.

The risk calculations above are generic and simplified, based on assumptions that are not always applicable. For example, the estimates have not considered the greater vulnerability of children to such exposures. Furthermore, it is assumed that individuals would be exposed to all the hexavalent chromium in the particulates. This may be conservative, as particulates with aerodynamic diameter above 10 µm are largely trapped in the nasopharyngeal region of the respiratory system, from where they may be washed out for ingestion through mucociliary action. This is an important consideration in assessing exposure and risk, because carcinogenicity of hexavalent chromium by the oral route of

exposure has not been shown.

Since not all combustion processes result in release of Cr^{6+} it is valuable, in assessing the increased life-time cancer risk as a result of inhalation, to understand the contribution of Cr^{6+} to total Cr in ash, and especially in the PM_{10} (inhalable) fraction. In two recent studies of Cr in ash from Australian coal-fired power stations, it was found that a small proportion of total Cr occurs as Cr^{6+} (Shah *et al.*, 2008; 2012). The focus of the earlier study (Shah *et al.*, 2008) was on the speciation of trace metals (As, Cr and selenium) in the coal ash from a single power station in New South Wales using bituminous rank coal. The authors found that Cr^{6+} accounted for only 2.7% of the total Cr in coal fly-ash. The later investigation (Shah *et al.*, 2012) focussed on the Cr speciation in bituminous rank coal and ash by-product from four coal-fired power stations across Australia. The range of contribution of Cr^{6+} to total Cr in ash products ranged between 0.9 and 1.6%. Further analyses showed that in the PM_{10} fraction, only 1.1% of total Cr was in the toxic Cr^{6+} form (Shah *et al.*, 2012).

Increased life-time cancer risk as a result of long-term exposure to Cr in ash from Tutuka was calculated from the annual PM_{10} concentrations assuming 1.1% of total Cr as carcinogenic.

2.2.4 Acceptable Cancer Risk

The identification of an acceptable cancer risk level has been debated for many years and it possibly will still continue as societal norms and values change. Some people would easily accept higher risks than others, even if it were not within their own control; others prefer to take very low risks. An acceptable risk is a question of societal acceptance and will therefore vary from society to society.

In spite of the difficulty to provide a definitive “acceptable risk level”, the estimation of a risk associated with an activity provides the means for a comparison of the activity to other everyday hazards, and therefore allowing risk-management policy decisions. Technical risk assessments seldom set the regulatory agenda because of the different ways in which the non-technical public perceives risks. Consequently, science does not directly provide an answer to the question.

Risk assessment, as an organized activity of the US Food and Drug Administration (FDA) and the EPA, began in the 1970s. During the middle 1970s, the EPA and FDA issued guidance for estimating risks associated with small exposures to potentially carcinogenic chemicals. Their guidance made estimated risks of one extra cancer over the life-time of 100 000 people (EPA) or 1 million people (FDA) action levels for regulatory attention. Estimated risks below those levels are considered negligible because they add individually so little to the background rate of about 250 000 cancer deaths out of every 1 million people who die every year in the United States, i.e. 25%. Accepting 1 in 100 000 or 1 in 1 million risk translates to 0.004% or 0.0004% increase in the existing cancer risk level, respectively.

The European Parliament and the European Council, when considering the proposal for a Directive on Drinking Water, agreed that an excess life-time risk of 1 in 1 million should be taken as the starting point

for developing limit values. In South Africa, the Department of Environmental Affairs (DEA) has only been noted to give an indication of cancer risk acceptability in the case of dioxin and furan exposures. According to the DEA, emissions of dioxins and furans from a hazardous waste incineration may not result in an excess life-time cancer risk of greater than 1 in 100 000 on the basis of annual average exposure (DEAT, 1994). Excess cancer risks of less than 1 in 100 000 appear therefore to be viewed as acceptable to the DEA.

Whilst it is perhaps inappropriate to make a judgment about how much risk should be acceptable, through reviewing acceptable risk levels selected by other well-known organizations, it would appear that the US-EPA's application is the most suitable, i.e.

"If the risk to the maximally exposed individual (MEI) is no more than $1x10^{-6}$, then no further action is required. If not, the MEI risk must be reduced to no more than $1x10^{-4}$, regardless of feasibility and cost, while protecting as many individuals as possible in the general population against risks exceeding $1x10^{-6}$".

Some authorities tend to avoid the specification of a single acceptable risk level. Instead a "risk-ranking system" is preferred. For example, the New York Department of Health produced a qualitative ranking of cancer risk estimates, from very low to very high (**Table 2-7**). Therefore if the qualitative descriptor was "low", then the excess life-time cancer risk from that exposure is in the range between one per ten thousand and one per million.

Table 2-7: Excess Life-time Cancer Risk (as applied by New York Department of Health)

Risk Ratio	Qualitative Descriptor
Equal to or less than one in a million	*Very low*
Greater than one in a million to less than one in ten thousand	*Low*
One in ten thousand to less than one in a thousand	*Moderate*
One in a thousand to less than one in ten	*High*
Equal to or greater than one in ten	*Very high*

3 DESCRIPTION OF THE PROJECT

The project involves the proposed continuous ashing at the existing ash disposal facilities at the Tutuka Power Station in the Mpumalanga Province. Tutuka Power Station currently disposes of ash in a dry (8% - 10% moisture content) form by means of conveyors, spreader and a stacker system from the station terrace to the ash disposal site. According to the Eskom Holdings SOC Limited (Eskom) plans, the complete ash disposal site would eventually cover an area of 2 500 hectares (ha) (existing and remaining ash disposal site, and pollution control canals) and is located within 8 km of the Power Station terrace. The current disposal facility is located approximately 4.5 km east of the station terrace. Three alternative sites for continuous ash disposal facility have been considered in this assessment ranging in size between 534.41 and 764.94 ha.

The coal-fired power generation process results in large quantities of ash, which is disposed of in an ash disposal facility. Generally, Eskom has access to, and uses, coal of a low grade (called middlings coal) which produces a larger mass of ash during combustion. Over time, the quality of the coal provided to Eskom has degraded, due to higher ash quantities in the coal. The Tutuka Power Station utilises a dry ashing disposal method.

The waste product is deposited onto the disposal site by means of a stacker, which handles some 85% of the total ash whilst the remaining 15% is placed by a standby spreader system. Currently, the ash disposal progresses from west to east. In the event that the existing ash disposal facility continues, the two extendible conveyors will be extended to its final lengths of 4 000 metres (m) each. The ash disposal facility is built out in two layers. The front stack is deposited by the stacker and spreader to a height of approximately 45 m. The ash is bulldozed out to a slope of 1:3 for dust suppression and rehabilitation purposes. The stacker then moves around the head – end of the shiftable conveyor to dump another 20 m high back stack. The total ash disposal facility height is then approximately 65 m.

As the ash disposal advances, the topsoil is stripped ahead of the activities and is taken by truck and placed on top of the final disposal facility height, as a rehabilitation means. Grass seeds are then planted in this top soil.

The proposed continuous development is an ash disposal facility with the following specifications:

- Capacity of airspace of 353.1 million cubic metres (m^3) (Existing and remaining);
- Total ground footprint of the existing and remaining ash disposal facility and associated pollution control canals should cover approximately 2 500 ha; and,
- Expansion of the emergency dump, used when the ash conveyor system is offline, from 1 880 m^2 to 20 785 m^2.

4 DESCRIPTION OF THE AFFECTED ENVIRONMENT

The baseline evaluation primarily comprises the assessment of near-site surface meteorology. Eskom ambient monitoring data from the Grootdraaidam monitoring site, 13.5 km south-south-east of the Tutuka Power Station, provided an indication of the background air pollution in the region (Section 4.2).

4.1 Study area in general

The meteorological characteristics of a site govern the dispersion, transformation and eventual removal of pollutants from the atmosphere (Pasquill and Smith, 1983; Godish, 1990). The extent to which pollution will accumulate or disperse in the atmosphere is dependent on the degree of thermal and mechanical turbulence within the earth's boundary layer. Dispersion comprises vertical and horizontal components of motion. The vertical component is defined by the stability of the atmosphere and the depth of the surface mixing layer. The horizontal dispersion of pollution in the boundary layer is primarily a function of the wind field. The wind speed determines both the distance of downwind transport and the rate of dilution as a result of plume 'stretching'. The generation of mechanical turbulence is similarly a function of the wind speed, in combination with the surface roughness. The wind direction and the variability in wind direction, determine the general path pollutants will follow, and the extent of cross-wind spreading (Shaw and Munn, 1971; Pasquill and Smith, 1983; Oke, 1990).

Pollution concentration levels therefore fluctuate in response to changes in atmospheric stability, to concurrent variations in the mixing depth, and to shifts in the wind field. Spatial variations and diurnal and seasonal changes in the wind field and stability regime are functions of atmospheric processes operating at various temporal and spatial scales (Goldreich and Tyson, 1988). Atmospheric processes at macro- and meso-scales must be accounted for to accurately parameterise the atmospheric dispersion potential of a particular area. A qualitative description of the synoptic climatology of the study region is provided based on a review of the pertinent literature. The analysis of meteorological data observed for the proposed site, where available, and data for neighbouring sites will provide the basis for the parameterisation of the meso-scale ventilation potential of the site.

The analysis of at least one year of hourly average meteorological data for the study site is required to facilitate a reasonable understanding of the ventilation potential of the site. The most important meteorological parameters to be considered are: wind speed, wind direction, ambient temperature, atmospheric stability and mixing depth. Atmospheric stability and mixing depths are not routinely recorded and frequently need to be calculated from diagnostic approaches and prognostic equations, using as a basis routinely measured data, e.g. temperature, predicted solar radiation and wind speed.

Meteorological data from the Eskom monitoring site at Grootdraaidam was used to describe the dispersion potential at the Tutuka Power Station site for the period 2009 - 2011.

4.1.1 Local wind field

Figure 4-1 provides period wind roses for the Grootdraaidam Eskom monitoring station, with **Figure** 4-2 including the seasonal wind roses for the same site. The predominant wind direction is east-south-easterly with a ~16% frequency of occurrence. Winds from the south-western sector are relatively infrequent occurring <4% of the total period. Calm conditions (wind speeds < 1 m.s^{-1}) occur for 9.9% of the time.

Winds from the north-western sector increases during day-time conditions. During the night-time an increase in east-southeast flow is observed with a decrease in westerly air flow.

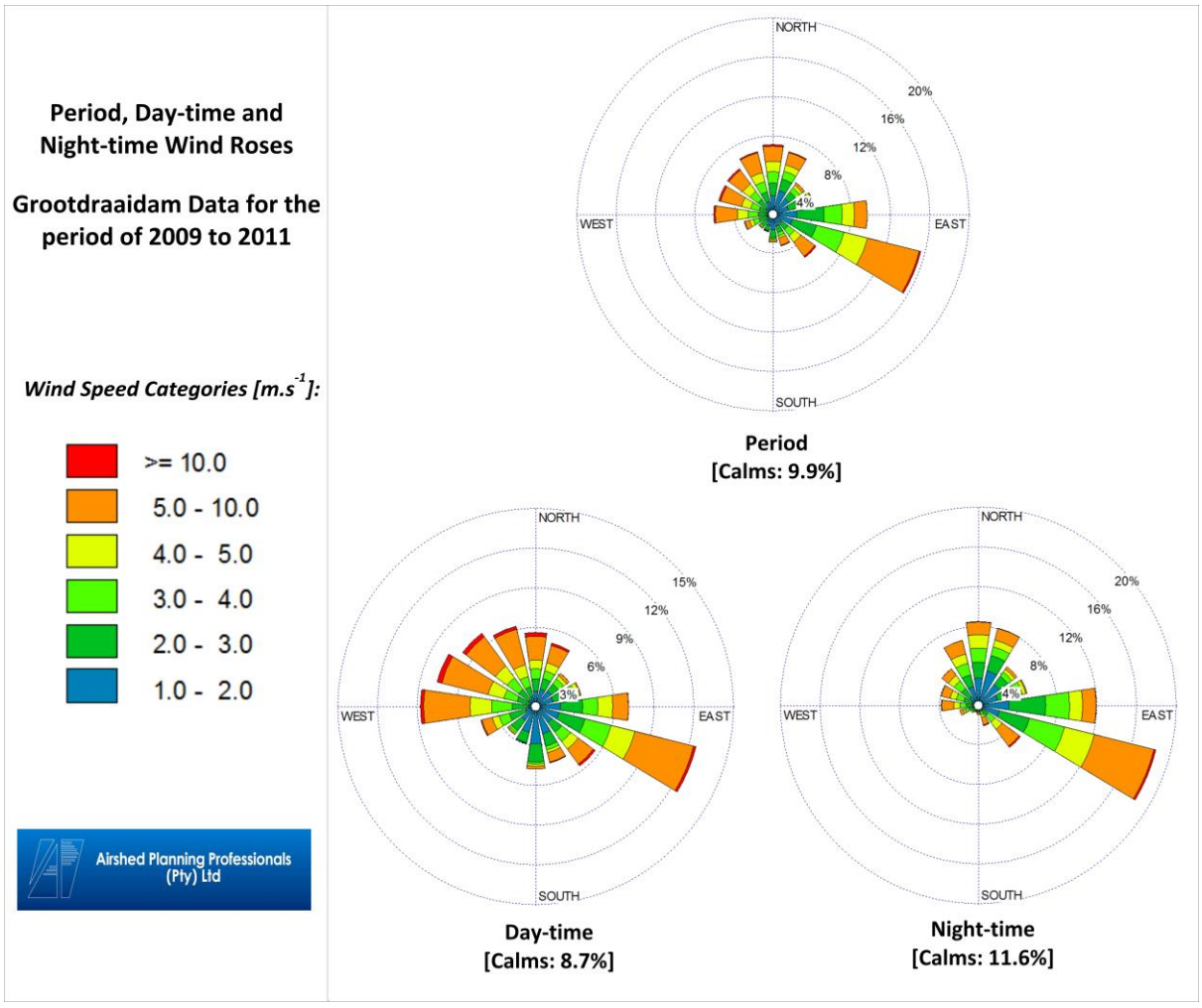


Figure 4-1: Period, day-time and night-time wind roses for Grootdraaidam (2009-2011)

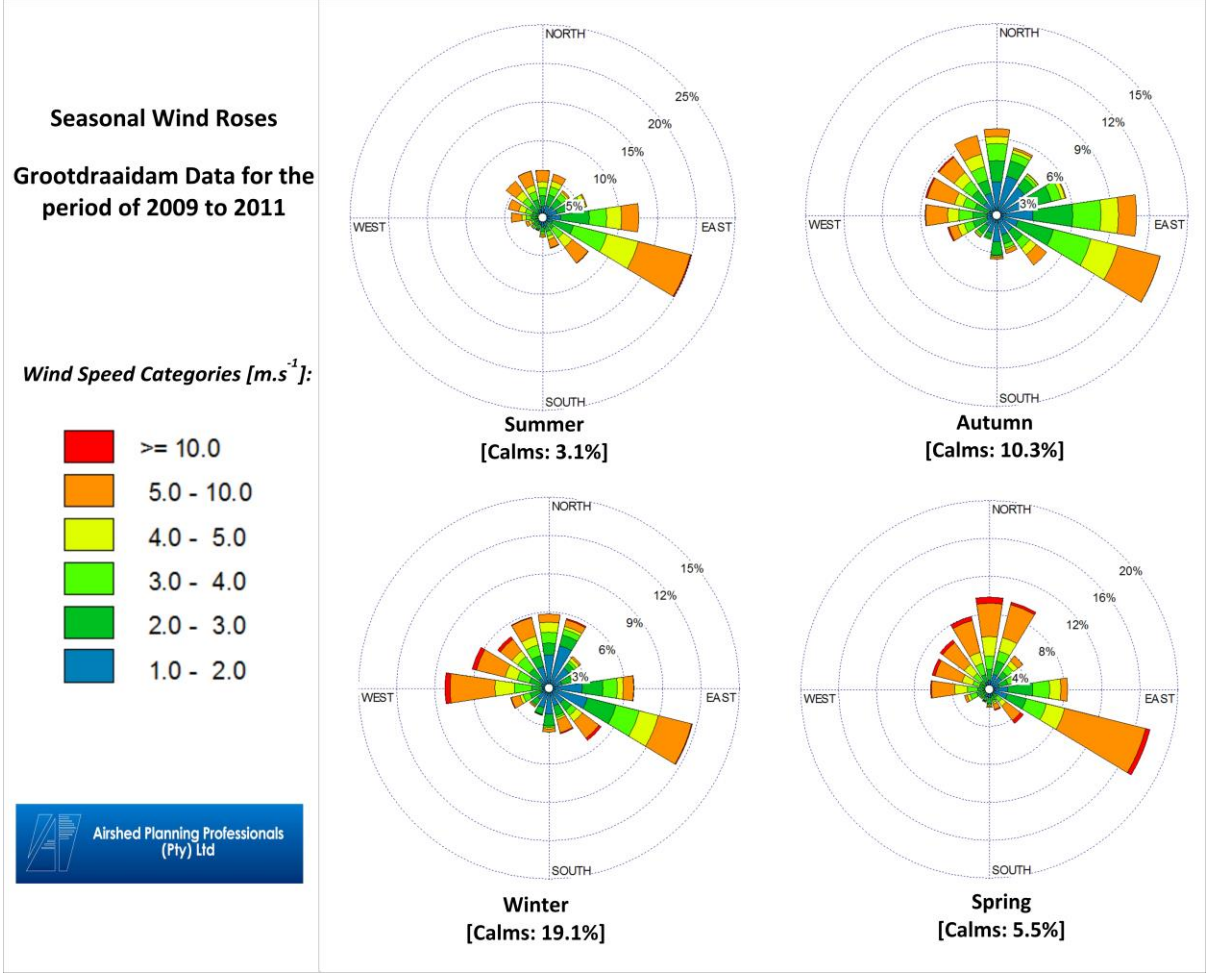


Figure 4-2: Seasonal wind roses for Grootdraaidam (2009-2011)

During summer months, winds from the east-southeast become more frequent, due to the strengthened influence of the tropical easterlies and the increasing frequency of occurrence of ridging anticyclones off the east coast. There is an increase in the frequency of calm periods (i.e. wind speeds <1 m.s^{-1}) during the winter months of 19.1% with an increase in the westerly flow.

4.1.2 Surface Temperature

Air temperature has important implications for the buoyancy of plumes; the larger the temperature difference between the plume and the ambient air, the higher the plume is able to rise. Temperature also provides an indication of the extent of insolation, and therefore of the rate of development and dissipation of the mixing layer.

The diurnal temperature profile for the area is given in **Figure 4-3**. Annual average maximum, minimum and mean temperatures for the site are given as 31.5°C, 0.9°C and 15.3°C, respectively, based on the measured data at the Eskom Grootdraaidam monitoring site for the period 2009-2011. Average daily

maximum temperatures range from 35.7°C in October to 24.5°C in July, with daily minima ranging from 11.7°C in January to -9.8°C in June (**Figure 4-3**).

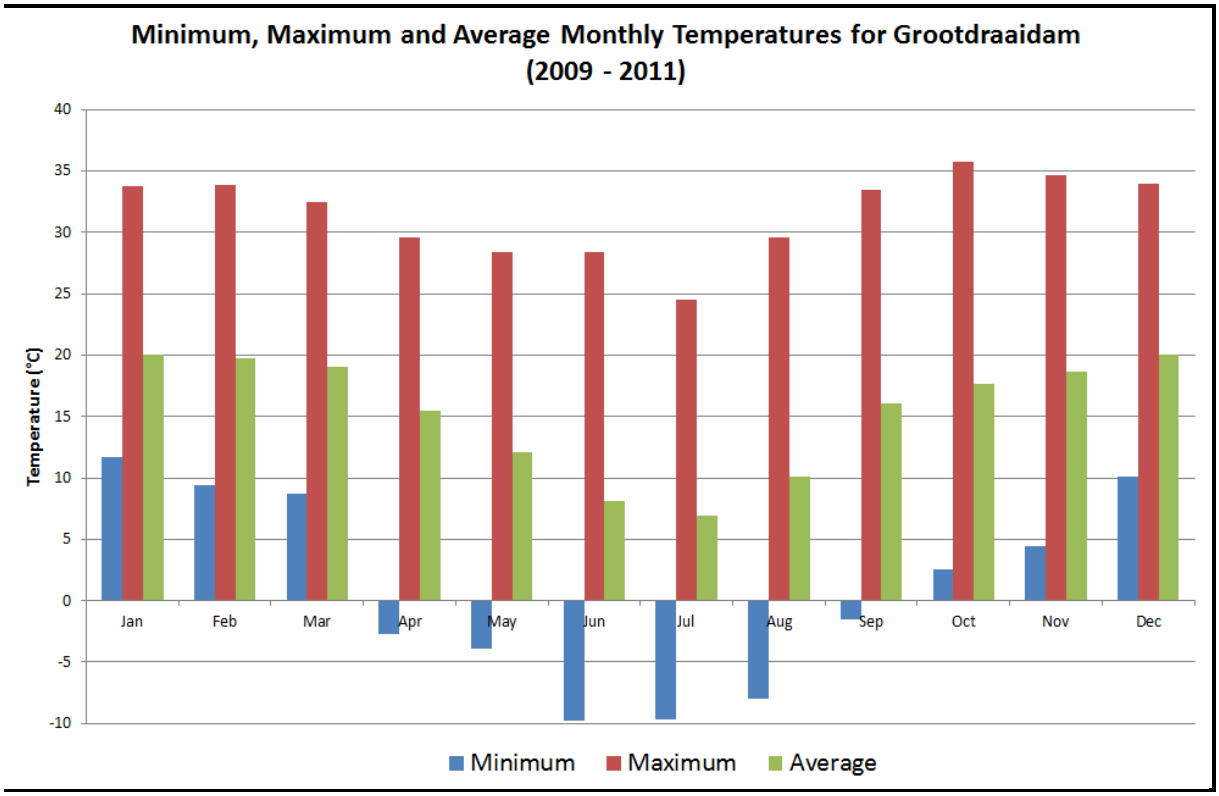


Figure 4-3: Minimum, maximum and average monthly temperatures for the site during the period 2009-2011

4.1.3 Precipitation

Rainfall represents an effective removal mechanism of atmospheric pollutants and is therefore frequently considered during air pollution studies.

Monthly rainfall for the Tutuka ash disposal facility (January 2010 to November 2012) is given in **Table 4-1**. Average annual rainfall between 2007 and 2012 is 730 mm. The study area falls within a summer rainfall region, with over 80% of the annual rainfall occurring during the October to March period.

Table 4-1: Monthly rainfall at the Tutuka ash disposal facility for the period January 2010 to November 2012

Month	Precipitation (mm)		
	2010	2011	2012
January	175	127	111
February	55	18	62
March	122	56	49
April	32	66	24
May	16	10	1
June	0	0	6
July	0	20	0
August	0	15	0
September	0	50	115
October	123	60	54
November	98	28	252
December	204	77	162

4.2 Ambient Air Quality near Tutuka Ash Disposal Facility

4.2.1 Highveld Priority Area

The Highveld Airshed Priority Area (HPA) was the second national air quality priority area declared (after the Vaal Triangle Airshed Priority Area) by the Minister of Environmental Affairs at the end of 2007 (HPA, 2011). This required that an Air Quality Management Plan for the area be developed. The plan includes the establishment of emissions reduction strategies and intervention programmes based on the findings of a baseline characterisation of the area. The implication of this is that all contributing sources in the area will be assessed to determine the emission reduction targets to be achieved over the following few years.

The DEA published the management plan for the Highveld Priority Area in September 2011. Included in this management plan are 7 goals, each of which has a further list of objectives that has to be met. The 7 goals for the Highveld Priority area are as follows:

- **Goal 1:** By 2015, organisational capacity in government is optimised to efficiently and effectively maintain, monitor and enforce compliance with ambient air quality standards.
- **Goal 2:** By 2020, industrial emissions are equitably reduced to achieve compliance with ambient air quality standards and dust fallout limit values.
- **Goal 3:** By 2020, air quality in all low-income settlements is in full compliance with ambient air quality standards.
- **Goal 4:** By 2020, all vehicles comply with the requirements of the National Vehicle Emission Strategy.
- **Goal 5:** By 2020, a measurable increase in awareness and knowledge of air quality exists.

- **Goal 6:** By 2020, biomass burning and agricultural emissions will be 30% less than current.
- **Goal 7:** By 2020, emissions from waste management are 40% less than current.

The Tutuka Ash Disposal Facility proposed alternatives fall within the HPA. The alternatives are located in the vicinity of the Lekwa Hot Spot (HPA, 2011) and the ambient air quality, with particular reference to particulates, is outlined below.

4.2.2 Ambient Air Quality within the Region

The Department of Environmental Affairs (DEA) operates a monitoring network over the Highveld region at the residential areas of Hendrina, Ermelo, Middleburg, Secunda and eMalahleni. The closest monitoring station to the proposed operations is located at Secunda. The highest daily and PM_{10} and $PM_{2.5}$ concentrations for the period December 2011 (period for which there is information available) is given in **Figure 4-4**.

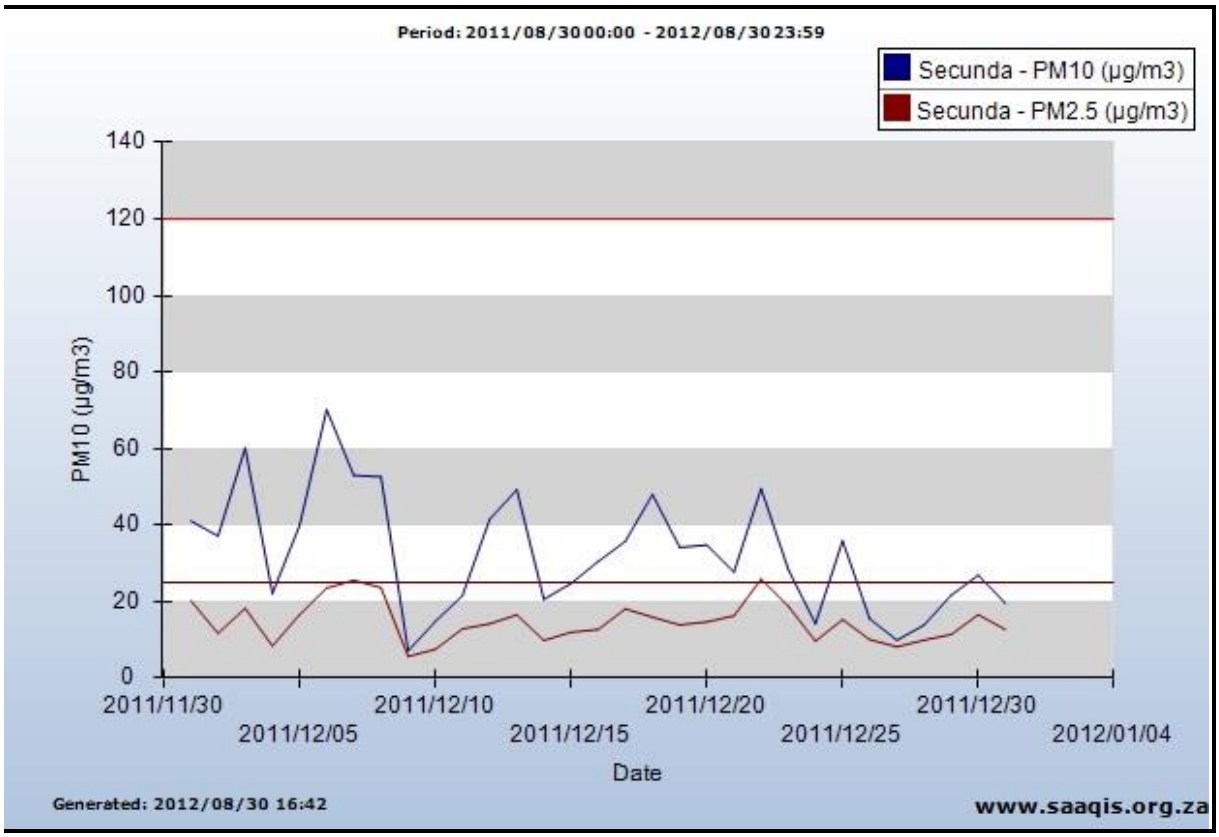


Figure 4-4: Daily measured PM_{10} and $PM_{2.5}$ ground level concentrations ($\mu g.m^{-3}$) at the Secunda DEA monitoring station (for the period December 2011) (www.saaqis.org.za)

No exceedances of the National Ambient Air Quality Standard (NAAQS) for PM_{10} and $PM_{2.5}$ were observed for the short monitoring period available. It should be noted however, that the monitoring period is for 1 month only and may exceed the NAAQS if a full monitoring period is assessed.

The ambient measured daily PM_{10} concentrations from the Eskom Grootdraaidam monitoring site is provided in **Figure 4-5** for the period 2009 to 2011 with measured frequency of exceedance of NAAQS provided in **Table 4-2**. The ambient PM_{10} measurements should be evaluated in context with the data availability of the monitored data. As the ambient air quality data availability at Grootdraaidam is relatively poor for the period 2009 to 2011, the predicted frequency of exceedance of the National Ambient Air Quality limits for PM_{10} may be even higher than actual measured values.

High ambient particulate concentrations have been found to coincide with low ambient temperatures and low rainfall (Burger, 1994). Increases in domestic coal burning and poor atmospheric dispersion potentials, together with persistent industrial emissions, combine to produce elevated ambient concentrations during winter months. High concentrations during summer months are usually associated with increases in fugitive dust emissions. Rainfall events result in a reduction of airborne concentrations due to reductions in the potential for fugitive dust emissions and due to the removal of particulates in the atmosphere by raindrops. Other sources of particulates in the vicinity of the Tutuka Power Station include domestic fuel burning in the residential communities of Standerton, coal mining near the power station, agricultural activities for example ploughing of fallow fields prior to planting and the production of synfuels in Secunda.

Table 4-2: Measured daily ambient PM_{10} concentrations at Eskom's Grootdraaidam monitoring station for the period 2009 to 2011

Monitoring Period	Data Availability (%)	Number of Exceedances of the NAAQ limit of 120 µg/m³ (applicable immediately)	Exceedance of the NAAQS (applicable immediately) (Y/N)	Number of Exceedances of the NAAQ limit of 75 µg/m³ (applicable 2015)	Exceedance of the NAAQS (applicable 2015) (Y/N)
2009	53	9	N	60	N
2010	31	0	Y	4	Y
2011	19	0	Y	16	N

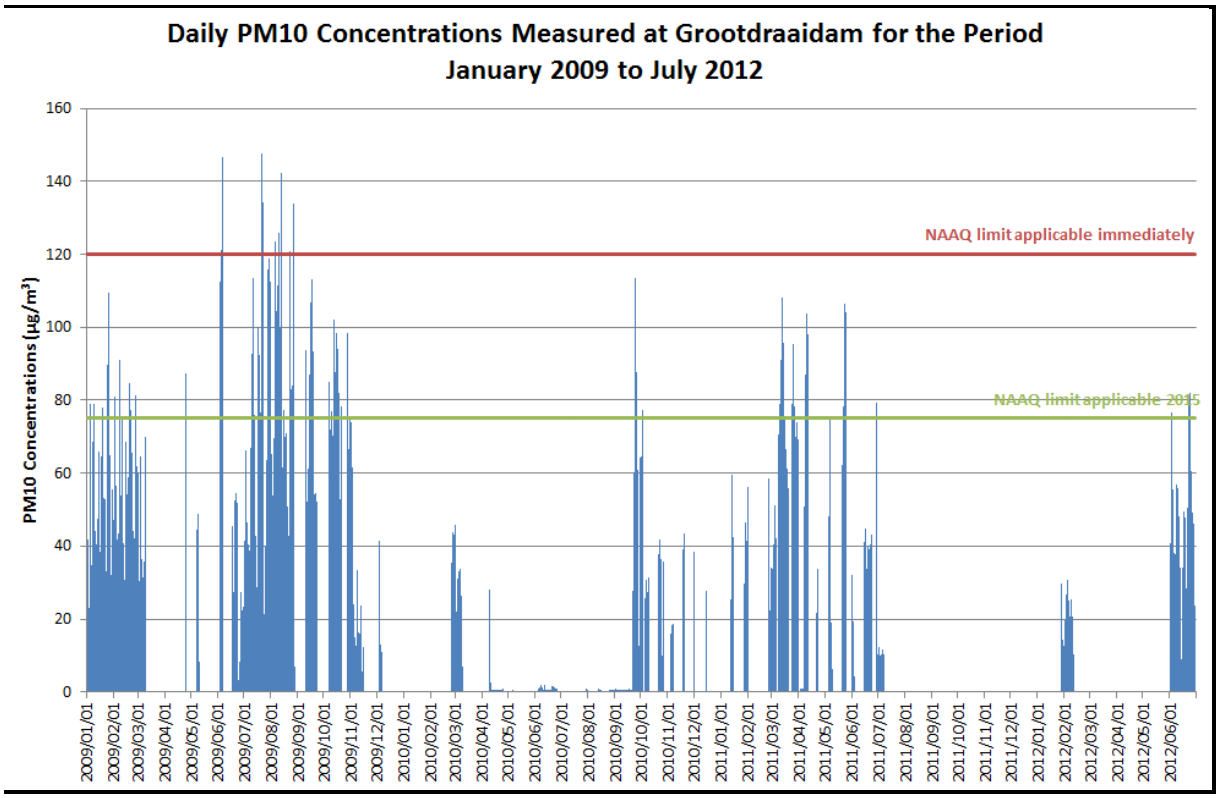


Figure 4-5: Measured daily PM_{10} concentrations for the Eskom Grootdraaidam monitoring station

A dust fall-out monitoring network (18 stations) surrounds the Tutuka Power Station. Six of the dust-buckets surround the ash disposal facility. The 2011/2012 dust fall-out rates (**Figure 4-6**) were below the monthly draft standard for residential areas with the exception of two sites on a total of 4 occasions (Offices in September 2011, November 2011 and February 2012; Dam in October 2011). The dust fall-out rates at the Offices exceeded the monthly draft standard for industrial areas in October 2011. The highest dust fall-out rates at all sites were recorded between September and November. From the Grootdraaidam meteorological data, these three months have the highest average (greater than 4.0 $m.s^{-1}$) and highest maximum wind speeds (greater than 14.6 $m.s^{-1}$).

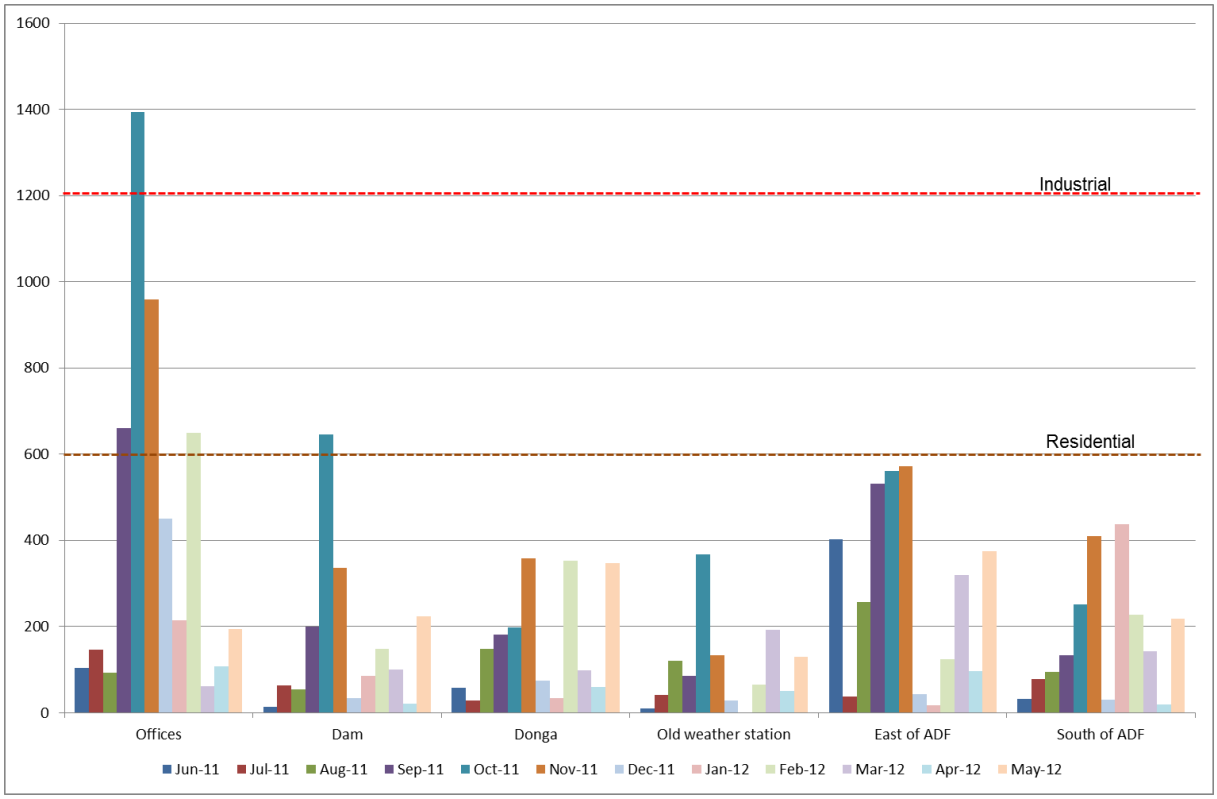


Figure 4-6: Dustfall rates (mg.m^{-2}.day^{-1}) at monitoring dust-buckets surrounding the ash disposal facility (ADF)

5 FINDINGS

5.1 Ash Disposal Facility

Dispersion modelling was used to simulate: maximum monthly dust-fall rates as well as second highest daily and annual average incremental ground-level concentrations for PM_{10} and $PM_{2.5}$. These averaging periods were selected to facilitate the comparison of predicted pollutant concentrations with relevant dust-fall guideline and air quality standards. It has, however, generally been found that the accuracy of dispersion models improves with increased averaging periods. The accurate prediction of instantaneous peaks are the most difficult and are normally performed with more complicated dispersion models specifically fine-tuned and validated for the location. For the purposes of this study and for selecting a preferred alternative site, the averaging period presented in this report is annual. It should be noted that the ground-level concentration isopleths depicted present interpolated values from the concentrations predicted by ADMS 5 for each of the receptor grid points specified.

5.1.1 Dust fall-out

Dust fall-out in the unmitigated scenario is likely to exceed the draft dust fallout regulation for residential areas over large extents surrounding any of the alternative ash disposal facility locations (**Figure 5-1**). Although reduced in area, exceedances of the guideline are also expected if mitigation is limited to water sprays. However, the re-vegetation and combination mitigation strategies, meet the residential draft dust-fall regulation (**Figure 5-1**).

The potential impact of dust-fall on agricultural crops near the ash disposal facility was plotted (**Figure** 5-2) at the 400 $mg.m^{-2}.day^{-1}$ guideline (Appendix A, Section A1). The predicted areas of impact where dust-fall rates are above the agricultural guideline, for the unmitigated scenario, are lowest for Alternative C, followed by Alternatives B and A (**Table 5-1**).

Table 5-1: Area of impact (ha) for dust fall-out rates from each site alternative

Scenario	Receptor name	Area of impact (ha)
		Dust fall-out >400 $mg.m^{-2}.day^{-1}$
Unmitigated	Alternative A	4002
	Alternative B	3907
	Alternative C	2880
Re-vegetation	*No impact predicted off-site for any alternative*	
Wetting	Alternative A	900
	Alternative B	781
	Alternative C	532
Both (re-vegetation and wetting)	*No impact predicted off-site for any alternative*	

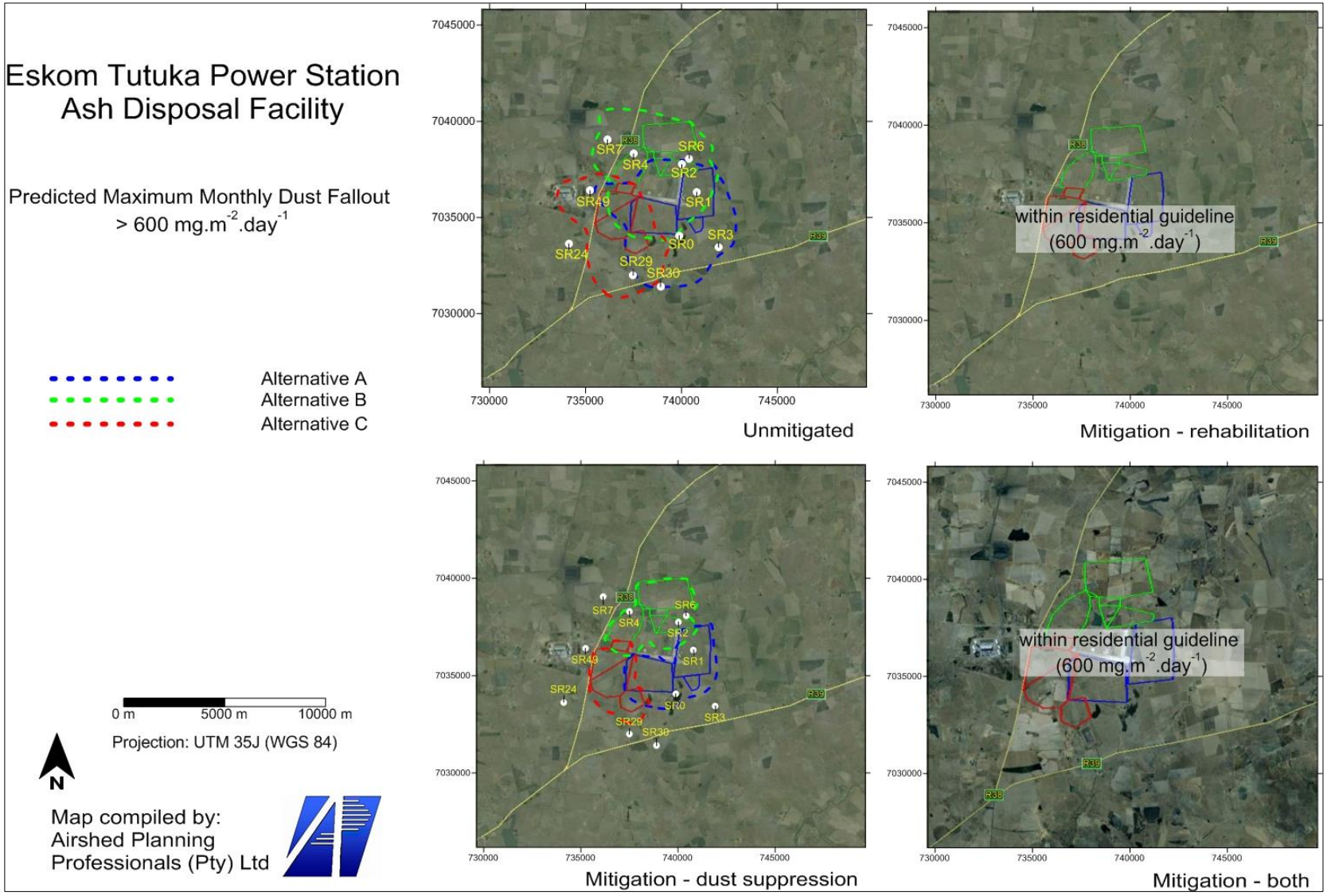


Figure 5-1: Predicted maximum monthly dust fall-out as a result of each of the three alternative ash disposal facilities at Tutuka Power Station

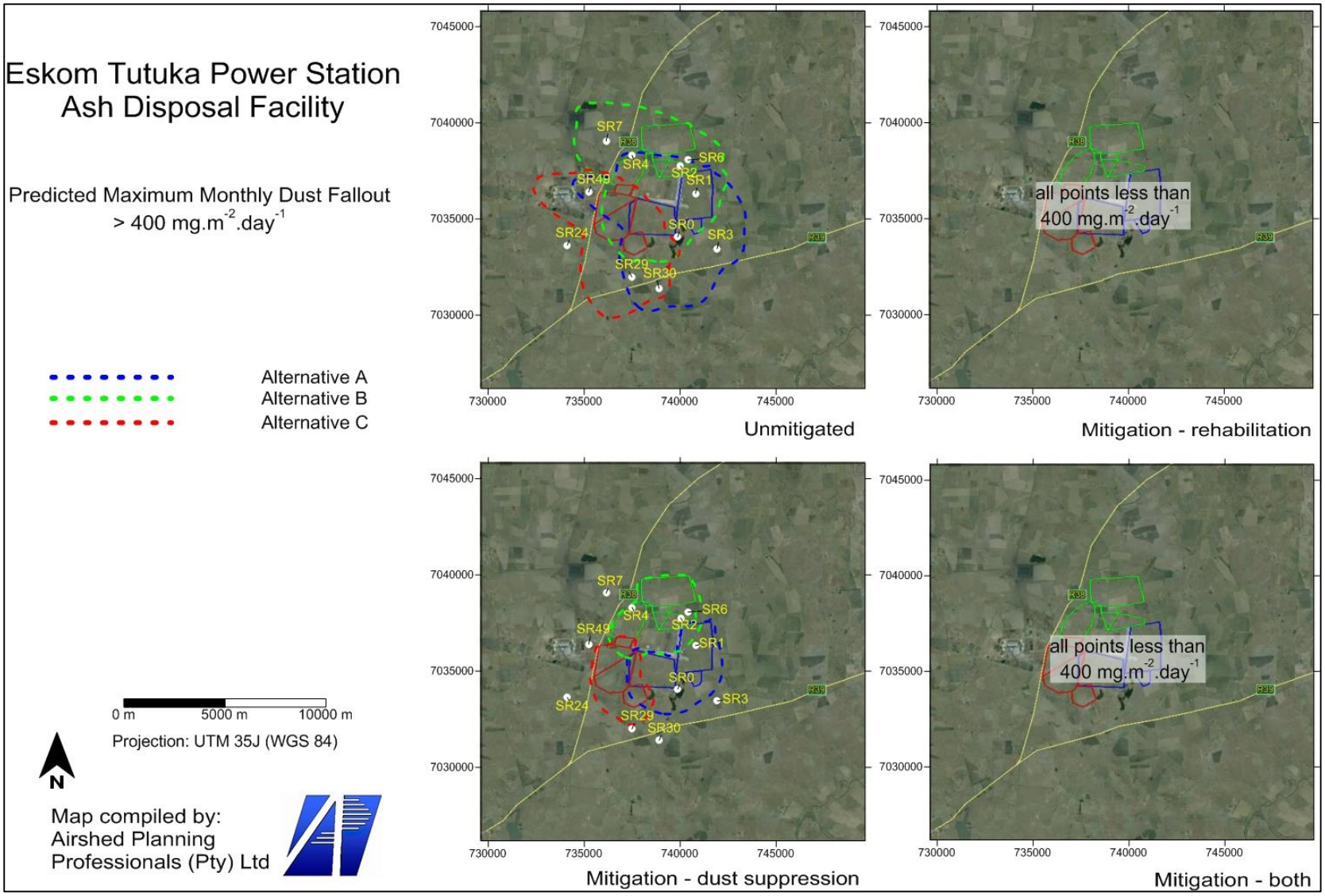


Figure 5-2: Areas impacted by dust fall-out rates exceeding 400 mg.m^{-2}.day^{-1}, as a result of each of the three alternative ash disposal facilities at Tutuka Power Station

5.1.2 PM_{10} ground-level concentrations

Non-compliance with the annual average PM_{10} standard (40 µg.m^{-3}) is expected for large areas around all alternatives in the unmitigated scenario (**Figure 5-3**). Non-compliance is limited near to the alternative ash disposal facilities in the water spraying scenario. Compliance with the annual standard could be achieved with mitigation by either effective re-vegetation or with the combination of effective re-vegetation and watering (**Figure 5-3**).

The areas impacted by elevated annual PM_{10} concentrations as a result of unmitigated wind-blown dust are predicted to be the lowest for Alternative C, followed by Alternatives B and A (**Table 5-2**), although areas can be drastically reduced by introducing mitigation techniques.

Table 5-2: Area of impact (ha) for daily PM_{10} from each site alternative

Scenario	Receptor name	Area of impact (ha)*
		Annual PM_{10}
Unmitigated	Alternative A	949
	Alternative B	944
	Alternative C	611
Re-vegetation	*No impact predicted off-site for any alternative*	
Wetting	Alternative A	0
	Alternative B	133
	Alternative C	117
Both (re-vegetation and wetting)	*No impact predicted off-site for any alternative*	

Exceedances of the annual NAAQS for PM_{10} are likely to be limited to six of the identified sensitive receptors (**Table 5-3**) where three sensitive receptors are affected by Alternative B, two by Alternative A and one by Alternative C. Improvements are likely with effective mitigation where annual NAAQS is exceeded only at two sensitive receptors both near Alternative B in the watering only scenario (**Table 5-3**).

Peak impacts, as exceedances of PM_{10} NAAQS, are predicted to affect more sensitive receptors than the annual average PM_{10} GLCs (**Table 5-3**): 10 (of 11) by Alternative A; 7 by Alternative B and 6 by Alternative C. Sensitive receptors SR0, SR1 and SR3 are affected by all three alternatives.

5.1.3 $PM_{2.5}$ ground-level concentrations

The impact for $PM_{2.5}$ is more restricted than $PM_{10;}$ however, exceedances of the annual standard are expected under the unmitigated scenario (**Figure 5-4**). The area affected by exceedances of the annual

limits can be reduced through mitigation via watering and controlled within the annual limits via re-vegetation and a combination mitigation strategy (**Figure 5-4** and **Table 5-4**).

Non-compliance with annual $PM_{2.5}$ NAAQS is expected at six of the sensitive receptors without mitigation of dust emissions: three as a result of Alternative B; two as a result of Alternative A and one as a result of Alternative C (**Table 5-4**). Only one sensitive receptor is likely to affected by elevated PM_{10} GLCs under dust suppression by watering (as a result of Alternative B).

Exceedances of the daily $PM_{2.5}$ NAAQS are likely during peak emission (i.e. high wind speed) events (**Table 5-4**). Five sensitive receptors are affected by emissions from Alternative B, four sensitive receptors by Alternative A and two from Alternative C. No exceedances of daily $PM_{2.5}$ standards are expected for the re-vegetation and combination scenarios.

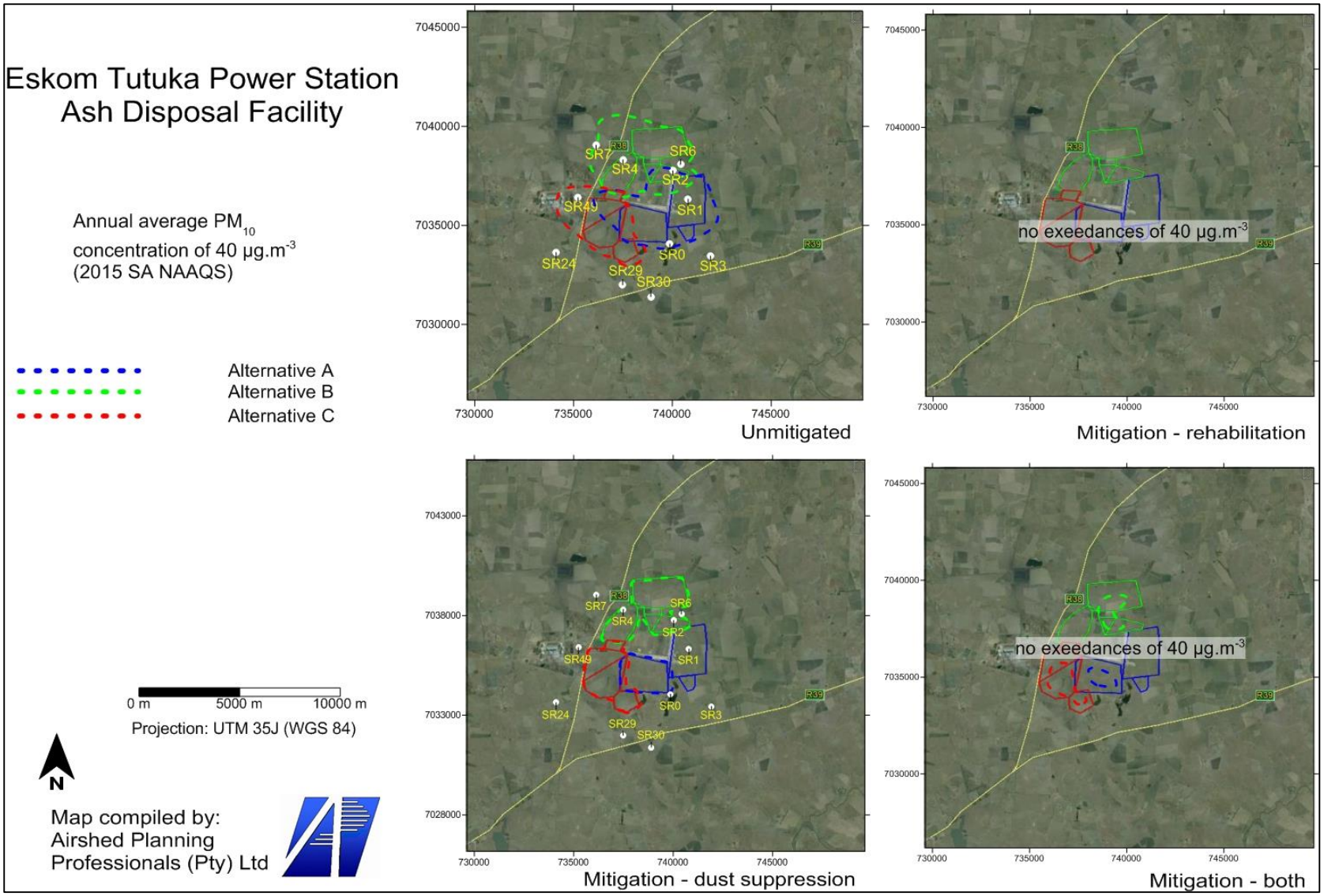


Figure 5-3: Predicted annual average PM_{10} concentration as a result of the three alternative ash disposal facilities at Tutuka Power Station

Table 5-3: Predicted exceedances of the PM_{10} annual standards and daily limits at sensitive receptors as a result of wind-blown emissions from the alternative ash disposal facilities

Scenario	Receptor name	Annual average (µg.m^{-3})			Daily limit exceedances (allowed 4)		
		Alt A	Alt B	Alt C	Alt A	Alt B	Alt C
Unmitigated	SR0	52.03			57	14	24
	SR1	121.84			114	35	5
	SR2	44.47	129.84		51	117	
	SR3				27	6	11
	SR4		76.78		32	70	
	SR6		54.16		29	70	
	SR7		40.12		23	49	
	SR24						
	SR29				5		18
	SR30				5		18
	SR49			64.56	34		62
Re-vegetation	No exceedances of annual standards or daily limits at sensitive receptors.						
Wetting	SR0				21		6
	SR1				27	9	
	SR2		92.14		6	53	
	SR3				6		
	SR4		48.92			41	
	SR6					23	
	SR7					8	
	SR24						
	SR29						
	SR30						
	SR49						12
Re-vegetation & wetting	No exceedances of annual standards or daily limits at sensitive receptors.						

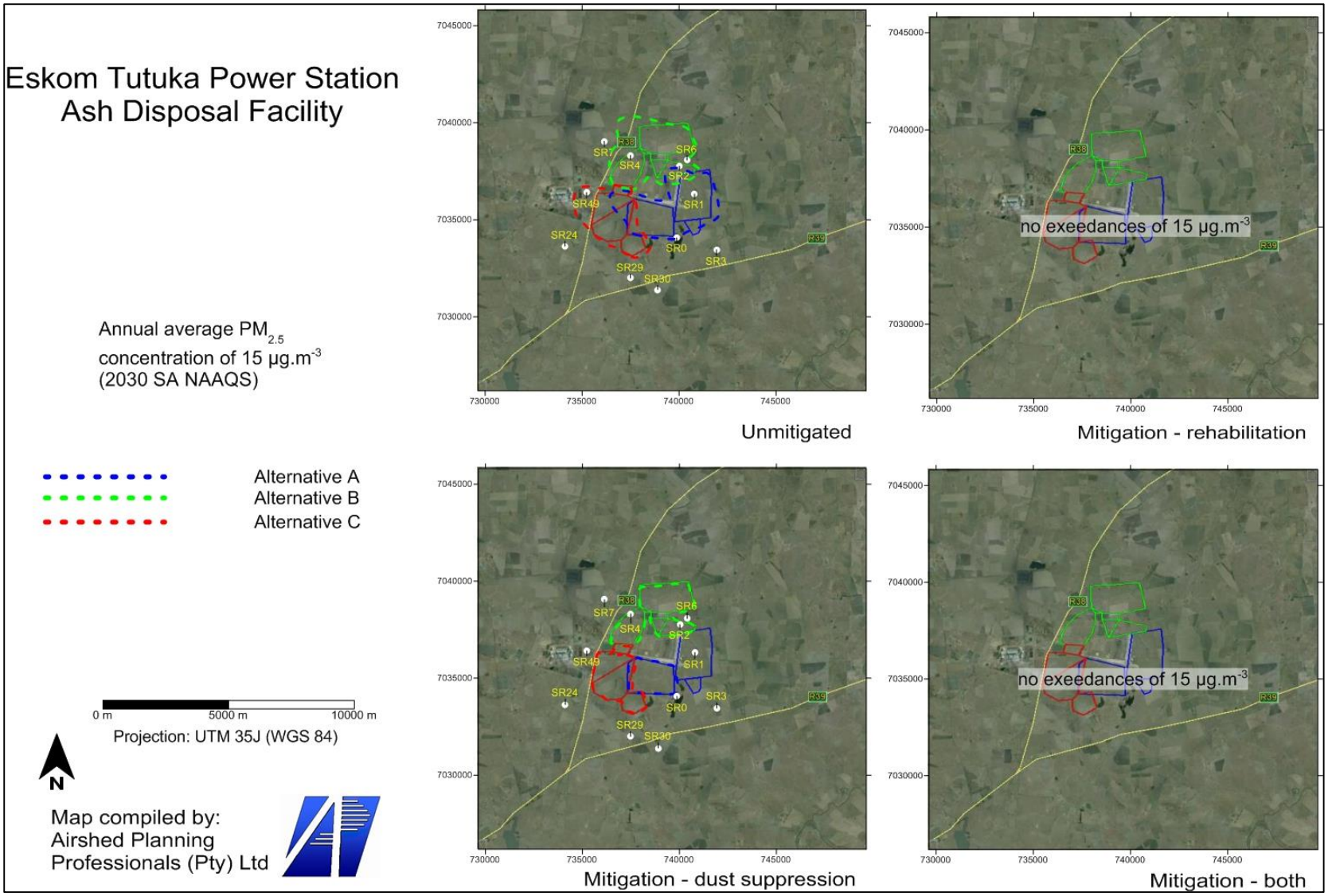


Figure 5-4: Predicted annual average $PM_{2.5}$ concentration as a result of the three alternative ash disposal facilities at Tutuka Power Station

Table 5-4: Predicted exceedances of the $PM_{2.5}$ annual standards and daily limits at sensitive receptors as a result of wind-blown emissions from the alternative ash disposal facilities

Scenario	Receptor name	Annual average (µg.m^{-3})			Daily limit exceedances (allowed 4)		
		Alt A	Alt B	Alt C	Alt A	Alt B	Alt C
Unmitigated	SR0	15.27			54	11	21
	SR1	36.26			109	33	
	SR2		38.64		50	112	
	SR3				25	5	9
	SR4		22.85		31	64	
	SR6		16.12		26	63	
	SR7				20	45	
	SR24						
	SR29				5		15
	SR30				5		15
	SR49			19.21	32		59
Re-vegetation	No exceedances of annual standards or daily limits at sensitive receptors.						
Wetting	SR0				18		6
	SR1				25	9	
	SR2		27.42		5	51	
	SR3				5		
	SR4					39	
	SR6					22	
	SR7					6	
	SR24						
	SR29						
	SR30						
	SR49						12
Re-vegetation & wetting	No exceedances of annual standards or daily limits at sensitive receptors.						

5.1.4 Increased life-time cancer risk

The increased life-time cancer risk at the identified sensitive receptors is very low to low, for all three metals (arsenic, nickel and chromium) (**Table 5-5**). These estimates are based on the annual PM_{10} concentrations for the *unmitigated* scenario (**Table 5-3**). Cancer risk as a result of exposure to nickel in the PM_{10} fraction of the ash shows the most variability and the highest number of 'low' cancer risk. The uncertainty with respect to the nickel compounds, and their proportion of total nickel in the ash, results in a more conservative cancer risk calculation. This conservative estimation of cancer risk adds support to the need for effective dust emission control through mitigation strategies, which will reduce the cancer risk further.

Table 5-5: Increased life-time cancer risk at identified sensitive receptors, as a result of exposure to arsenic, nickel and chromium in the PM_{10} fraction of dust from the Tutuka ash disposal facility

<table>
<tr><th rowspan="2">Sensitive receptor</th><th colspan="3">Ash disposal facility alternative</th></tr>
<tr><th>A</th><th>B</th><th>C</th></tr>
<tr><td colspan="4">Arsenic</td></tr>
<tr><td>SR0</td><td colspan="3" rowspan="10">Very low</td></tr>
<tr><td>SR1</td></tr>
<tr><td>SR2</td></tr>
<tr><td>SR3</td></tr>
<tr><td>SR4</td></tr>
<tr><td>SR6</td></tr>
<tr><td>SR7</td></tr>
<tr><td>SR24</td></tr>
<tr><td>SR29</td></tr>
<tr><td>SR30</td></tr>
<tr><td>SR49</td></tr>
<tr><td colspan="4">Nickel</td></tr>
<tr><td>SR0</td><td rowspan="2">Low</td><td rowspan="7">Low</td><td rowspan="7">Low</td></tr>
<tr><td>SR1</td></tr>
<tr><td>SR2</td><td>Very low</td></tr>
<tr><td>SR3</td><td>Low</td></tr>
<tr><td>SR4</td><td>Very low</td></tr>
<tr><td>SR6</td><td>Very low</td></tr>
<tr><td>SR7</td><td>Low</td></tr>
<tr><td>SR24</td><td>Very low</td><td>Very low</td><td>Very low</td></tr>
<tr><td>SR29</td><td rowspan="3">Low</td><td rowspan="3">Low</td><td rowspan="2">Low</td></tr>
<tr><td>SR30</td></tr>
<tr><td>SR49</td><td>Very low</td></tr>
<tr><td colspan="4">Chromium</td></tr>
<tr><td>SR0</td><td rowspan="10">Very low</td><td rowspan="3">Low</td><td>Very low</td></tr>
<tr><td>SR1</td><td>Low</td></tr>
<tr><td>SR2</td><td rowspan="8">Very low</td><td>Very low</td></tr>
<tr><td>SR3</td><td rowspan="3">Low</td></tr>
<tr><td>SR4</td></tr>
<tr><td>SR6</td></tr>
<tr><td>SR7</td><td rowspan="5">Very low</td><td rowspan="5">Very low</td></tr>
<tr><td>SR24</td></tr>
<tr><td>SR29</td></tr>
<tr><td>SR30</td></tr>
<tr><td>SR49</td><td>Low</td></tr>
</table>

5.2 Linear Infrastructure Corridors

The linear infrastructure corridors associated with the disposal of ash at the Tutuka Power station, irrespective of the alternative, are likely to affect surrounding air quality to a very small extent. Ash is disposed via a system of conveyors (some covered) and the conditioned ash moisture content is (approximately 15% and when mixed with coarse ash then the moisture content) is approximately 20% when on overland conveyors and it should reduce the emission of ash even under windy conditions. (This moisture would decrease as this ash travels over a distance of about 9 km) During upset conditions, when the conveyor is not operational and ash is left to air-dry on the conveyor belt, there is a likelihood of emissions although this will be limited by the duration of the upset period and should be managed via water sprays, especially during windy conditions.

5.3 Emergency ashing area upgrade

During the periods when the ash disposal conveyor systems are offline, ash is temporarily stored at 1 880 m^2 emergency ash area. The current amount of ash off-loaded during emergency events exceeds the capacity of the existing footprint and Eskom has initiated an expansion and upgrade project. The emergency ashing area and associated infrastructure will increase to a total area of 20 785 m^2.

The upgrade project will be a source of particulate and gaseous emissions during the construction phase; however, these will be of a temporary nature. Emission sources would be similar to those mentioned for the construction phase of the continuous ash disposal facility (Table 2.1). It is not anticipated that the various construction activities will result in higher off-site impacts than the operational activities. The temporary nature of the construction activities, and the likelihood that these activities will be localised and for small areas at a time, will reduce the potential for significant off-site impacts. Dust suppression using screens and water sprays will reduce the impact as a result of construction activities.

The ash material temporarily stored at the emergency ashing area is moved between conveyor systems and/or 10 ton haul trucks. During operational periods, this movement of the material will generate particulate emissions; however, due to the conditioned state of the ash (8% - 10% moisture content) emissions can be limited if the material is moved prior to drying out. Management actions required to minimise the impact of the particulate emissions associated with materials handling have been recommended in Table 5-6.

Table 5-6: Aspects and activities identified for the Emergency ashing area during operational periods

Aspect	Impact	Management Actions/Objectives
Emergency ashing area		
Materials handling operations	PM_{10} and $PM_{2.5}$ concentrations and dust fallout rates	• Restrict materials handling activities to low wind speed events (when wind speed is less than 5 $m.s^{-1}$) • Move material when still moist (8% - 10% moisture content) • Drop height from front-end loader should be kept to a minimum when moving ash to emergency transport (i.e. overland conveyor or haul trucks) • Establish water sprays to use when material has dried and/or during periods of higher wind speeds
Ambient Monitoring	Dust fallout rates	Establish a dust fallout bucket near the emergency ashing area to monitor dust fallout rates remain below 1 200 $mg.m^{-2}.day^{-1}$.

6 ASSESSMENT OF IMPACTS

The impact of each of the ash disposal facility alternatives was compared using the (provided) significance rating table. A summary of the rating table scores are given in Table 6-1. The construction and decommissioning phases are expected to have medium impact (32 points) which can be lowered further with mitigation measures (as recommended in Section 2.1.1 and Section 7). Impacts during the operational phase are expected to be of medium significance, except Alternative A, if left unmitigated. Due to the elevated particulate concentrations in the vicinity, the cumulative impact of any of the disposal facilities will be of medium significance, even if mitigated.

Table 6-1: Impact significance rating scores for the phases of ash disposal facility development for each alternative

Alternative	Construction phase		Operational phase		Decommissioning phase		Cumulative	
	without[1]	with[2]	without	with	without	with	without	with
Alternative A	32	12	64	18	32	12	68	36
Alternative B	32	12	56	18	32	12	60	36
Alternative C	32	12	44	18	32	12	48	36
No-go	42		42		42		42	
Linear infrastructure	16		16		16		16	

1. Without mitigation; 2. With mitigation

7 MITIGATION AND MANAGEMENT MEASURES

Appropriate mitigation and management measures will not be influenced by the final location of the ash disposal facility. The following sections describe the mitigation and management measure appropriate to each stage of the ash disposal facility development.

7.1 Construction phase

The construction of the ash disposal facility will be mostly a sporadic process, including vegetation and top-soil clearing ahead of the active disposal area. The complexity of estimating dust emissions during this phase is a result of the types of activities, the varying duration and extent of each activity. The impact of the construction phase on air quality is expected to be limited to on-site impacts. Typical dust suppression techniques, for example, water sprays, will reduce dust emissions further, especially during dry and windy conditions.

7.2 Operational phase

Irrespective of the location of the ash disposal facility the model simulations show that mitigation of dust emissions will be critical to maintain PM_{10} concentrations with the South African NAAQS. The re-vegetation and watering scenario described in preceding sections is based on the Tutuka Ash Disposal Operations Manual (SRK, 1984). In order to ensure that mitigation is effective it is recommended that dust fall monitoring around the perimeter of the ash disposal facility continues, especially in the direction of the prevailing winds and near any sensitive receptors. It is also recommended that PM_{10} be monitored near the ash disposal facility, especially if this is away from any monitoring undertaken by the power station. The PM_{10} filters and dust fall-out can further be analysed for heavy metals.

7.3 Decommissioning phase

The mitigation measures applied during the operational phase should continue during the decommissioning phase to limit dust emissions from the ash disposal facility. This will include dust suppression by watering and covering with top-soil and replanting of grass seeds. Decommissioning should also include inspection of the entire disposal facility to ensure that vegetation coverage is complete and effective in minimising dust emissions.

8 SITE PREFERENCE RANKING

The alternatives for the ash disposal facility were compared on the basis of minimising the impact on air quality (**Table 8-1**). The comparison was made using the unmitigated scenario. Because longer-term (annual) modelled estimates are more confidently projected, the comparison focussed on these findings, especially at the identified sensitive receptors. Because national standards are defined for PM_{10} and $PM_{2.5}$, due to potential human health impacts, these criteria were assigned more weight in the overall comparison. The impact of dust fall-out on agriculture, where dust fall-out rates exceed >400 $mg.m^{-2}.day^{-1}$, was also included as an assessment criteria. Based on the four criteria (**Table** 8-1), Alternative C is considered most preferred followed by A or B.

Table 8-1: Alternative preference based on four criteria for minimising impacts to air quality*

Criteria	Preferred	Acceptable	Not preferred	Not suitable
Annual PM_{10} at sensitive receptors	C	A	B	-
Annual PM_{10} impact zone area	C	B	A	-
Annual $PM_{2.5}$ at sensitive receptors	C	A	B	-
Dust fall-out >400 $mg.m^{-2}.day^{-1}$ impact area	C	B	A	-

9 CONCLUSIONS

The following can be concluded from the air quality impact assessment:

- Particulate matter, as dust fall-out, PM_{10} and $PM_{2.5}$, were identified as the pollutants of concern.
- Annual average ground-level concentrations of PM_{10} simulated by dispersion modelling did exceed NAAQS over an area ranging between 611 ha (Alternative C) and 949 ha (Alternative A). The number of sensitive receptors where exceedances are predicted ranges between 1 (Alternative C) and 4 (Alternative B).
- Exceedances of daily standards for PM_{10} are expected lowest as a result of Alternative C.
- Irrespective of the alternative, effective and continuous application of the mitigation measures will be essential to maintaining compliance with the NAAQS.
- Alternatives C is the preferred sites, with Alternative A being acceptable.

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APPENDIX A: EFFECT OF PARTICULATE MATTER ON VEGETATION, ANIMALS AND SUSCEPTIBLE HUMAN RECEPTORS

A1: Effects of particular matter on vegetation

Suspended particulate matter can produce a wide variety of effects on the physiology of vegetation that in many cases depend on the chemical composition of the particle. Heavy metals and other toxic particles have been shown to cause damage and death of some species as a result of both the phytotoxicity and the abrasive action during turbulent deposition (Harmens *et al.*, 2005). Heavy particle loads can also result in reduced light transmission to the chloroplasts and the occlusion of stomata (Ricks and Williams, 1974, Hirano *et al.*, 1995; Naidoo and Chirkoot; 2004; Harmens *et al.*, 2005), decreasing the efficiency of gaseous exchange (Ernst 1981; Naidoo and Chirkoot, 2004; Harmens *et al.*, 2005) and hence water loss (Harmens *et al.*, 2005). Disruption of other physiological processes such as bud-break, pollination and light absorption/reflectance may also result under heavy particulate loads (Harmens *et al.*, 2005). The chemical composition of the dust particles can also affect exposed plant tissue and have indirect effects on the soil pH (Spencer, 2001).

To determine the impact of dust deposition on vegetation, two factors are of importance: (i) Does dust accumulate on vegetation surfaces and if it does, what are the factors influencing the rate of deposition (ii) Once the dust has been deposited, what is the impact of the dust on the vegetation? Regarding the first question, there is adequate evidence that dust does accumulate on all types of vegetation. Any type of vegetation causes a change in the local wind fields, increasing turbulence and enhancing the collection efficiency. Vegetation structure alters the rate of dust deposition such that the larger the "collecting elements" (branches and leaves), the lower the impaction efficiency per element. Therefore, for the same volume of tree/shrub canopy, finer leaves will have better collection efficiencies. However, the roughness of the leaves themselves, in particularly the presence of hairs on the leaves and stems, plays a significant role, with venous surfaces increasing deposition of 1-5 µm particles by up to seven-times compared to smooth surfaces. Collection efficiency rises rapidly with particle size; wind tunnel studies show a relationship of deposition velocity on the fourth power of particle size for moderate wind speeds (Tiwary and Colls, 2010). In wind tunnel studies also show that windbreaks or "shelter belts" of three rows of trees has shown a decrease of between 35 and 56% of the downwind mass transport of inorganic particles.

After deposition onto vegetation, the effect of particulate matter depends on the composition of the dust. South African ambient standards are set in terms of PM_{10} but internationally it is recognised that there are major differences in the chemical composition of the fine PM (the fraction between 0 and 2.5 µm in aerodynamic diameter) and coarse PM (the fraction between 2.5 µm and 10 µm in aerodynamic diameter). The former is often the result of chemical reactions in the atmosphere and may have a high proportion of black carbon, sulfate and nitrate; whereas the latter often consists of primary particles as a result of abrasion, crushing, soil disturbances and wind erosion (Grantz *et al.*, 2003). Sulfate is however often hygroscopic and may exist in significant fractions in coarse PM. This has been shown at

the Elandsfontein, Eskom air quality monitoring station where the PM_{10} has been shown to vary between 15% (winter) and 49% (spring) sulfate (Alade, 2010). Grantz *et al.* (2003) however indicate that sulfate is much less phototoxic than gaseous sulfur dioxide and that "it is unusual for injurious levels of particular sulfate to be deposited upon vegetation".

Naidoo and Chirkoot (2004) conducted a study to investigate the effects of coal dust on mangrove trees at two sites in the Richards Bay harbour. Mature fully-exposed sun leaves of 10 trees (*Avicennia marina)* were tagged as being covered or uncovered with coal dust and photosynthetic rates were measured. It was concluded that coal dust significantly reduced photosynthesis of upper and lower leaf surfaces and reduction in growth and productivity was expected. In addition, trees in close proximity to the coal stockpiles were in poorer health than those further away. Coal dust particles, which are composed predominantly of carbon, were not toxic to the leaves; neither did they occlude stomata as they were larger than fully open stomatal apertures (Naidoo and Chirkoot, 2004).

According to the Canadian Environmental Protection Agency (CEPA), generally air pollution adversely affects plants in one of two ways. Either the quantity of output or yield is reduced or the quality of the product is lowered. The former (invisible) injury results from pollutant impacts on plant physiological or biochemical processes and can lead to significant loss of growth or yield in nutritional quality (e.g. protein content). The latter (visible) may take the form of discolouration of the leaf surface caused by internal cellular damage. Such injury can reduce the market value of agricultural crops for which visual appearance is important (e.g. lettuce and spinach). Visible injury tends to be associated with acute exposures at high pollutant concentrations whilst invisible injury is generally a consequence of chronic exposures to moderately elevated pollutant concentrations. However given the limited information available, specifically the lack of quantitative dose-effect information, it is not possible to define a reference level for vegetation and particulate matter (CEPA, 1998).

Exposure to a given concentration of airborne PM may therefore lead to widely differing phytotoxic responses, depending on the mix of the deposited particles. The majority of documented toxic effects indicate responses to the chemical composition of the particles. Direct effects have most often been observed around heavily industrialised point sources, but even there, effects are often associated with the chemistry of the particulate rather than with the mass of particulate.

A review of European studies has shown the potential for reduced growth and photosynthetic activity in sunflower and cotton plants exposed to dust fall rates greater than 400 $mg.m^{-2}.day^{-1}$. Little direct evidence of the effects of dust-fall on South African vegetation, including crops, exists.

Effects of particulate matter on animals

As presented by the Canadian Environmental Protection Agency (CEPA, 1998) studies using experimental animals have not provided convincing evidence of particle toxicity at ambient levels. Acute exposures (4-6 hour single exposures) of laboratory animals to a variety of types of particles, almost always at concentrations well above those occurring in the environment have been shown to cause:

- decreases in ventilatory lung function;
- changes in mucociliary clearance of particles from the lower respiratory tract (front line of defence in the conducting airways);
- increased number of alveolar macrophages and polymorphonuclear leukocytes in the alveoli (primary line of defence of the alveolar region against inhaled particles);
- alterations in immunologic responses (particle composition a factor, since particles with known cytotoxic properties, such as metals, affect the immune system to a significantly greater degree);
- changes in airway defence mechanisms against microbial infections (appears to be related to particle composition and not strictly a particle effect);
- increase or decrease in the ability of macrophages to phagocytize particles (also related to particle composition);
- a range of histologic, cellular and biochemical disturbances, including the production of proinflammatory cytokines and other mediators by the lungs alveolar macrophages (may be related to particle size, with greater effects occurring with ultrafine particles);
- increased electrocardiographic abnormalities (an indication of cardiovascular disturbance); and,
- increased mortality.

Bronchial hypersensitivity to non-specific stimuli, and increased morbidity and mortality from cardio-respiratory symptoms, are most likely to occur in animals with pre-existing cardio-respiratory diseases. Sub-chronic and chronic exposure tests involved repeated exposures for at least half the life-time of the test species. Particle mass concentrations to which test animals were exposed were very high (> 1 mg m^{-3}), greatly exceeding levels reported in the ambient environment. Exposure resulted in significant compromises in various lung functions similar to those seen in the acute studies, but including also:

- reductions in lung clearance;
- induction of histopathologic and cytologic changes (regardless of particle types, mass, concentration, duration of exposure or species examined);
- development of chronic alveolitis and fibrosis; and
- development of lung cancer (a particle and/or chemical effect).

The epidemiological finding of an association between 24-hour ambient particle levels below 100 $\mu g.m^{-3}$ and mortality has not been substantiated by animal studies as far as PM_{10} and $PM_{2.5}$ are concerned. At ambient concentrations, none of the other particle types and sizes used in animal inhalation studies result in acute effects, including high mortality, with exception of ultrafine particles (0.1 µm). The lowest concentration of $PM_{2.5}$ reported that caused acute death in rats with acute pulmonary inflammation or chronic bronchitis was 250 $g.m^{-3}$ (3 days, 6 $hour.day^{-1}$), using continuous exposure to concentrated ambient particles.

Most of the literature regarding air quality impacts on cattle refers to the impacts from feedlots on the surrounding environment, hence where the feedlot is seen as the source of pollution. This mainly pertains to odours and dust generation. The US-EPA recently focussed on the control of air pollution from feed yards and dairies, primarily regulating coarse particulate matter. However, the link between particulates and public health is considered to be understudied (Sneeringer, 2009).

A study was conducted by the State University of Iowa on the effects of air contaminants and emissions on animal health in swine facilities. Air pollutants included gases, particulates, bioaerosols, and toxic microbial by-products. The main findings were that ammonia is associated with lowered average number of pigs weaned, arthritis, porcine stress syndrome, muscle lesions, abscesses, and liver ascarid scars. Particulates are associated with the reduction in growth and turbine pathology, and bioaerosols could lower feed efficiency, decrease growth, and increase morbidity and mortality. The authors highlighted the general lack of information on the health effects and productivity-problems of air contaminants on cattle and other livestock. Ammonia and hydrogen sulphide are regarded the two most important inorganic gases affecting the respiratory system of cattle raised in confinement facilities, affecting the mucociliary transport and alveolar macrophage functions. Holland *et al.,* (2002) found that the fine inhalable particulate fraction is mainly derived from dried faecal dust.

Inhalation of confinement-house dust and gases produces a complex set of respiratory responses. An individual's response depends on characteristics of the inhaled components (such as composition, particle size and antigenicity) and of the individual's susceptibility, which is tempered by extant respiratory conditions (Davidson *et al.*, 2005). Most studies concurred that the main implication of dusty environments is the stress caused to animals which is detrimental to their general health. However, no threshold levels exist to indicate at what levels these are having a negative effect. In this light it was decided to use the same screening criteria applied to human health, i.e. the South African Standards and SANS limit values.

An investigation into extra-pulmonary migration of metals in coal fly-ash revealed that potentially carcinogenic trace metals (chromium, copper, cadmium, lead, and manganese) can accumulate in the livers of rats subsequent to acute inhalation of fly-ash, resulting in altered cellular biochemistry and histomorphology (Mani *et al.*, 2007). These results suggest that exposure to elevated particulate matter concentrations may not be limited to the pulmonary system.

Effect of particulate matter on susceptible human receptors

The impact of particles on human health is largely depended on (i) particle characteristics, particularly particle size and chemical composition, and (ii) the duration, frequency and magnitude of exposure. The potential of particles to be inhaled and deposited in the lung is a function of the aerodynamic characteristics of particles in flow streams. The aerodynamic properties of particles are related to their size, shape and density. The deposition of particles in different regions of the respiratory system depends on their size.

The nasal openings permit very large dust particles to enter the nasal region, along with much finer airborne particulates. These larger particles are deposited in the nasal region by impaction on the hairs of the nose or at the bends of the nasal passages. The smaller particles (PM_{10}) pass through the nasal region and are deposited in the tracheobronchial and pulmonary regions. Then particles are removed by impacting with the wall of the bronchi when they are unable to follow the gaseous streamline flow through subsequent bifurcations of the bronchial tree. As the airflow decreases near the terminal bronchi, the smallest particles are removed by Brownian motion, which pushes them to the alveolar membrane (CEPA, 1998; Dockery and Pope, 1994).

The air quality guidelines for particulates are given for various particle size fractions, including total suspended particulates (TSP), thoracic particulates or PM_{10} (i.e. particulates with an aerodynamic diameter of less than 10 µm), and respirable particulates or $PM_{2.5}$ (i.e. particulates with an aerodynamic diameter of less than 2.5 µm). Although TSP is defined as all particulates with an aerodynamic diameter of less than 100 µm, and effective upper limit of 30 µm aerodynamic diameter is frequently assigned. The PM_{10} and $PM_{2.5}$ are of concern due to their health impact potentials. As indicated previously, such fine particles are able to be deposited in, and damaging to, the lower airways and gas-exchanging portions of the lung.

The World Health Organization states that the evidence on airborne particulates and public health consistently shows adverse health effects at exposures experienced by urban populations throughout the world. The range of effects is broad, affecting the respiratory and cardiovascular systems and extending from children to adults including a number of large, susceptible groups within the general population (Table A-1). Long-term exposure to particulate matter has been found to have adverse effects on human respiratory health (Abbey *et al.*, 1995). Respiratory symptoms in children resident in an industrialised city were found not to be associated with long-term exposure to particulate matter; however non-asthmatic symptoms and hospitalizations did increase with increased total suspended particulate concentrations (Hruba *et al.*, 2001). The epidemiological evidence shows adverse effects of particles after both short-term and long-term exposures. However, current scientific evidence indicates that guidelines cannot be proposed that will lead to complete protection against adverse health effects as thresholds have not been identified.

Many scientific studies have linked inhaled particulate matter to a series of significant health problems, including:

- aggravated asthma;
- increases in respiratory symptoms like coughing and difficult or painful breathing;
- chronic bronchitis;
- decreased lung function; and,
- premature death.

PM_{10} is the standard measure of particulate air pollution used worldwide and studies suggest that asthma symptoms can be worsened by increases in the levels of PM_{10}, which is a complex mixture of

particle types. PM_{10} has many components and there is no general agreement regarding which component(s) could exacerbate asthma. However, pro-inflammatory effects of transition metals, hydrocarbons, ultrafine particles (due to combustion processes) and endotoxins - all present to varying degrees in PM_{10} - could be important.

Table A-1: Summary of adverse human health effects from particulate matter exposure

Health Effects	Susceptible Groups	Notes
Acute (short-term) exposure		
Mortality	Elderly, infants, persons with chronic cardiopulmonary disease, influenza or asthma	Uncertainty regarding how much life shortening is involved and how much is due to short-term mortality displacement.
Hospitalisation / other health care visits	Elderly, infants, persons with chronic cardiopulmonary disease, pneumonia, influenza or asthma	Reflects substantive health impacts in terms of illness, discomfort, treatment costs, work or school time lost, etc.
Increased respiratory symptoms	Most consistently observed in people with asthma, and children	Mostly transient with minimal overall health consequences, although for a few there may be short-term absence from work or school due to illness.
Decreased lung function	Observed in both children and adults	For most, effects seem to be small and transient. For a few, lung function losses may be clinically relevant.
Chronic (long-term) exposure		
Increased mortality rates, reduced survival times, chronic cardiopulmonary disease, reduced lung function, lung cancer	Observed in broad-based cohorts or samples of adults and children (including infants). All chronically exposed are potentially affected.	Long-term repeated exposure appears to increase the risk of cardiopulmonary disease and mortality. May result in lower lung function. Average loss of life expectancy in highly polluted cities may be as much as a few years.

Source: Adopted from Pope (2000) and Pope *et al.* (2002)

APPENDIX B: FUGITIVE DUST EMISSIONS FROM EXPOSED AREAS

Significant emissions arise due to the mechanical disturbance of granular material from disturbed open areas and storage piles. Parameters which have the potential to impact on the rate of emission of fugitive dust include the extent of surface compaction, moisture content, ground cover, the shape of the storage pile, particle size distribution, wind speed and precipitation. Any factor that binds the erodible material, or otherwise reduces the availability of erodible material on the surface, decreases the erosion potential of the fugitive source. High moisture contents, whether due to precipitation or deliberate wetting, promote the aggregation and cementation of fines to the surfaces of larger particles, thus decreasing the potential for dust emissions. Surface compaction and ground cover similarly reduces the potential for dust generation. The shape of a storage pile or disposal dump influences the potential for dust emissions through the alteration of the airflow field. The particle size distribution of the material on the disposal site is important since it determines the rate of entrainment of material from the surface, the nature of dispersion of the dust plume, and the rate of deposition, which may be anticipated (Burger, 1994).

Wind erosion is a complex process, including three different phases of particle entrainment, transport and deposition. It is primarily influenced by atmospheric conditions (e.g. wind, precipitation and temperature), soil properties (e.g. soil texture, composition and aggregation), land-surface characteristics (e.g. topography, moisture, aerodynamic roughness length, vegetation and non-erodible elements) and land-use practice (e.g. farming, grazing and mining).

Windblown dust generates from natural and anthropogenic sources. For wind erosion to occur, the wind speed needs to exceed a certain threshold, called the threshold velocity. This relates to gravity and the inter-particle cohesion that resists removal. Surface properties such as soil texture, soil moisture and vegetation cover influence the removal potential. Conversely, the friction velocity or wind shear at the surface is related to atmospheric flow conditions and surface aerodynamic properties. Thus, for particles to become airborne the wind shear at the surface must exceed the gravitational and cohesive forces acting upon them, called the threshold friction velocity (Shao, 2008).

Estimating the amount of windblown particles to be generated from a stockpile is not a trivial task and requires detailed information on the particle size distribution, moisture content, silt content and particle density. Dust will only be generated under conditions of high wind speed which is likely to occur when winds exceed 5.4 $m.s^{-1}$ (US-EPA, 1995b).

An hourly emissions file was created for each of these source groups. The calculation of an emission rate for every hour of the simulation period was carried out using the ADDAS model (Burger *et al.*, 1997). This software is based on the dust emission models proposed by Marticorena and Bergametti (1995) and Shao (2008). The models attempt to account for the variability in source erodibility through the parameterisation of the erosion threshold (based on the particle size distribution of the source) and the roughness length of the surface.

In the quantification of wind erosion emissions, the models incorporates the calculation of two important parameters, viz. the threshold friction velocity of each particle size, and the vertically integrated horizontal dust flux, in the quantification of the vertical dust flux (i.e. the emission rate). In the Marticorena and Bergametti Model, the vertical flux is given by the following equation:

$$F(i) = G(i)10^{(0.134(\%clay)-6)}$$

for

$$Q(i) = 0.261\left[\frac{P_a}{g}\right]u^{*3}(1+R)(1-R^2)$$

and $$R = \frac{u_*^t}{u^*}$$

where,

$F_{(i)}$	=	emission rate (g/m²/s) for particle size class i
P_a	=	air density (g/cm³)
g	=	gravitational acceleration (cm.s^{-2})
u_*^t	=	threshold friction velocity (m/s) for particle size i
u^*	=	friction velocity (m.s^{-1})

With the model based on Shao (2008), the horizontal flux is as described by the equation above and the vertical flux is given by

$$F(i) = \beta(i)Q(i)u_*^{-2}$$

for

$$\beta(i) = 10^{-5}\left[1.25\ln(d_s) + 3.28\right]\exp\left(-140.7d_d + 0.37\right)$$

where,

d_s	=	the saltator particle size (mm)
d_d	=	the dust particle size (mm)

Dust mobilisation occurs only for wind velocities higher than a threshold value, and is not linearly dependent on the wind friction and velocity. The threshold friction velocity, defined as the minimum friction velocity required to initiate particle motion, is dependent on the size of the erodible particles and the effect of the wind shear stress on the surface. The threshold friction velocity decreases with a decrease in the particle diameter, for particles with diameters >60 µm. Particles with a diameter <60 µm result in increasingly high threshold friction velocities, due to the increasingly strong cohesion forces linking such particles to each other (Marticorena and Bergametti, 1995). The relationship between particle sizes ranging between 1 µm and 500 µm and threshold friction velocities (0.24 to 3.5 m.s^{-1}), estimated based on the equations proposed by Marticorena and Bergametti (1995), is illustrated in Figure.

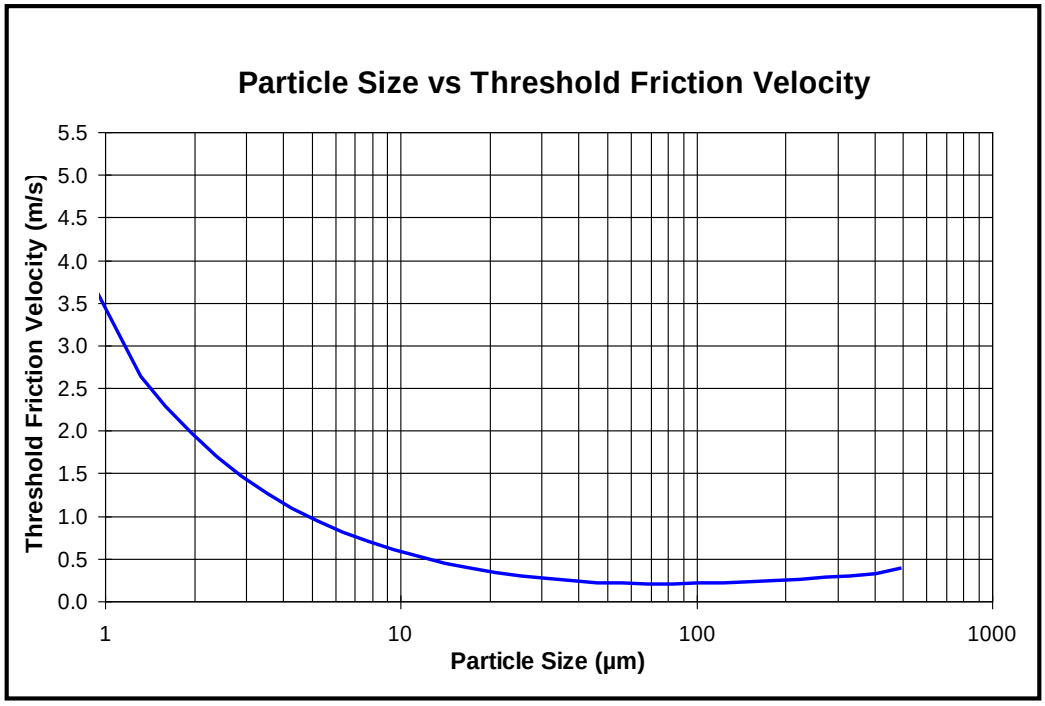

Figure B-1: Relationship between particle sizes and threshold friction velocities using the calculation method proposed by Marticorena and Bergametti (1995)

APPENDIX C: EVALUATION OF SUSPENDED PARTICULATE SAMPLERS

Suspended particle samplers can be filter-based or non-filter-based, intermittent or continuous and off-line or near real time.

B1: Filter-based Monitors

Filter-based monitors include various *off-line* samplers, such as stacked filter units (SFU) and sequential air samplers, and certain continuous *real-time* monitors such as the Tapered Element Oscillating Microbalance (TEOM) and the beta gauge or beta-attenuation mass (BAM) monitors.

B1.1 Filter-based, Off-line Samplers (SFUs, Sequential Samplers)

Stacked filter units and sequential air samplers are most frequently used when elemental, ionic and/or carbon analyses are required of the measured particulates. Filters are required to be weighed prior to their being loaded in the sampler for exposure in the field. Following exposure the filters are removed are reweighed in a lab to determine the particulate concentration. The filters may then be sent for elemental (etc.) analysis. Teflon-membrane filters are commonly used for mass and elemental analysis. These filters do have the advantage that they are economical to purchase and operate, can be operated by site personnel with limited training and provide results that are directly comparable to the SA daily standards.

Sequential air samplers with sequential dichotomous configurations splits the PM_{10} sample stream into its fine ($PM_{2.5}$) and coarse (particles between 2.5 and 10 µm in size) fractions - collecting the fine and coarse mode particulates simultaneously on two different filters. Certain of these systems (e.g. Partisol-Plus Air Samplers, Figure C-1, have capacities of up to 16 filter cassettes with an automatic filter exchange mechanism. (Filter changes can be triggered on a temporal basis or based on wind direction.) Once the 16 filters have been exposed, the filters would require collection and replacement.

Figure C-1: Partisol-Plus Sequential Air Sampler

Key disadvantages of *off-line* filter-based samplers such as the SFU and sequential air sampler include: the labour intensive nature of this monitoring technique and the large potential which exists for filter contamination due to the level of filter handling required. Real-time measurements are also not possible through the application of these samplers making it impossible to identify pollution episodes on a timely basis.

B1.2 Filter-based, On-line Samplers (TEOM, BAM)

The TEOM is operates by continuously measuring the weight of particles deposited onto a filter. The filter is attached to a hollow tapered element which vibrates at its natural frequency of oscillation - as particles progressively collect on the filter, the frequency changes by an amount proportional to the mass deposited. As the airflow through the system is regulated, it is possible to determine the concentration of particulates in the air. The filter requires changing periodically, typically every 2 to 4 weeks, and the instrument is cleaned whenever the filter is changed. Different inlet arrangements are used to configure the instrument. TEOMs can monitor PM_{10}, $PM_{2.5}$, PM_1 and TSP continuously. Data averages and update intervals include: 5-minute total mass average (every 2 seconds), 10-minute rolling averages (every 2 seconds), 1-hour averages, 8-hour averages, 24-hour averages (etc.). The TEOM has a minimum detection limit of 0.01 µg/m^3.

Beta attenuation monitors collect particulates on a filter paper over a specified cycle time. The attenuation of beta particles through the filter is continuously measured over this time. BAMs give real-time measurement of either TSP, PM_{10} or $PM_{2.5}$ depending on the inlet arrangement. At the start of the

cycle, air is drawn through a glass fibre filter tape, where the particulates deposit. Beta particles that are emitted from either a C14 or a K85 sources are attenuated by the particles collecting on the filter. The radiation passing through the tape is detected by a scintillator and photomultiplier assembly. A reference measurement is made through a clean portion of the filter, either during or prior to the accumulation of the particles - the measurement enables baseline shifts to be corrected for.

Application of filter-based, on-line samplers such as either the BAM or TEOM monitors has several distinct advantages including:

- continuous, near-real-time aerosol mass monitoring;
- self-contained, automated monitoring approach requiring limited operator intervention following installation;
- a choice of averaging times from 1 minute to 24 hours;
- low labour costs, minimal filter handling and a reduction in the risk of filter contamination; and
- non-destructive monitoring methods providing the potential of supplying samples which may be submitted for chemical analysis.

The TEOM is US-EPA approved (EQPM-1090-079) as an equivalent method for measuring 24-hour average PM_{10} concentrations in ambient air quality. It represents the only continuous monitor which meets the California Air Resources Board acceptance criteria for 1-hour mass concentration averages. TEOM instrumentation also has German TÜV approval for TSP measurements. Not all beta gauges are US-EPA approved, with only the Andersen (FAG-Kigelfischer, Germany) and Wedding beta monitor having been approved.

The performance of the TEOM and BAM monitors are compared in Table C-1. The TEOM tends to perform better than BAMs in many respects, particularly with regard to the precision of measurements made. An additional advantage of the TEOM (14000 series) is the optional inclusion of the ACCU system. This system allows for conditional sampling by time/date, particulate concentration and/or wind speed and direction. The application of the TEOM in combination with the ACCU system could therefore allow for the assessment of an operation's contribution to particulate concentrations occurring at a site on an on-line real-time basis.

Table C-1-1: Comparison of TEOM and BAM performance

	TEOM	BAM
Principle of operation	*Measured mass* on a filter based upon inertia (as fundamental as gravimetric method).	*Inferred mass* on a filter based upon the strength of a radioactive beam.
	Measures *only mass* (represents a true mass measurement)	Do *not* measure mass but rather the transmission of beta rays
Advantages and disadvantages	Performs well under varying humidity conditions. Samples and measures at a defined filter face velocity and conditioning temperature to ensure standardized data under low humidities	Can produce erroneous measurements under changing humidity conditions
	Not sensitive to particulate composition since it makes a mass-based measurement.	Sensitive to interferences (site/season specific) arising due to: particle composition, particle distribution across the filter, radioactive decay and the effect of air density in the radioactive beam.
Precision (measured by standard deviation)	Standard deviation for hourly data: ± 1.5-2.0 µg/m³. Precision of ±5 µg/m^3 for 10-minute averaged data.	Beta monitors with strong source: standard deviation for hourly data: ± 15-20 µg/m³. Beta monitors with weak source: hourly data not acceptable.

TEOMs have been found to typically under-predict actual particulate concentrations by a consistent amount (typically 18% to 25%). In the US TEOM results are typically multiplied by a factor of 1.3 to determine actual concentrations (this single factor is made possible by the consistency or high precision of the instrument). TEOMs tend to be less effective in environments with elevated nitrate concentrations or high potentials for the adsorption of volatile compounds on particles. Beta attenuation monitors perform poorly in areas with soils that have a radioactive component.

A common disadvantage of the TEOM and BAM monitors is that they all require electricity to operate thus limiting the potential sites for the location of such monitors. A further disadvantage of the TEOM and BAM monitors are that they are relatively costly to purchase. Despite the relatively high costs of purchasing continuous real-time monitors such as the TEOM and beta gauge monitors, significant savings can be achieved in the operation of such monitors due to the low labour costs and the minimal filter handling required by these techniques.

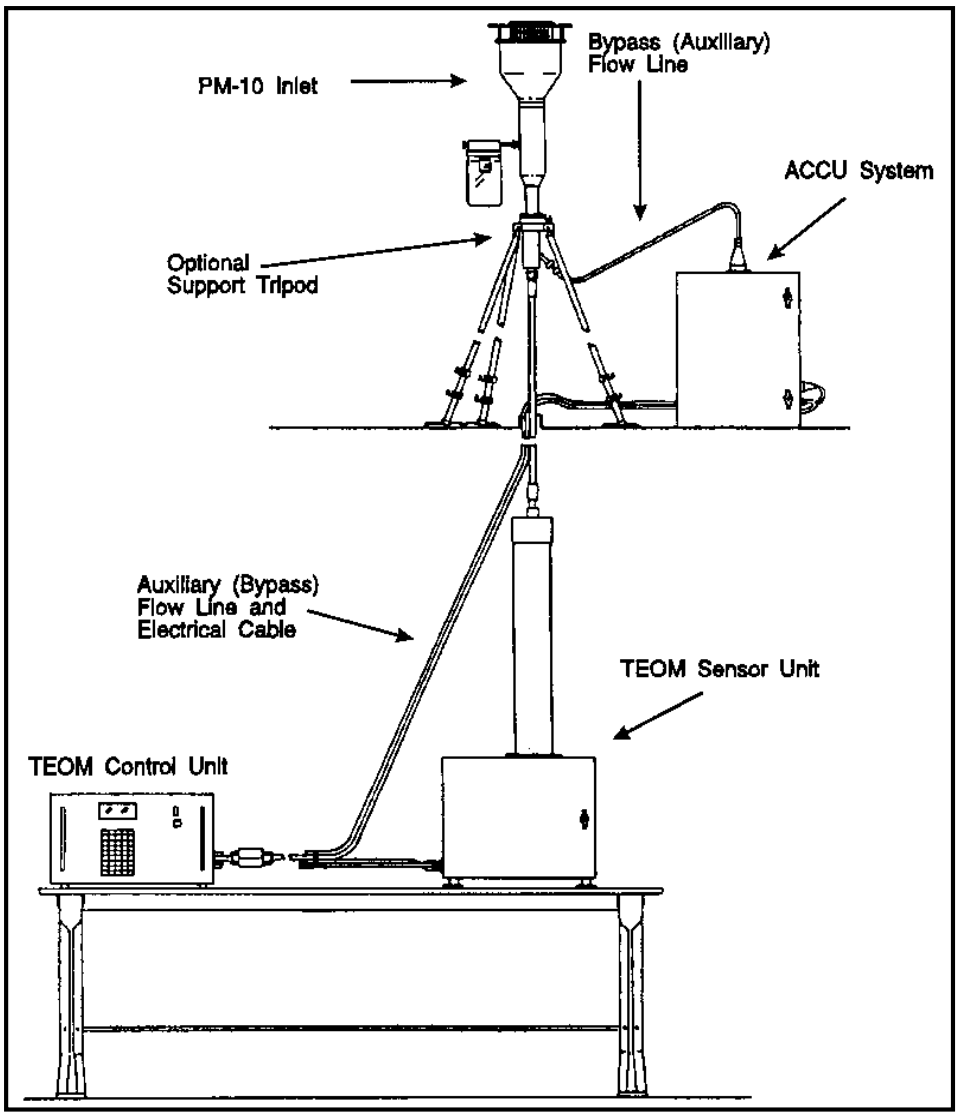

Figure C-2: TEOM sampler linked to the ACCU™ conditional sampling system

B2: Non-filter-based Monitors

Real-time but non-filter based monitors include the TSI DustTrak, the DustScan Sentinel Aerosol Monitor and the Topas Dust Monitor. Several of these monitors can be solar-powered negating the need for selecting a site with power access. Such monitors measures particle concentrations corresponding to various size fractions, including PM_{10}, $PM_{2.5}$ and $PM_{1.0}$, and comprise many of the benefits of the TEOM and BAM monitors including:

- continuous, near-real-time aerosol mass monitoring;
- a choice of averaging times from 1 minute to 24 hours;
- limited operator intervention; and
- minimal filter handling.

B3: Data Transfer Options

Although most analysers have internal data storage facilities, logging is usually carried out by means of a dedicated data logger (PC or specialised data logger). Data transfer may be undertaken in various ways:

- downloaded intermittently from the instrument - PC link cable required;
- real-time, continuous transfer via telemetry - telemetry control unit required;
- near real-time, intermittent transfer via radio link - requires transmitter and license to use frequency; or,
- continuous download via satellite.

In selecting the data transfer option possible future accreditation requirements must be taken into account, e.g.: (i) raw data is to be kept for minimum of 3 years, and (ii) all manipulations of data must be recorded.

B4: Sampler and Data Transfer Recommendations

The most suitable sampler type depends on the specific objectives of monitoring. Pertinent monitoring objectives in the case of the Tutuka Ash Disposal Facility are expected to include: on-going compliance evaluation, on-going estimation of contribution to airborne particulate concentrations, and evaluation of the effectiveness of dust control measures implemented at the mine.

Given the above objectives, it is recommended that Tutuka power station invest in the purchase of a filter-based, on-line monitor (e.g. TEOM, BAM). Real-time, continuous transfer of the measured concentrations (via telemetry, satellite, etc.) would contribute significantly to the use of such measurements to trigger rapid responses to pollution episodes.

Should the TEOM or BAM be considered too costly, investment in one of the non-filter based automatic monitors (e.g. DustTrak, DustScan, Topas). These instruments provide an indication of the range of particulate concentrations and despite possibly not being the preferred method for compliance monitoring, would provide the mine with a means of tracking progress made through emission reduction measure implementation.