*Project done for*

*Iliso Consulting (Pty) Ltd*

# The Co-Disposal of Gypsum with Ash at Kusile Power Station

## Air Quality Assessment

**Report No.: 13ILI01 Rev0**

***DATE: October 2013***

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## REPORT DETAILS

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| **Prepared by** | 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. |
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| **Acknowledgements** | The author would like to express their sincere appreciation for the invaluable discussions and technical input from Iliso Consulting (Pty) Ltd and to Eskom for making their meteorological and ambient data available for the assessment. |

# EXECUTIVE SUMMARY

Airshed Planning Professionals (Pty) Ltd was appointed by Iliso Consulting (Pty) Ltd to determine the potential for dust impacts on the surrounding environment and human health from the proposed disposal facility operations, with specific reference to air quality.

The proposed ash/gypsum dump is located approximately 20 km from the towns of Bronkhorstspruit (to the northwest), Kwa-Guaqa (to the northeast) and Ogies (to the southeast). Kusile Power Station and the disposal facility fall on the boundary of the Highveld Priority Area – an area of known or potentially poor air quality. It is likely that the disposal facility will influence the air quality within the Priority Area.

In modelling the projected impacts to air quality in the vicinity, meteorological data from the Kendal monitoring station for the period January 2009 to October 2012 was used. The dominant wind direction is west-northwest with a frequency of occurrence approaching 12%. Easterly sector winds are the next dominant with a frequency of 10%. The modelling of the impact to air quality included four scenarios, with respect to windblown dust emissions from the disposal facility: (1) unmitigated emissions; (2) mitigation through re-vegetation (to 80% of the facility area); (3) mitigation through wetting (maintaining the moisture content to 5%); and, (4) mitigation through both re-vegetation and wetting.

## ASSUMPTIONS AND LIMITATIONS

The following assumptions and limitations should be considered when interpreting the findings from the air quality assessment for the Project:

- An ash sample was acquired from Kendal Power Station. It is assumed that the particle size distribution and elemental composition will be similar to that from Kusile, when operational.
- Meteorological data was acquired from Eskom (Gerhardt de Beer) for the Kendal Power Station, for January 2009 to October 2012. Due to the proximity between Kusile and Kendal, it was assumed that the meteorological data are representative of the site.
- 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. 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.

- 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 United States Environmental Protection Agency (US-EPA) unit risk factor (URF), $4.3 \times 10^{-3} (\mu g/m^3)^{-1}$, 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 URF for cancer as a result of exposure to nickel used was $2.4 \times 10^{-4} (\mu g/m^3)^{-1}$.
    - The following important assumptions were made with regards to $Cr^{6+}$ 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 $1.1 \times 10^{-2} (\mu g/m^3)^{-1}$ to $13 \times 10^{-2} (\mu g/m^3)^{-1}$ as specified by the WHO. The US-EPA URF of $1.2 \times 10^{-3} (\mu g/m^3)^{-1}$ 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.
- The gypsum material co-disposed of on the disposal facility is expected to provide a crust when mixed with water. To what extent this material will crust will depend on how the material is disposed (i.e. mixed with the ash or deposited as layers of gypsum material in between the ash material) and how much water is added to the disposal facility. The crust may also be disturbed from time to time with activity on the disposal facility. For the current assessment, the effectiveness of this crust in lowering windblown emissions could not be quantified.

## KEY FINDINGS

The predicted $PM_{10}$ ground level concentrations exceeded the NAAQS beyond the boundary. Mitigation scenarios were included to illustrate the value in effective mitigation of wind-blown dust emissions to reduce the impact of the disposal facility. Mitigation using re-vegetation was more effective in controlling wind-blown dust emissions than only watering; however, the combination of both re-vegetation and watering was the most effective. Using either re-vegetation or a combination of re-vegetation and watering will reduce particulate concentrations to levels, off-site, that comply with NAAQS. Similar pattern is evident for $PM_{2.5}$ concentrations. Dust deposition due to unmitigated

operations exceeds the draft dust fallout regulations of 600 mg/m²/day beyond the boundary. Impacts are, however, significantly reduced to within the boundary once mitigation measures are applied.

The life-time increased cancer risk was calculated at identified sensitive receptors for exposure to inhalable arsenic, nickel and chromium. The calculations were based on the projected annual $PM_{10}$ concentrations at the various sensitive receptors, literature values for the proportion of the toxic forms of the trace metals in coal fly ash in combination with total trace metal concentrations in a sample of ash from Kendal Power station and the US-EPA IRIS Unit Cancer Risk Factor for exposure via inhalation. These calculations showed that the increased life-time cancer risk was low to very low.

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| | |
|---|---|
| **µg/m³** | Microgram per metre cubed |
| **µm** | Micrometre |
| **ASTM** | American Society for Testing and Materials |
| **CE** | Control efficiency |
| **CO** | Carbon monoxide |
| **$CO_2$** | Carbon dioxide |
| **DEA** | Department of Environmental Affairs |
| **FDA** | United States Food and Drug Administration |
| **FGD** | Fluidised Gas Desulphurisation |
| **g/s** | Grams per second |
| **g/m³** | Gram per cubic meter |
| **HC** | Hydro carbons |
| **HFO** | Heavy Fuel Oil |
| **HPA** | Highveld Priority Area |
| **m** | metre |
| **m²** | Metre squared |
| **m/s** | Metre per second |
| **mg/m²/day** | Milligram per metre squared per day |
| **mamsl** | metres above mean sea level |
| **mg/m²/day** | Milligram per meter squared per day |
| **mg/m³** | Milligram per cubic meter |
| **ng/m³** | Nano gram per cubic meter |
| **NAAQS** | National Ambient Air Quality Standards |
| **$NO_x$** | Oxides of nitrogen |
| **$NO_2$** | Nitrogen dioxide |
| **PM** | Particulate matter |
| **$PM_{10}$** | Particulate matter with an aerodynamic diameter of less than 10µm |
| **$PM_{2.5}$** | Particulate matter with an aerodynamic diameter of less than 2.5µm |
| **RfC** | Reference Concentration |
| **SA** | South Africa |
| **tpa** | Tonnes per annum |
| **TSP** | Total Suspended Particles |
| **URF** | Unit Risk Factor |
| **USA** | United States of America |
| **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 any area 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

Kusile Power Station is a coal-fired power generation facility on which construction started in mid-2008 with completion expected in 2016. The power station is located in the Nkangala District of Mpumalanga, approximately 20 km north-west of the existing Kendal Power Station (near the town of Ogies).

Above ground ash disposal will be used at the Kusile Power Station. The ash produced through the combustion of the coal will be removed from the bottom of the boiler (boiler bottom ash) and the fly ash removed from the top of the boiler together with the flue gas (via electrostatic precipitators or bag filters) and sent to an ash/gypsum dump. The Flue Gas Desulphurisation (FGD) process that will be used to reduce sulphur emissions will also result in filter cake/gypsum which will be transported via a conveyer belt to the ash/gypsum disposal facility.

It is expected that the ash/gypsum dump will handle approximately 3 600 tonnes of ash and gypsum per day within the first four years, and 21 600 tonnes of ash and gypsum per day at year 5. For the next 5 years (year 6-10), the amounts of gypsum to be handled at the ash/gypsum dump will be 2 783.52 tonnes per day. It is expected that an additional 72 tonnes of gypsum per day will be produced from the FGD as belt filter press sludge.

Airshed Planning Professionals (Pty) Ltd was appointed by Iliso Consulting (Pty) to determine the potential for dust impacts on the surrounding environment and human health from the proposed ash/gypsum dump, 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 disposal facility and a watering programme for dust suppression.

## 1.1 Site Description

The proposed ash/gypsum dump is primarily surrounded by neighbouring mining operations, the Kusile Power Station, and agricultural activities. Major residential areas in the region include Bronkhorstspruit (20km northwest) and Kwa-Guaqa (~17km northeast). Smaller residential areas in the region include Wilge (~7km east-southeast), Phola (~11km east-southeast), Ogies (~17km southeast) and Kendal Forest Holdings (~10km south-southeast). Individual residences (i.e. farm houses) are also in the immediate vicinity of the proposed operations.

## 1.2 Air Quality Evaluation Approach

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 predicted impacts from the proposed activities.

## 1.3 Assumptions and limitations

- An ash sample was acquired from Kendal Power Station. It is assumed that the particle size distribution and elemental composition will be similar to that from Kusile, when operational.
- Meteorological data was acquired from Eskom (Gerhardt de Beer) for the Kendal Power Station, for January 2009 to October 2012. Due to the proximity between Kusile and Kendal, it was assumed that the meteorological data are representative of the site.
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is disposed (i.e. mixed with the ash or deposited as layers of gypsum material in between the ash material) and how much water is added to the disposal facility. The crust may also be disturbed from time to time with activity on the disposal facility. For the current assessment, the effectiveness of this crust in lowering windblown emissions could not be quantified.

## 1.4 Report Outline

Section 2 describes the legislative context applicable to the process. Section 3 of the report provides a description of the site specific dispersion potential through the discussion of near-site surface meteorology. Section 4 describes the approach taken to assess the impact of the disposal facility on the air quality in the vicinity. The main findings, thus far, are outlined in Section 5 and the significance rating in Section 6. An environmental impact statement for the Project is presented in Section 7. The references are provided in Section 8.

# 2 LEGAL REQUIREMENTS, HUMAN HEALTH CRITERIA AND EFFECTS ON ANIMALS AND VEGETATION

The environmental regulations and guidelines governing the emissions and impact of the ash disposal operations need to be considered prior to 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.

## 2.1 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 $PM_{10}$, $SO_2$, $NO_2$, ozone ($O_3$), CO, lead (Pb) and benzene. The NAAQS were published in the Government Gazette (no. 32816) on 24 December 2009 (Table 2-1). The $PM_{2.5}$ national ambient air quality standards were recently finalised and gazetted (Government Gazette no. 35463) on the 29th June 2012 with lowering concentration limits over three commitment periods.

**Table 2-1: South African national ambient air quality standards (Government Gazette 32816, 2009)**

| Substance | Molecular formula / notation | Averaging period | Concentration limit (µg/m$^3$) | Frequency of exceedance[(a)] | Compliance date[(b)] |
|---|---|---|---|---|---|
| Sulphur dioxide | $SO_2$ | 10 minutes | 500 | 526 | Immediate |
| | | 1 hour | 350 | 88 | Immediate |
| | | 24 hours | 125 | 4 | Immediate |
| | | 1 year | 50 | 0 | Immediate |
| Nitrogen dioxide | $NO_2$ | 1 hour | 200 | 88 | Immediate |
| | | 1 year | 40 | 0 | Immediate |
| 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 |

| Substance | Molecular formula / notation | Averaging period | Concentration limit ($\mu g/m^3$) | Frequency of exceedance[(a)] | Compliance date[(b)] |
|---|---|---|---|---|---|
| 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 |
| Ozone | $O_3$ | 8 hours (running) | 120 | 11 | Immediate |
| Benzene | $C_6H_6$ | 1 year | 10 | 0 | Immediate – 31 Dec 2014 |
| | | | 5 | 0 | 1 Jan 2015 |
| Lead | Pb | 1 year | 0.5 | 0 | Immediate |
| Carbon monoxide | CO | 1 hour | 30 000 | 88 | Immediate |
| | | 8 hour (calculated on 1 hour averages) | 10 000 | 11 | Immediate |

(a) The number of averaging periods where exceedance of limit is acceptable.

(b) Date after which concentration limits become enforceable.

## 2.2 National Regulations for Dust Deposition

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 averaged over 30 days in residential and light commercial areas measured using reference method ASTM 01739; or
    - 1200 $mg/m^2$/day averaged over 30 days in areas other than residential and light commercial areas measured using reference method ASTM 01739.

## 2.3 Highveld Priority Area

Highveld Airshed Priority Area Air Quality Management Plan – the Highveld Airshed was declared the second priority area by the minister at the end of 2007. This requires that an Air Quality Management Plan for the area be developed. The plan includes the establishment of an 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 Project is within the footprint demarcated as the Highveld Priority Area. Emission reduction strategies will be included for the numerous operations in the area with specific targets associated with it. The DEA has in September 2011 published the management plan for the Highveld Priority Area. 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

Goal 2 applies directly to the Project, the objectives associated with this goal include:

- Emissions are quantified from all sources.
- Gaseous and particulate emissions are reduced.
- Fugitive emissions are minimised.
- Emissions from dust generating activities are reduced.
- Incidences of spontaneous combustion are reduced.
- Abatement technology is appropriate and operational.
- Industrial Air Quality Management (AQM) decision making is robust and well-informed, with necessary information available.
- Clean technologies and processes are implemented.
- Adequate resources are available for AQM in industry.

- Ambient air quality standard and dust fallout limit value exceedances as a result of industrial emissions are assessed.
- A line of communication exists between industry and communities.

Each of these objectives is further divided into activities, each of which has a timeframe, responsibility and indicator. Refer to the HPA (2011) Highveld Priority Management Plan for further details.

## 2.4 Effect of Dust on Vegetation, Animals and Susceptible Human Receptors

### *2.4.1 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/m²/day. Little direct evidence of the effects of dust-fall on South African vegetation, including crops, exists.

### *2.4.2 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/m³), 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 µg $m^{-3}$ 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), 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.

### *2.4.3 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 2-2). 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 2-2: 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)

## 2.5 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 2-3), based on histologically diagnosed cancers in 2004, provide context for the increased risk as a result of exposure to the coal ash from the Kusile Power Station. From the metal analysis undertaken for the ash sample (from Kendal Power Station), increased life-time cancer risk was calculated for the three most abundant metals likely to result in increased risk of cancer.

**Table 2-3: 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 |

### *2.5.1 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 ng/m³ to 3 ng/m³ 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/m³. Concentrations can reach several hundred nanograms per cubic metre in some cities and exceed 1000 ng/m³ (1 µg/m³) 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 *et al.*, 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 µg/m$^3$, an estimate of life-time risk is 1.5 x 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 x 10$^{-3}$ (µg/m³)$^{-1}$. The US-EPA Integrated Risk Information System (IRIS) recommends a more conservative 4.3 x 10$^{-3}$ (µg/m³)$^{-1}$ URF for arsenic. It was decided to use the more conservative URF to estimate increased cancer risk through exposure to ash from the Kusile 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 in ash from the Kusile Power Station was calculated from the annual $PM_{10}$ concentrations at the identified sensitive receptors, assuming 10% of total As being carcinogenic.

### *2.5.2 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 µg.$m^{-3}$ of Ni compounds ranges between 2.1 x $10^{-4}$ (µg/$m^3$)$^{-1}$ and 37 x $10^{-4}$ (µg/$m^3$)$^{-1}$. The recommended inhalation URF for exposure to Ni refinery dust is 2.4 x $10^{-4}$ (µg/$m^3$)$^{-1}$ and for exposure to Ni subsulfide is 4.8 x $10^{-4}$ (µg.$m^{-3}$)$^{-1}$. Haney *et al.* (2012) recently presented a weighted URF of 1.74 x $10^{-4}$ (µg/$m^3$)$^{-1}$, translating into an ambient Ni concentration of 0.059 µg.$m^{-3}$ 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 Kusile Power Station was calculated from the annual $PM_{10}$ concentrations at the identified sensitive receptors using the URF of 2.4 x $10^{-4}$ (µg/$m^3$)$^{-1}$, recommended for nickel refinery dust. Due to the uncertainty in the literature of the carcinogenic Ni species and the proportion of carcinogenic species in relation to total Ni, it was conservatively assumed that 100% of Ni present in the ash from the Kusile Power Station would be carcinogenic.

### *2.5.3 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, Slimak, & Bagel, 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).

#### 2.5.3.1 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 Integrated Risk Information System (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.

#### 2.5.3.2 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 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.

$Cr^{6+}$ 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 $1.2 \times 10^{-2}$ $(\mu g/m^3)^{-1}$. 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 $13 \times 10^{-2}$ $(\mu g/m^3)^{-1}$. 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 Kusile was calculated from the annual $PM_{10}$ concentrations assuming 1.1% of total Cr as carcinogenic.

### *2.5.4 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 2-4). 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 2-4: 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 AIR QUALITY BASELINE EVALUATION

The baseline evaluation primarily comprises the assessment of near-site surface meteorology. Eskom ambient monitoring data from the Kendal Power Station monitoring site, 20 km south-east of the Kusile Power Station, provided an indication of the background air pollution in the region (Section 3.3).

## 3.1 Regional Climate and Atmospheric Dispersion Potential

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 for the Kendal Power Station site were available for the period January 2009 – October 2012.

### 3.1.1 Local wind field

The dominant wind direction (Figure 3-1), during the period under investigation, is west-north-west with a frequency of occurrence approaching 12%. Easterly sector winds are the next dominant with a frequency of 10%. Winds from the southern and south-western sectors occur relatively infrequently (<4% of the total period). Calm conditions (wind speeds <1 m/s) occur 6.66% of the time.

A frequent north-westerly flow dominates day-time conditions with >12% frequency of occurrence. At night, an increase in easterly flow is observed (~11% frequency).

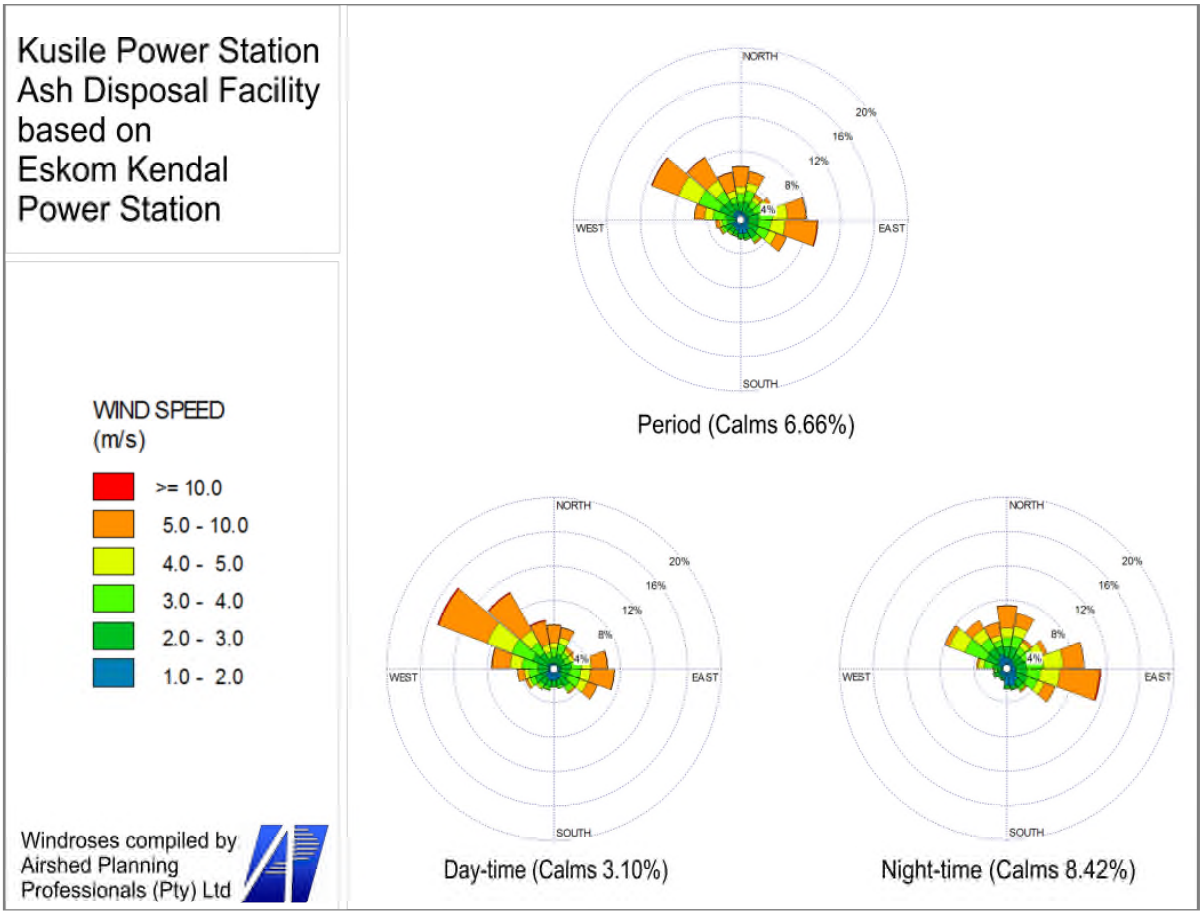


**Figure 3-1: Period, day-time and night-time wind roses for Kendal monitoring station (January 2009 – October 2012)**

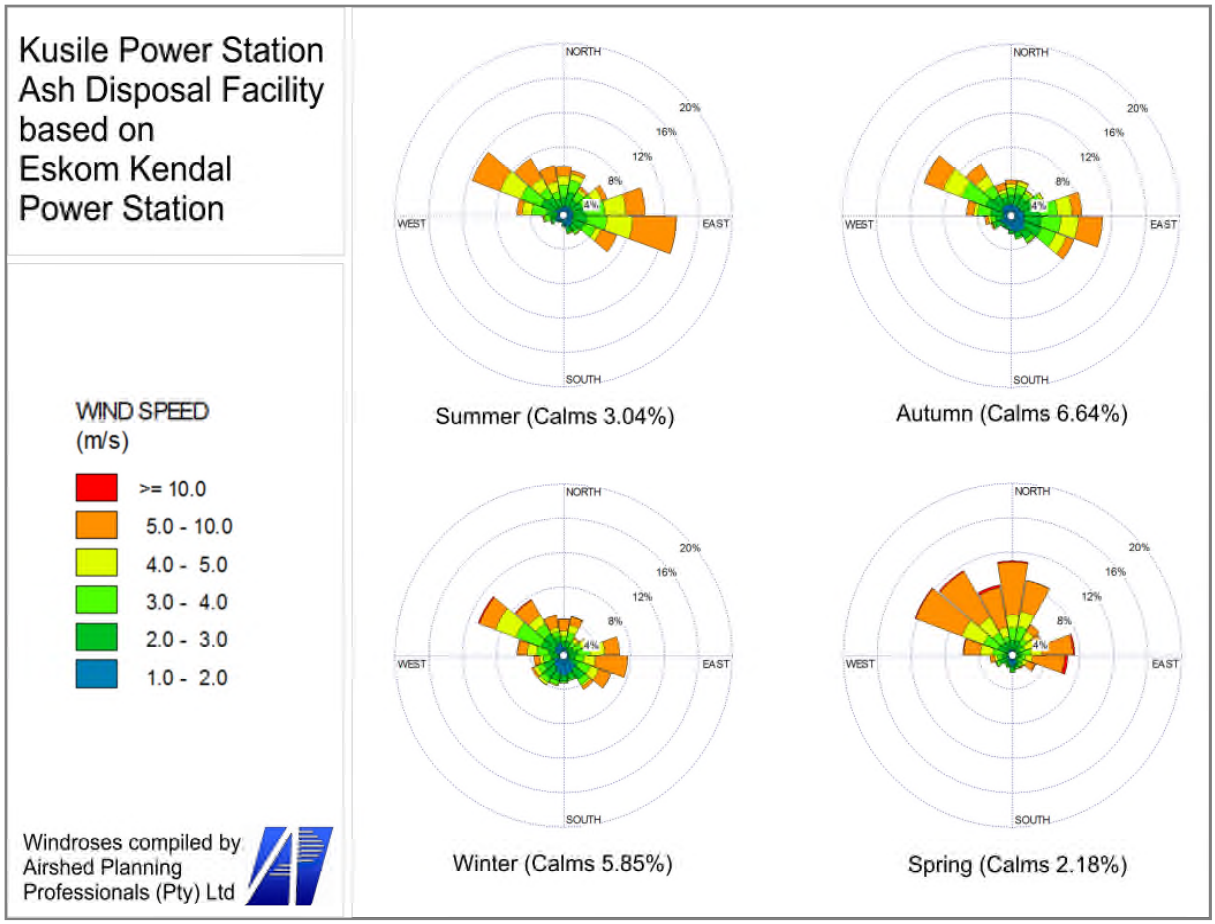


**Figure 3-2: Seasonal wind roses for Kendal monitoring station (January 2009 – October 2012)**

During summer months (Figure 3-2), winds from the east become slightly 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) during the autumn (6.64%) and winter months (5.85%) with an increase in the westerly flow. During spring-time, winds from the north-westerly sector dominate, frequently in the range of 5.0 to 10.0 m/s, with calm conditions only 2.18% of the time.

### *3.1.2 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 monthly temperature profile for the area is given in Figure 3-3. Annual average maximum, minimum and mean temperatures for the site are given as 26.5°C, 9.6°C and 16.2°C, respectively,

based on the measured data at Eskom's Kendal Power station for the period 2009 - October 2012. Average daily maximum temperatures range from 31.5°C in December to 19.9°C in June, with daily minima ranging from 14.5°C in December to 2.1°C in July (Figure 3-3).

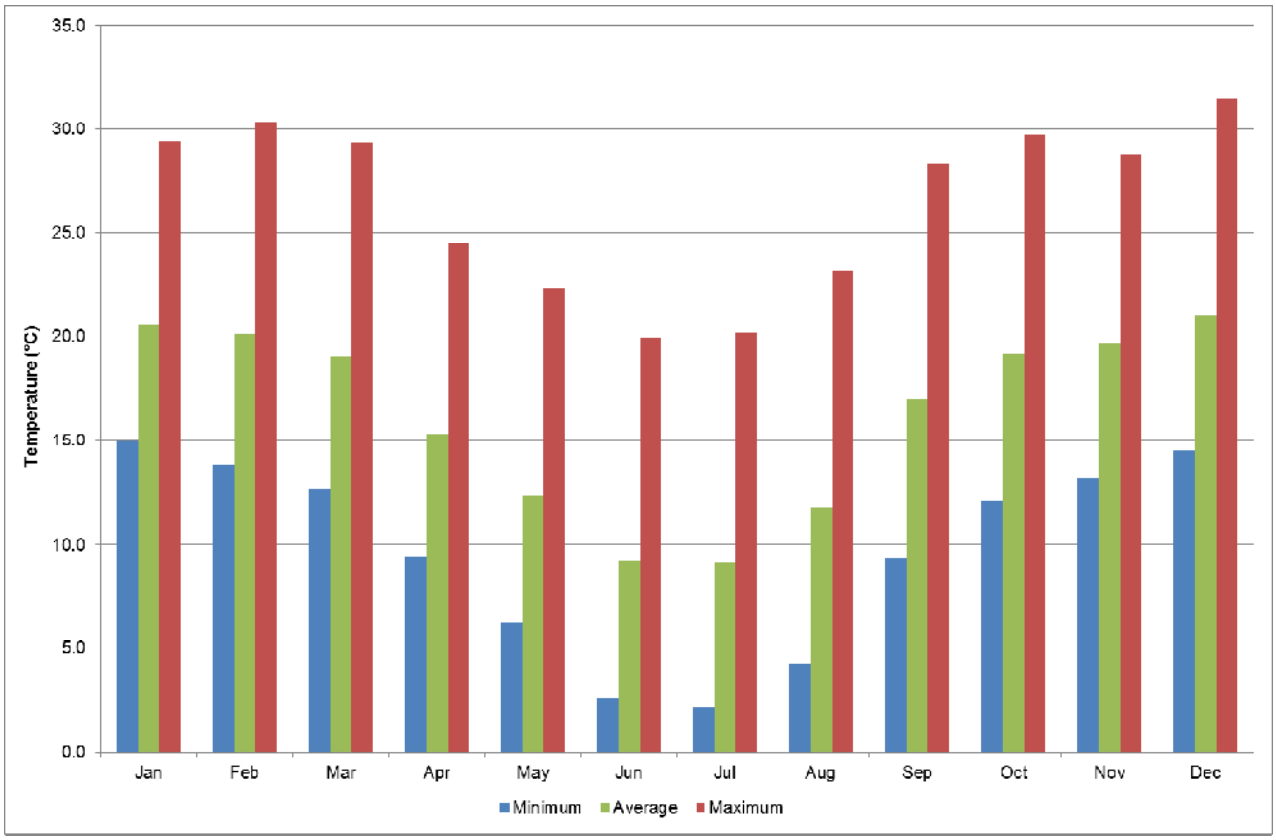


**Figure 3-3: Minimum, maximum and average monthly temperatures as measured at the Kendal monitoring station during the period January 2009 – October 2012**

### *3.1.3 Precipitation*

Rainfall represents an effective removal mechanism of atmospheric pollutants and is therefore frequently considered during air pollution studies. Precipitation records for the Kendal monitoring station were not available; long-term precipitation records for Middleburg and Bethal are presented below in the absence of these records.

Long-term total annual rainfall figures for various stations within the Emalahleni region is in the range of 730 mm to 750 mm (Table 3-1). Rain falls mainly in summer from October to April, with the peak for the region being in January.

**Table 3-1: Long-term mean monthly rainfall figures (mm) for various stations within the Emalahleni region**

| Station | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec | Ann |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Middelburg (1904 – 1950) | 132 | 103 | 88 | 42 | 19 | 7 | 9 | 8 | 22 | 63 | 124 | 118 | 735 |
| Bethal (1904 – 1984) | 134 | 94 | 78 | 46 | 19 | 7 | 8 | 10 | 25 | 78 | 128 | 120 | 747 |

### *3.1.4 Atmospheric Stability*

The atmospheric boundary layer constitutes the first few hundred metres of the atmosphere. This layer is directly affected by the earth's surface, either through the retardation of flow due to the frictional drag of the earth's surface, or as result of the heat and moisture exchanges that take place at the surface. During the daytime, the atmospheric boundary layer is characterised by thermal turbulence due to the heating of the earth's surface and the extension of the mixing layer to the lowest elevated inversion. Radiative flux divergence during the night usually results in the establishment of ground based inversions and the erosion of the mixing layer (Figure 3-4).

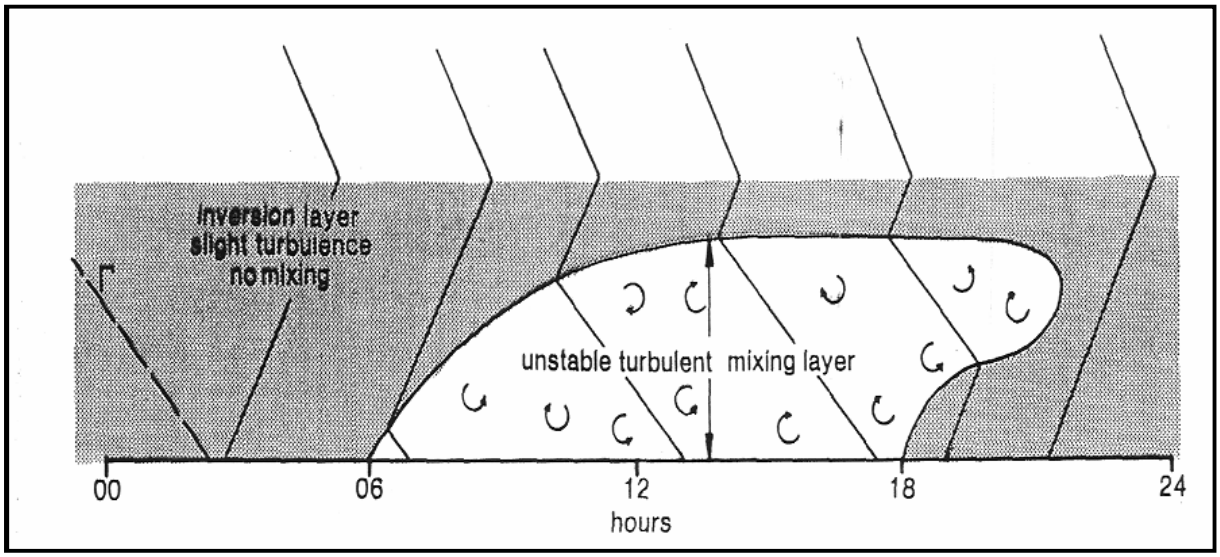


**Figure 3-4: Daytime development of a turbulent mixing layer (Preston-Whyte & Tyson, 1988)**

The atmospheric boundary layer is normally unstable during the day as a result of the turbulence due to the sun's heating effect on the earth's surface. The thickness of this mixing layer depends

predominantly on the extent of solar radiation, growing gradually from sunrise to reach a maximum at about 5 to 6 hours after sunrise. This situation is more pronounced during the winter months due to strong night-time inversions and slower developing mixing layer. During the night a stable layer, with limited vertical mixing, exists. During windy and/or cloudy conditions, the atmosphere is normally neutral.

For elevated releases, the highest ground level concentrations would occur during unstable, daytime conditions. The wind speed resulting in the highest ground level concentration depends on the plume buoyancy. If the plume is considerably buoyant (high exit gas velocity and temperature) together with a low wind, the plume will reach the ground relatively far downwind. With stronger wind speeds, on the other hand, the plume may reach the ground closer, but due to increased ventilation, it would be more diluted. A wind speed between these extremes would therefore be responsible for the highest ground level concentrations. In contrast, the highest concentrations for ground level, or near-ground level releases would occur during weak wind speeds and stable (night-time) atmospheric conditions.

The new generation air dispersion models differ from the 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 therefore described by two parameters; the boundary layer depth and the Monin-Obukhov length, rather than in terms of the single parameter Pasquill Class. The Monin-Obukhov length (LMo) provides a measure of the importance of buoyancy generated by the heating of the ground and mechanical mixing generated by the frictional effect of the earth's surface. Physically, it can be thought of as representing the depth of the boundary layer within which mechanical mixing is the dominant form of turbulence generation (CERC, 2004).

The atmospheric boundary layer constitutes the first few hundred metres of the atmosphere. During the daytime, the atmospheric boundary layer is characterised by thermal turbulence due to the heating of the earth's surface. Night times are characterised by weak vertical mixing and the predominance of a stable layer. These conditions are normally associated with low wind speeds and less dilution potential.

## 3.2 Existing Sources of Emissions near Kusile Power Station

Sources of $SO_2$ and $NO_x$ that occur in the region include veld burning, vehicle exhaust emissions and household fuel burning.

Various local and far-a-field sources are expected to contribute to the suspended fine particulate concentrations in the region. Local sources include wind erosion from exposed areas, fugitive dust from agricultural operations, vehicle entrainment from roadways and veld burning. Long-range transport of particulates, emitted from remote tall stacks and from large-scale biomass burning in countries to the north of South Africa, has also been found to contribute significantly to background

fine particulate concentrations over the interior (Andrea *et al.*, 1996; Garstang *et al.*, 1996; Piketh, 1996).

### 3.2.1 Wind-blow Dust from Eskom's Ash Dams and Dumps

Parameters which have the potential to impact on the rate of emission from ash dam/dump facilities include the extent of surface compaction, moisture content, ground cover, the shape of the dam, particle size distribution, wind speed and precipitation.

Ash dumps in close proximity to the proposed activities consists of the existing Kendal ash dump.

### 3.2.2 Materials handling

Materials handling operations associated with mining and power station activities in the area include the transfer of coal by means of tipping, loading and off-loading of trucks. The quantity of dust that will be generated from such loading and off-loading operations will depend on various climatic parameters, such as wind speed and precipitation, in addition to non-climatic parameters such as the nature (i.e. moisture content) and volume of the material handled.

### 3.2.3 Industrial Emissions

Industrial sources within the Mpumalanga region include the following:

- Emissions from coal combustion by power generation, metallurgical and petrochemical industries represents the greatest contribution to total emissions from the industrial / institutional / commercial fuel use sector within the Mpumalanga region.
- The metallurgical group is estimated to be responsible for at least ~50% of the particulate emissions from this sector. This group includes iron and steel, ferro-chrome, ferro-alloy and stainless steel manufacturers (includes Highveld Steel & Vanadium, Ferrometals, Columbus Stainless, Transalloys, Middelburg Ferrochrome).
- Petrochemical and chemical industries are primarily situated in Secunda (viz. Sasol Chemical Industries). The use of coal for power generation and the coal gasification process represent significant sources of sulphur dioxide emissions. (Particulate emissions are controlled through the implementation of stack gas cleaning equipment.)
- Other industrial sources include: brick manufacturers which use coal (e.g. Witbank Brickworks, Quality Bricks, Corobrik, Hoeveld Stene, Middelwit Stene) and woodburning and wood drying by various sawmills (Bruply, Busby, M&N Sawmills) and other heavy industries (use coal and to a lesser extent HFO for steam generation). The contribution of fuel combustion (primarily coal) by institutions such as schools and hospitals to total emissions is

relatively due to the extent of emissions from other groups.

In the immediate vicinity of the proposed operations, the current industrial activities consist of the Kendal Power Station.

### 3.2.4 Vehicle Exhaust Emissions

Air pollution from vehicle emissions may be grouped into primary and secondary pollutants. Primary pollutants are those emitted directly into the atmosphere, and secondary, those pollutants formed in the atmosphere as a result of chemical reactions, such as hydrolysis, oxidation, or photochemical reactions. The significant primary pollutants emitted by motor vehicles include carbon dioxide ($CO_2$), carbon monoxide (CO), hydrocarbon compounds (HC), sulphur dioxide ($SO_2$), nitrogen oxides ($NO_x$) and particulate matter (PM). Secondary pollutants include nitrogen dioxide ($NO_2$), photochemical oxidants (e.g. ozone), hydrocarbon compounds (HC), sulphur acid, sulphates, nitric acid and nitrate aerosols. The main roads in the study area are the R545 to the east of the Kusile Power Station.

### 3.2.5 Biomass Burning

The biomass burning includes the burning of evergreen and deciduous forests, woodlands, grasslands, and agricultural lands. Within the project vicinity, wild fires (locally known as veld fires) may represent significant sources of combustion-related emissions.

The biomass burning is an incomplete combustion process (Cachier, 1992), with carbon monoxide, methane and nitrogen dioxide gases being emitted. Approximately 40% of the nitrogen in biomass is emitted as nitrogen, 10% is left is the ashes, and it may be assumed that 20% of the nitrogen is emitted as higher molecular weight nitrogen compounds (Held *et al*, 1996). The visibility of the smoke plumes is attributed to the aerosol (particulate matter) content.

### 3.2.6 Fugitive Dust Emissions from Mining

Mines are associated with significant dust emissions, sources of which include land clearing, materials handling, vehicle entrainment, crushing, and screening (etc.). Proposed mines in the immediate vicinity of Kusile Power Station will consist of the New Largo Colliery to the east.

### 3.2.7 Other Fugitive Dust Sources

Fugitive dust emissions may occur as a result of vehicle entrained dust from local paved and unpaved roads, wind erosion from open areas and dust generated by agricultural activities (e.g. tilling) and

mining. The extent of particulate emissions from the main roads will depend on the number of vehicles using the roads and on the silt loading on the roadways.

## 3.3 Ambient Air Quality near Kusile Disposal Facility

The Project is located in the vicinity of the Emahaleni Hot Spot (HPA, 2011) and the ambient air quality, with particular reference to particulates, is outlined below.

The poor ambient air quality in the Emahaleni Hot Spot is a result of emissions from power generation, metallurgical manufacturing processes, open-cast coal mining and residential fuel burning; where industrial processes dominate the source contribution (HPA, 2011). Dispersion modelling projected exceedances of the daily $PM_{10}$ limit for more than 12 days across the Emahaleni Hot Spot (HPA. 2011). Monitored daily $PM_{10}$ concentrations within the Hot Spot, at Witbank and Greendale High School show regular exceedances of the daily limit, between 2008 and 2012 (Figure 3-5). The HPA Air Quality Management Plan (2011) reported exceedance of the annual limit, for 2008 / 2009, at one of the two monitoring stations in Witbank with an annual averages ~83 $\mu g.m^{-3}$ for Witbank 2.

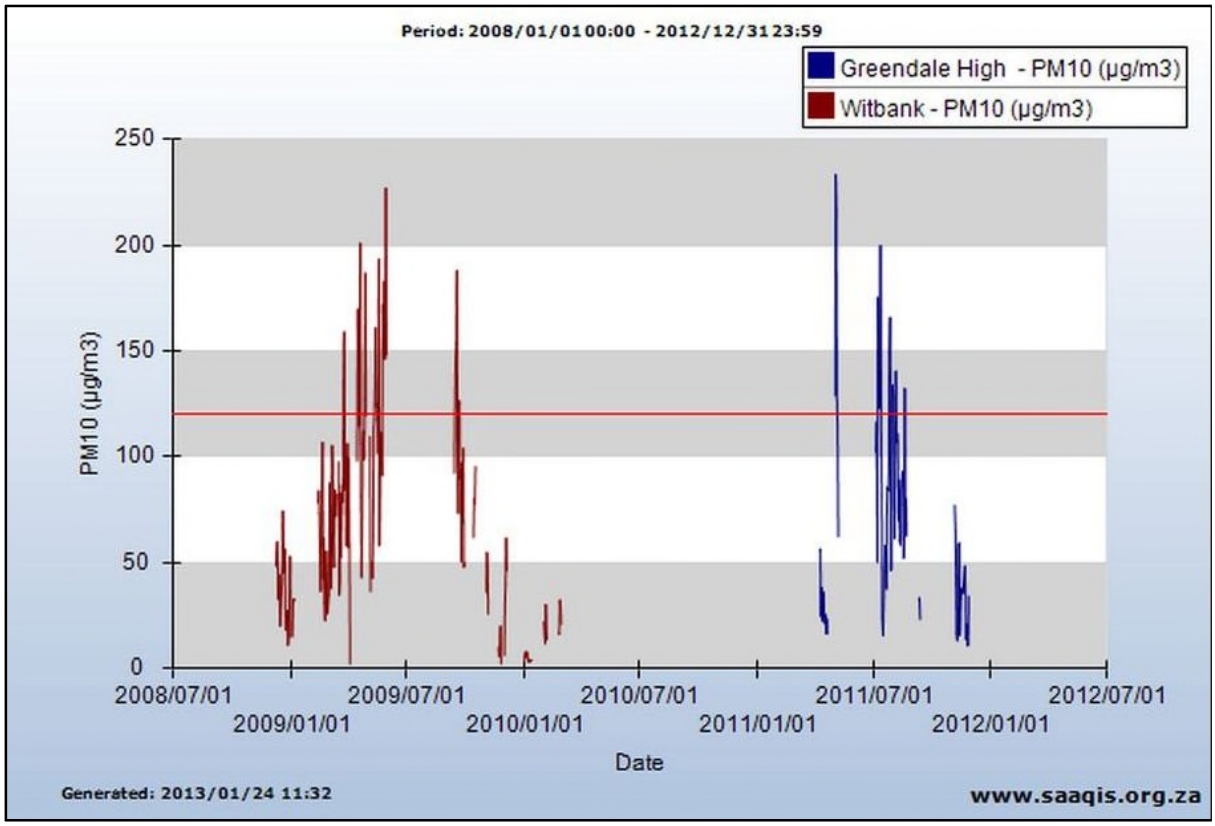


**Figure 3-5: Daily $PM_{10}$ concentrations monitored at two stations in the Emahaleni Hot Spot between 2008 and 2012 (from www.saaqis.org.za). The horizontal red line indicates the current daily limit of 120 $\mu g.m^{-3}$.**

# 4 METHODOLOGY

## 4.1 Source Identification

The project includes the co-disposal of gypsum and ash from the Kusile Power Station at a disposal facility to the south of the Kusile 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 $PM_{10}$ (particulates with a diameter less than 10 µm) and $PM_{2.5}$ (diameter less than 2.5 µm) 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 4-1) 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 4-1: 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 |
|---|---|---|
| **Co-disposal of gypsum and ash** | | |
| 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 |

### 4.1.1 Construction Phase

The construction phase for the disposal facility 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).

### 4.1.2 Disposal Facility

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 A). 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 4.3.3) where mitigation practices were calculated to have control efficiencies (CE) greater than 70% (Table 4-2).

In addition to the mitigation measures listed, the gypsum material is expected to provide a crust when mixed with water. To what extent this material will crust will depend on how the material is disposed (i.e. mixed with the ash or deposited as layers of gypsum material in between the ash material) and how much water is added to the disposal facility. The crust may also be disturbed from time to time with activity on the disposal facility. It is therefore not possible to determine the effectiveness of the gypsum material in mitigating the windblown dust from this source.

**Table 4-2: Annual emissions for the disposal facility for each of the modelled scenarios**

| Scenario | Particulate fraction | Annual emissions (tpa) |
|---|---|---|
| **Unmitigated** | TSP | 27913 |
| | $PM_{10}$ | 11098 |
| | $PM_{2.5}$ | 3198 |
| **Re-vegetation CE = 97%** | TSP | 840 |
| | $PM_{10}$ | 334 |
| | $PM_{2.5}$ | 96 |
| **Wetting CE = 74%** | TSP | 7259 |
| | $PM_{10}$ | 2871 |
| | $PM_{2.5}$ | 827 |
| **Both (re-vegetation & wetting) CE = 99%** | TSP | 218 |
| | $PM_{10}$ | 86 |
| | $PM_{2.5}$ | 25 |

### 4.1.3 Rehabilitation

Rehabilitation is planned to occur continuously throughout the disposal of ash and gypsum and will include the removal and tipping of topsoil onto the completed disposal facility surface areas. Dust may be generated from the dried out exposed 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 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 gypsum and ash material, 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 site boundary. As vegetation cover increases, the potential for wind erosion will decrease.

## 4.2 Identification of Sensitive Receptors

The National Ambient Air Quality Standards (NAAQS) are based on human exposure to specific criteria pollutants and are applicable to areas that are not regulated by the Occupational Health and Safety Act, 1993 (Act No. 85 of 1993).

The modelled ground-level $PM_{10}$ and $PM_{2.5}$ concentrations will be compared to National Ambient Air Quality Standards at the closest identified sensitive receptor (within the Kusile boundary as identified from satellite imagery), at the Kusile boundary, and at more established residential areas (i.e. Wilge, Kendal Forest Holdings, Phola and Ogies).

## 4.3 Compliance Analysis and Impact Assessment

The current air quality at the proposed site is discussed in Section 3.3. The disposal facility will continue to give rise to dust generation as the disposal operations are initiated. 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 m from the disposal facility surface.

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 m/s for storage piles (US.EPA, 1995). Wind data for the proposed ash disposal facility site (2009 to 2012) indicate an average wind speed of 3.42 m/s and a maximum of 15.2 m/s, where the wind speed threshold is exceeded 15.1% of the time.

### *4.3.1 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 4. 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 provide conservative values under unstable atmospheric conditions in that it predicts higher concentrations than the older models close to the source.

ADMS 4 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 4 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 4. 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.

### 4.3.2 Meteorological Data Requirements

Hourly average wind speed, wind direction and temperature data from the Eskom meteorological station at Kendal Power Station (approximately 19.4 km south-east of the Kusile construction site) were used. Given the proximity and the nature of the terrain, the data is considered to be suitably representative of the conditions near Kusile.

### 4.3.3 Source Data Requirements

The disposal facility, as the focus of this report, was the only source considered during model simulations. 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 material by water sprays and re-vegetation. A total of four scenarios were simulated:

- unmitigated (disposal of conditioned material but allowed to dry out);
- mitigation by means of re-vegetation covering 80% of the disposal facility (control efficiency of: 97%);
- mitigation by means of water sprays to maintain material moisture content at 5% (about half of the moisture content when ash deposited at disposal facility – control efficiency of: 74%); and,
- mitigation by means of re-vegetation of 80% of disposal facility and watering to maintain material 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 disposal facility size. An ash sample from the Kendal Power Station ash disposal facility was obtained for analysis as the ash from the Kusile Power Station is likely to be similar with regards to particle size distribution (Table 4-4) and elemental content (Table 4-5).

**Table 4-3: Particle size distribution for the ash material at the Kendal Power Station**

| Size (µm) | Fraction |
|---|---|
| 477.01 | 0.0018 |
| 258.95 | 0.0503 |
| 103.58 | 0.1950 |
| 76.32 | 0.0895 |
| 30.53 | 0.2783 |
| 22.49 | 0.0761 |
| 10.48 | 0.1388 |
| 5.69 | 0.0708 |
| 2.65 | 0.0511 |
| 1.06 | 0.0295 |

**Table 4-4: Elemental analysis of the ash material at the Kendal Power Station**

| Element | ppm |
|---|---|
| Silver | <0.2 |
| Aluminium | 17861 |
| Arsenic | 6.1 |
| Boron | 70 |
| Barium | 326 |
| Beryllium | 0.8 |
| Calcium | 31375 |
| Cadmium | <0.2 |
| Cobalt | 3.0 |
| Chromium | 21 |
| Copper | 9.3 |
| Iron | 7935 |
| Mercury | <1.0 |
| Potassium | 659 |
| Lithium | 24 |
| Magnesium | 5496 |
| Manganese | 78 |
| Molybdenum | 2.2 |
| Sodium | 3261 |
| Nickel | 5.2 |
| Phosphorous | 1288 |
| Lead | 4.7 |
| Antimony | <2.0 |
| Selenium | <4.0 |
| Tin | <4.0 |
| Strontium | 475 |
| Titanium | 562 |
| Vanadium | 31 |
| Zinc | 8.6 |

### 4.3.4 Modelling Domain

The dispersion of pollutants expected to arise from the proposed operations was modelled for an area covering approximately 30 km (east-west) by 30 km (north-south). The area was divided into a grid matrix with a resolution of 300 m by 300 m. ADMS 4 simulates ground-level concentrations for each of the receptor grid points. Sensitive receptors were included in the model as additional receptors points.

# 5 DISPERSION MODELLING RESULTS AND COMPLIANCE ASSESSMENT

Dispersion modelling was undertaken to determine: 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 should be noted that the ground-level concentration isopleths depicted present interpolated values from the concentrations predicted by ADMS 4 for each of the receptor grid points specified.

## 5.1 Dust Deposition

Dust deposition due to unmitigated operations exceeds the draft dust fallout regulations of 600mg/m²/day as recommended for residential areas at the closest sensitive receptors (identified with satellite imagery within the boundary) and at the boundary. With water sprayers, the impact is reduced to meet draft dust fallout regulations of 600mg/m²/day beyond the boundary. Predicted dust deposition under the re-vegetation and combination mitigation strategies falls within 600mg/m²/day. The potential impact of dust deposition on agricultural crops near the disposal facility was plotted (**Error! Reference source not found.**) at the 400 mg/m²/day guideline (Section 2.4.1).

**Table 5-1: Predicted dust deposition at sensitive receptors due to windblown dust from the disposal facility**

| Scenario | Receptor | Highest daily dust deposition (mg/m²/day) |
|---|---|---|
| **Unmitigated** | Closest identified sensitive receptor (individual farmstead onsite) | 2000 |
| | Boundary | 950 |
| | Wilge | <400 |
| | Kendal Forest Holdings | <400 |
| | Phola | <400 |
| | Ogies | <400 |
| **Re-vegetation** | *Dust deposition predicted to be <400mg/m²/day at all sensitive receptors* | |
| **Wetting** | Closest identified sensitive receptor (individual farmstead onsite) | 1000 |
| | Boundary | <400 |
| | Wilge | <400 |
| | Kendal Forest Holdings | <400 |
| | Phola | <400 |
| | Ogies | <400 |
| **Both (re-vegetation and wetting)** | *Dust deposition predicted to be <400mg/m²/day at all sensitive receptors* | |

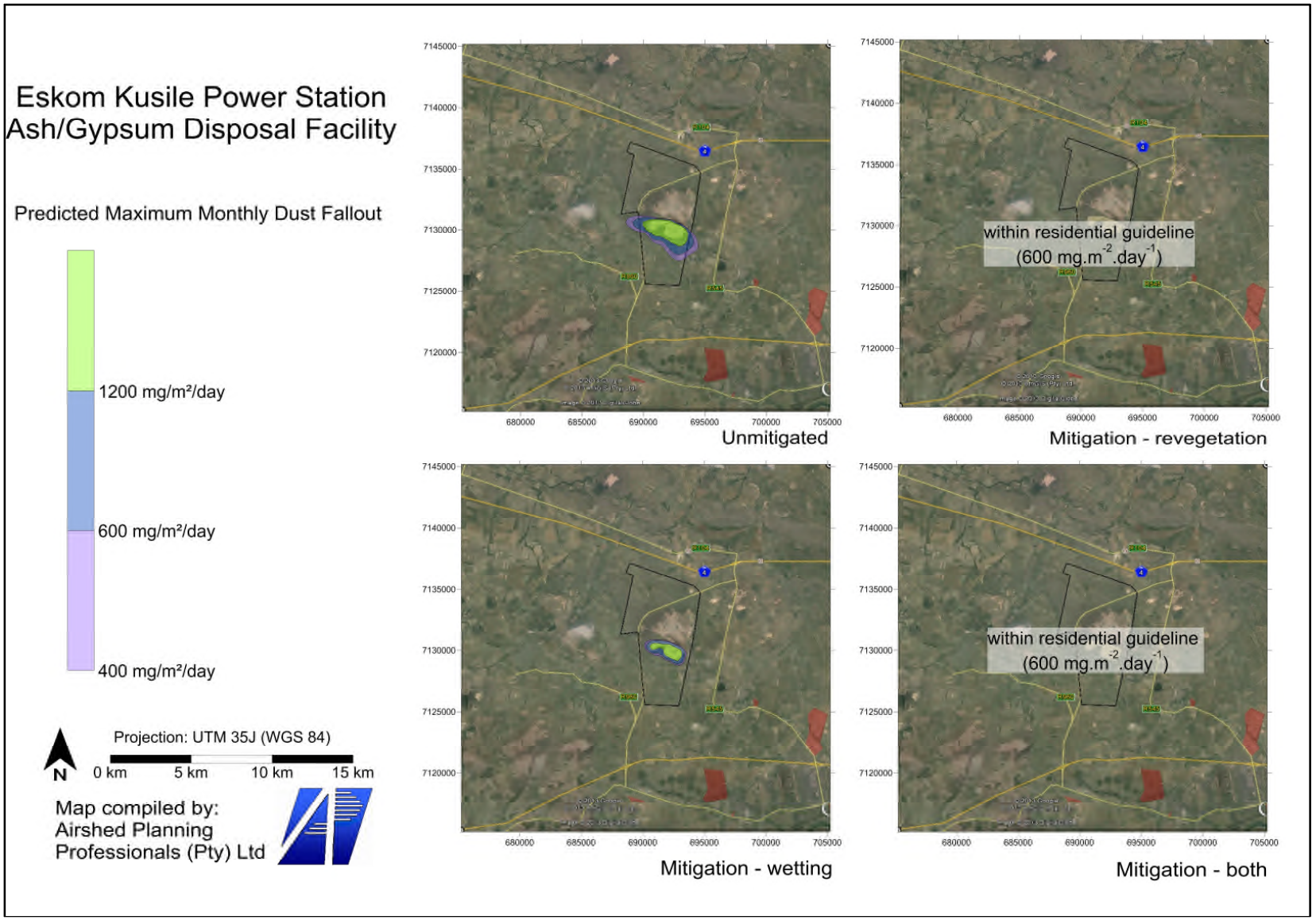


**Figure 5-1: Predicted maximum monthly dust deposition as a result of windblown dust from the disposal facility at the Kusile Power Station**

## 5.2 $PM_{10}$ and $PM_{2.5}$ ground-level concentrations

For unmitigated operations, the predicted impacts from the disposal facility are in non-compliance with the daily and annual $PM_{10}$ and $PM_{2.5}$ NAAQS beyond the boundary. Compliance with the daily NAAQS for these pollutants are predicted to be achieved with mitigation by either re-vegetation or with the combination of re-vegetation and watering (Figure 5-2 to Figure 5-5).

The predicted $PM_{10}$ and $PM_{2.5}$ concentrations may be conservative as the natural crusting of the gypsum that will reduce windblown dust from this facility could not be quantified for this assessment.

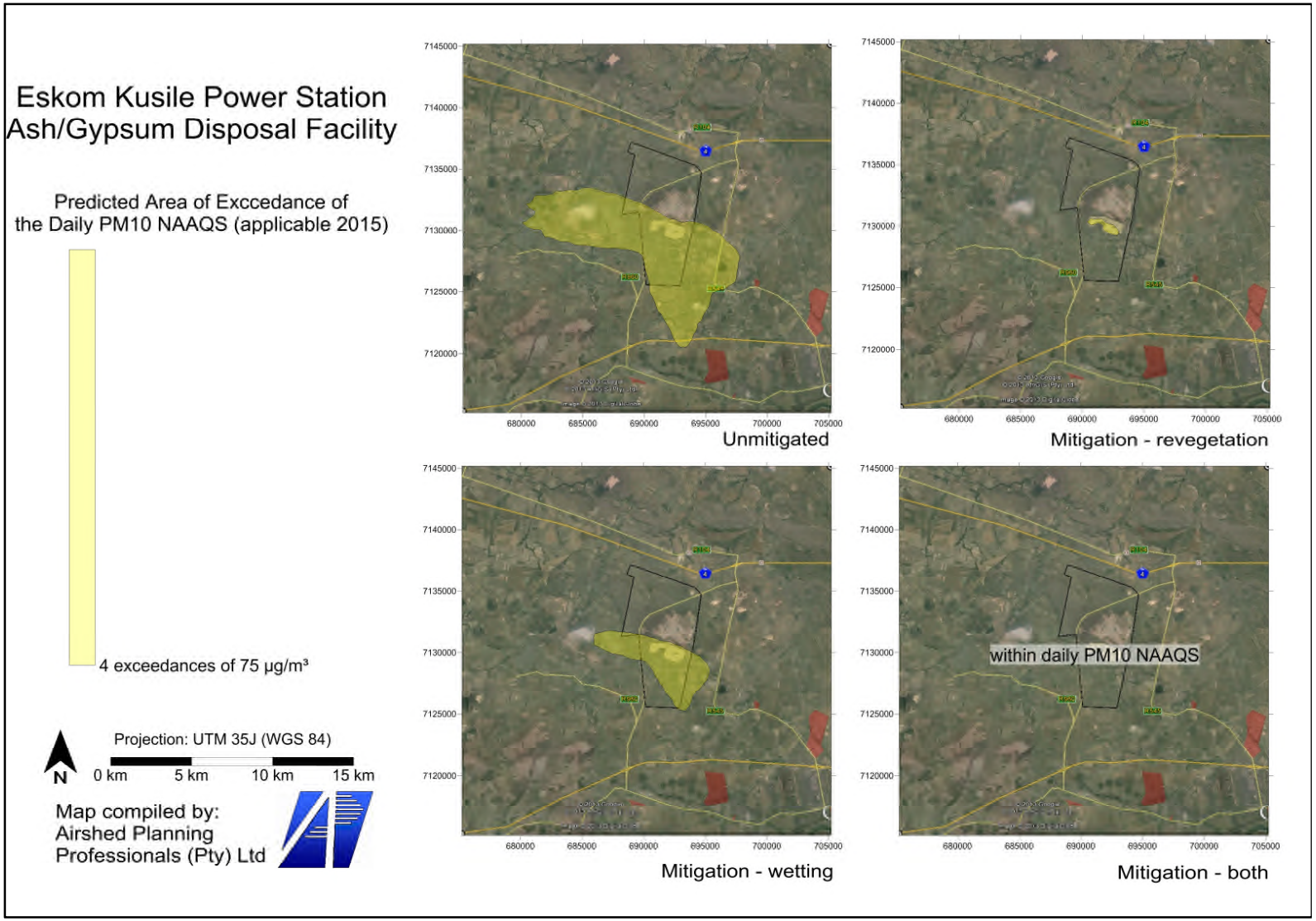


**Figure 5-2: Predicted area of exceedance of the daily $PM_{10}$ NAAQS due to the disposal facility at Kusile Power Station**

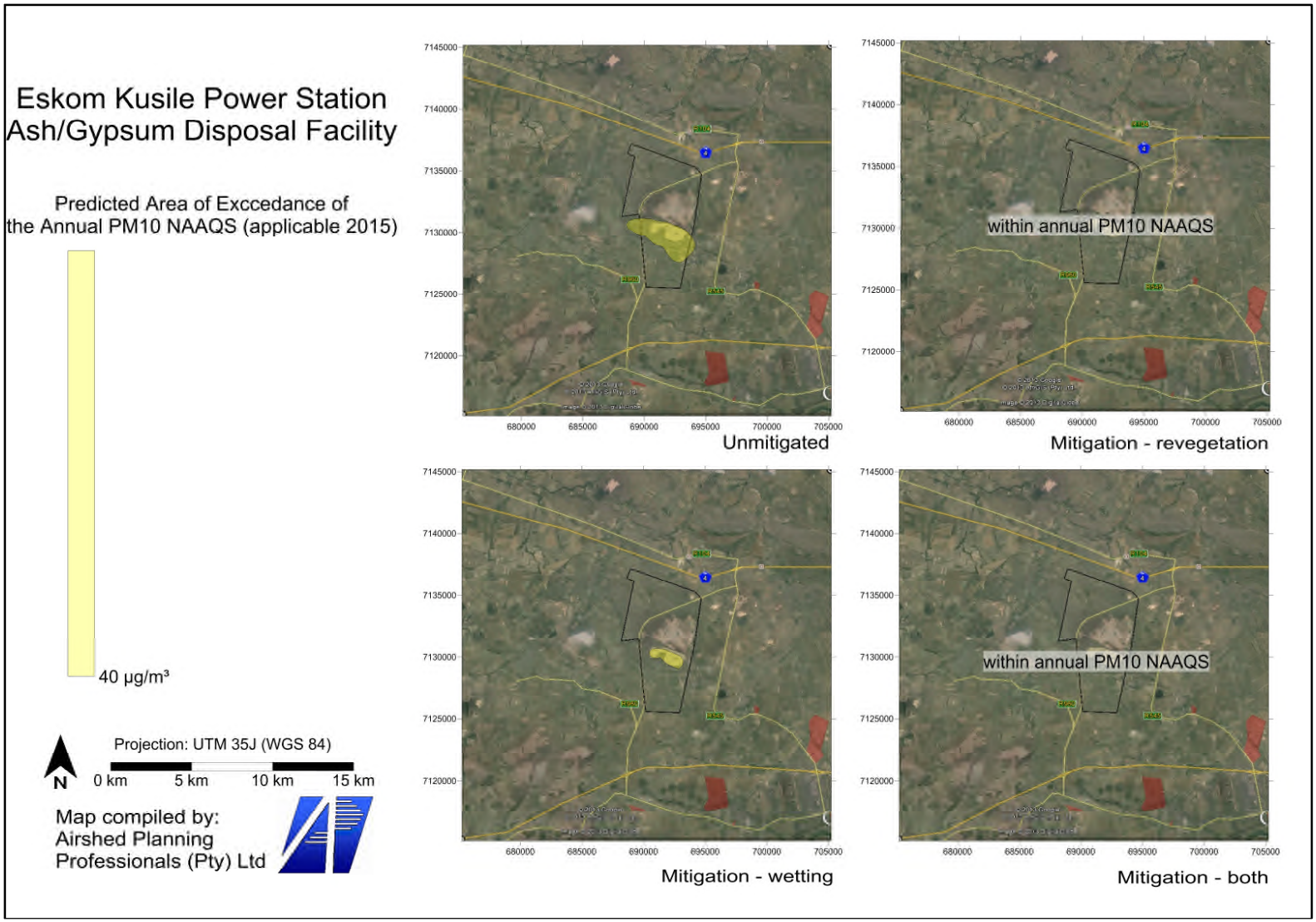


**Figure 5-3: Predicted annual average $PM_{10}$ concentrations due to the disposal facility at Kusile Power Station**

**Table 5-2: Predicted annual average $PM_{10}$ ground-level concentrations and number of exceedances of daily $PM_{10}$ NAAQ limits as a result of wind-blown emissions from the disposal facility**

| Scenario | Receptor | No. of exceedances of the daily $PM_{10}$ NAAQ limit of 75 µg/m³ (applicable from 2015) | Annual average $PM_{10}$ concentration (µg/m³) | Within compliance with the daily and annual $PM_{10}$ NAAQS applicable from 2015 (Y/N) |
|---|---|---|---|---|
| **Unmitigated** | Closest identified sensitive receptor (individual farmstead onsite) | 100 | 150 | N |
| | Boundary | 70 | 80 | N |
| | Wilge | 2 | <40 | Y |
| | Kendal Forest Holdings | 1 | <40 | Y |
| | Phola | <1 | <40 | Y |
| | Ogies | <1 | <40 | Y |
| **Re-vegetation** | Closest identified sensitive receptor (individual farmstead onsite) | 2 | <40 | Y |
| | Boundary | 1 | <40 | Y |
| | Wilge | <1 | <40 | Y |
| | Kendal Forest Holdings | <1 | <40 | Y |
| | Phola | <1 | <40 | Y |
| | Ogies | <1 | <40 | Y |
| **Wetting** | Closest identified sensitive receptor (individual farmstead onsite) | 30 | 40 | N |
| | Boundary | 15 | <40 | N |
| | Wilge | <1 | <40 | Y |
| | Kendal Forest Holdings | <1 | <40 | Y |
| | Phola | <1 | <40 | Y |
| | Ogies | <1 | <40 | Y |
| **Both (re-vegetation and wetting)** | Closest identified sensitive receptor (individual farmstead onsite) | <1 | <40 | Y |
| | Boundary | <1 | <40 | Y |
| | Wilge | <1 | <40 | Y |
| | Kendal Forest Holdings | <1 | <40 | Y |
| | Phola | <1 | <40 | Y |
| | Ogies | <1 | <40 | Y |

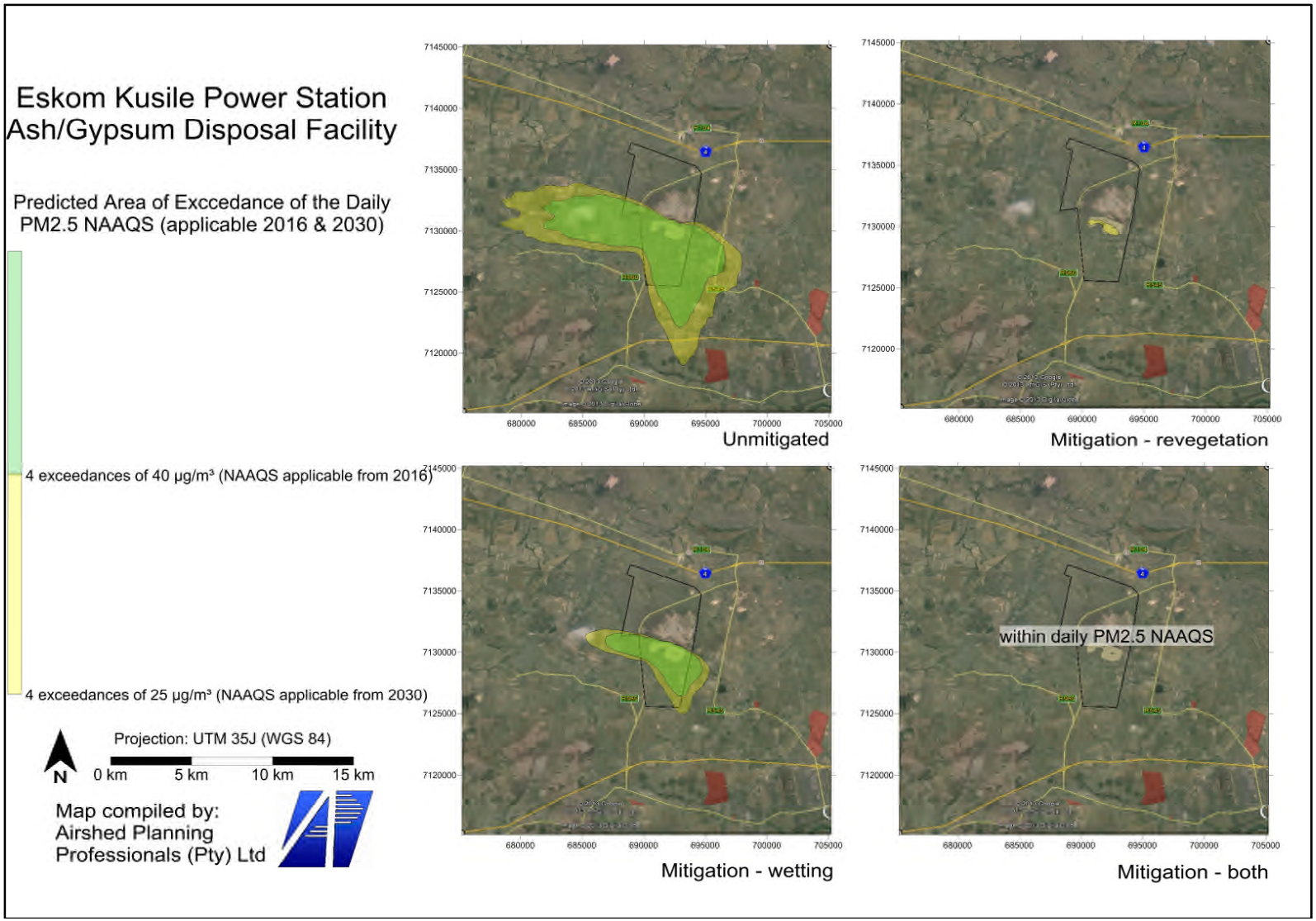


**Figure 5-4: Predicted area of exceedance of the daily $PM_{2.5}$ NAAQS due to the disposal facility at Kusile Power Station**

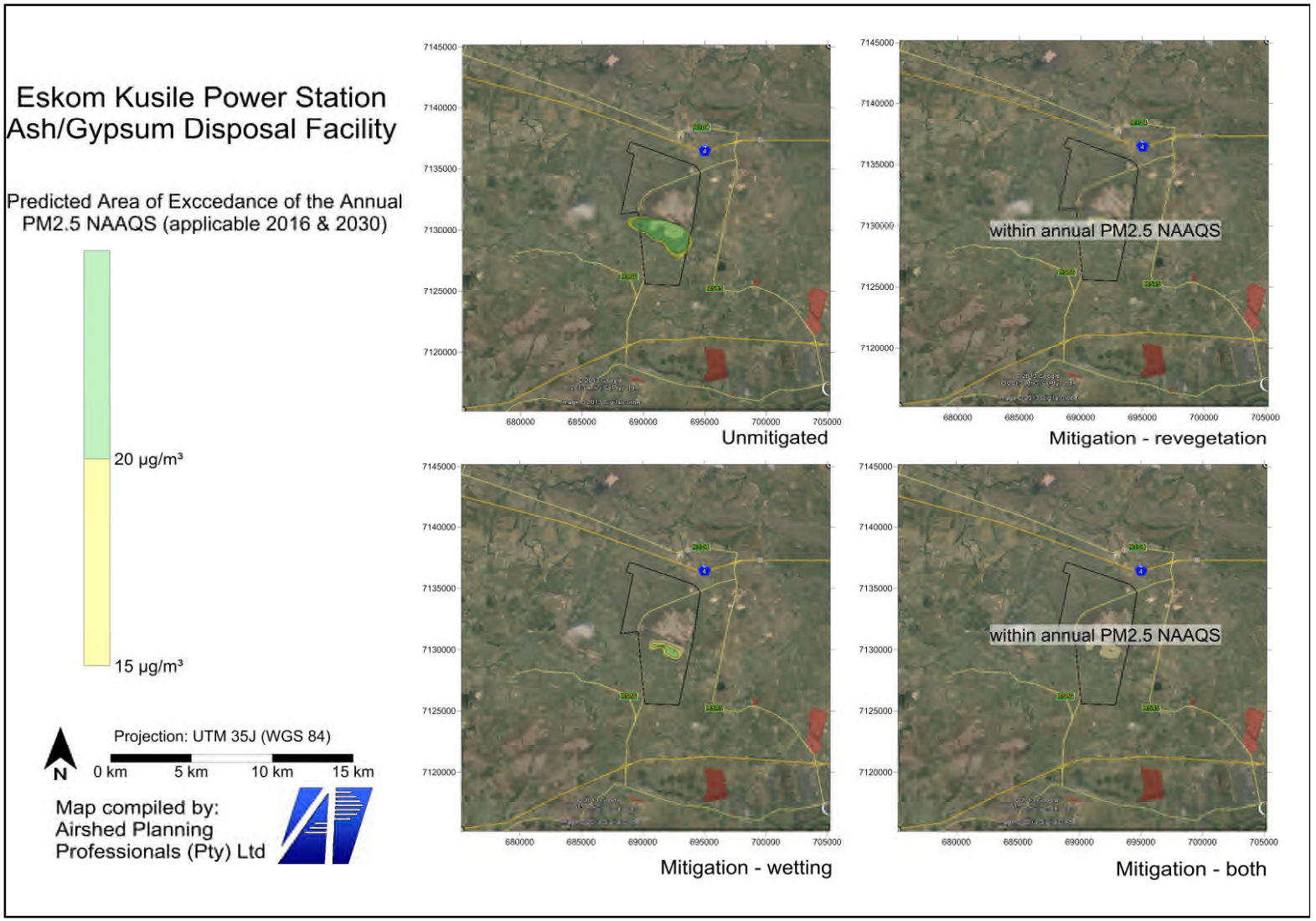


**Figure 5-5: Predicted annual average $PM_{2.5}$ concentrations due to the disposal facility at Kusile Power Station**

**Table 5-3: Predicted annual average $PM_{2.5}$ ground-level concentrations and number of exceedances of daily $PM_{2.5}$ NAAQ limits as a result of wind-blown emissions from the disposal facility**

| Scenario | Receptor | No. of exceedances of the daily $PM_{2.5}$ NAAQ limit of 40 µg/m³ (applicable from 2016) | No. of exceedances of the daily $PM_{2.5}$ NAAQ limit of 25 µg/m³ (applicable from 2030) | Annual average $PM_{2.5}$ concentration (µg/m³) | Within compliance with the daily and annual $PM_{2.5}$ NAAQS applicable from 2016 (Y/N) | Within compliance with the daily and annual $PM_{2.5}$ NAAQS applicable from 2030 (Y/N) |
|---|---|---|---|---|---|---|
| Unmitigated | Closest identified sensitive receptor (individual farmstead onsite) | 80 | 90 | 45 | N | N |
| | Boundary | 50 | 60 | 28 | N | N |
| | Wilge | <1 | 2 | <15 | Y | Y |
| | Kendal Forest Holdings | <1 | 1 | <15 | Y | Y |
| | Phola | <1 | <1 | <15 | Y | Y |
| | Ogies | <1 | <1 | <15 | Y | Y |
| Re-vegetation | Closest identified sensitive receptor (individual farmstead onsite) | <1 | 2 | <15 | Y | Y |
| | Boundary | <1 | 1 | <15 | Y | Y |
| | Wilge | <1 | <1 | <15 | Y | Y |
| | Kendal Forest Holdings | <1 | <1 | <15 | Y | Y |
| | Phola | <1 | <1 | <15 | Y | Y |
| | Ogies | <1 | <1 | <15 | Y | Y |
| Wetting | Closest identified sensitive receptor (individual farmstead onsite) | 23 | 30 | <15 | N | N |
| | Boundary | 12 | 15 | <15 | Y | Y |
| | Wilge | <1 | <1 | <15 | Y | Y |
| | Kendal Forest Holdings | <1 | <1 | <15 | Y | Y |
| | Phola | <1 | <1 | <15 | Y | Y |
| | Ogies | <1 | <1 | <15 | Y | Y |

| Scenario | Receptor | No. of exceedances of the daily $PM_{2.5}$ NAAQ limit of 40 µg/m³ (applicable from 2016) | No. of exceedances of the daily $PM_{2.5}$ NAAQ limit of 25 µg/m³ (applicable from 2030) | Annual average $PM_{2.5}$ concentration (µg/m³) | Within compliance with the daily and annual $PM_{2.5}$ NAAQS applicable from 2016 (Y/N) | Within compliance with the daily and annual $PM_{2.5}$ NAAQS applicable from 2030 (Y/N) |
|---|---|---|---|---|---|---|
| **Both (re-vegetation and wetting)** | Closest identified sensitive receptor (individual farmstead onsite) | <1 | <1 | <15 | Y | Y |
| | Boundary | <1 | <1 | <15 | Y | Y |
| | Wilge | <1 | <1 | <15 | Y | Y |
| | Kendal Forest Holdings | <1 | <1 | <15 | Y | Y |
| | Phola | <1 | <1 | <15 | Y | Y |
| | Ogies | <1 | <1 | <15 | Y | Y |

## 5.3 Increased Life-Time Cancer Risk

For all three metals (arsenic, nickel and chromium) the increased life-time cancer risk at the identified sensitive receptors is very low to low in all cases (Table 5-4). These estimates are based on the annual $PM_{10}$ concentrations for the *unmitigated* scenario (Table 5-2).

**Table 5-4: Increased 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 Kusile disposal facility**

| Sensitive receptor | Arsenic | Nickel | Chromium |
|---|---|---|---|
| Closest identified sensitive receptor (individual farmstead onsite) | *Very low* | *Low* | *Low* |
| Boundary | | | |
| Wilge | | *Very low* | *Very low* |
| Kendal Forest Holdings | | | |
| Phola | | | |
| Ogies | | | |

# 6 SIGNIFICANCE RATING

The alternatives for the ash disposal facility were compared on the basis of minimising the impact on air quality. The comparison was made using the unmitigated scenario. $PM_{10}$ and $PM_{2.5}$, due to potential human health impacts, were included as risk criteria. 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.

For the evaluation of risk, reference was made to the consequence and probability ranking provided in Table 6-1.

**Table 6-1: Consequence and probability ranking**

| Severity/ magnitude (S) | Reversibility (R) | Duration (D) | Spatial extent (E) | Probability (P) |
|---|---|---|---|---|
| 5 - very high / don't know | 1 - reversible (regenerates naturally) | 5 - permanent | 5 - international | 5 - definite / don't know |
| 4 - high | | 4 - long term (impact ceases after operational life) | 4 - national | 4 - high probability |
| 3 - moderate | 3 - recoverable (needs human input) | 3 - medium term (5-15 years) | 3 - regional | 3 - medium probability |
| 2 - low | | 2 - short term (0-5 years) | 2 - local | 2 - low probability-negligible |
| 1 - minor | 5 - irreversible | 1 - immediate | 1 - site only | 1 - improbable |
| 0 - none | | | | 0 - none |

**Consequence = severity + reversibility + duration + spatial extent**

**Consequence x Probability = Significance**

- More than 60 significance points indicate **High** environmental significance;
- Between 30 and 60 significance points indicate **Moderate** environmental significance;
- Less than 30 significance points indicate **Low** environmental significance.

The significance of the risk for the construction and operational phases are provided in Table 6-2 and Table 6-3 respectively.

**Table 6-2: Significance rating for the Construction Phase**

| Risk | Rating Before Mitigation Measures | | | | | | | Rating After Mitigation Measures | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | S | R | D | E | C | P | Significance=C*P | S | R | D | E | C | P | Significance=C*P |
| Dust deposition | 3 | 1 | 2 | 2 | 8 | 4 | *Moderate* | 2 | 1 | 2 | 1 | 6 | 3 | *Low* |
| $PM_{10}$ | 4 | 1 | 2 | 2 | 9 | 4 | *Moderate* | 2 | 1 | 2 | 1 | 6 | 3 | *Low* |
| $PM_{2.5}$ | 4 | 1 | 2 | 2 | 9 | 4 | *Moderate* | 2 | 1 | 2 | 1 | 6 | 3 | *Low* |

**Table 6-3: Significance rating for the Operation Phase**

| Risk | Rating Before Mitigation Measures | | | | | | | Rating After Mitigation Measures | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | S | R | D | E | C | P | Significance=C*P | S | R | D | E | C | P | Significance=C*P |
| Dust deposition | 3 | 1 | 4 | 2 | 10 | 4 | *Moderate* | 2 | 1 | 4 | 1 | 8 | 3 | *Low* |
| $PM_{10}$ | 4 | 1 | 4 | 2 | 11 | 4 | *Moderate* | 2 | 1 | 4 | 1 | 8 | 3 | *Low* |
| $PM_{2.5}$ | 4 | 1 | 4 | 2 | 11 | 4 | *Moderate* | 2 | 1 | 4 | 1 | 8 | 3 | *Low* |
| Cancer risk | 1 | 1 | 4 | 2 | 8 | 4 | *Low* | 1 | 1 | 4 | 1 | 7 | 3 | *Low* |

# 7 ENVIRONMENTAL IMPACT STATEMENT

The environmental impact statement that follows applies to the operational phase of the Disposal Facility. Operational phase is considered to be the phase with the largest impact on the ambient air quality. The Construction, Closure and Post-closure phases will not impact the ambient air quality more than the status quo situation. All impacts are determined based on the results from dispersion modelling where the certainty of impacts are considered **probable**.

## 7.1 Status Quo

The current sources of particulate emissions in the vicinity include mining, other power stations and agriculture. The Kusile Power Station falls within the Highveld Priority Area, near to the Emahaleni Hot Spot. The Emahaleni Hot Spot is an area of already poor air quality where the NAAQS for daily $PM_{10}$ concentrations are frequently exceeded. The status quo air quality is of MODERATE-HIGH significance at a *regional* scale. The impacts of the status quo have a ***high probability*** in the ***long-term*** and result in a **MODERATE-HIGH** impact risk.

## 7.2 Project Impact – Unmitigated

Impacts from the operational disposal facility will probably result in elevated $PM_{10}$ concentrations, exceeding the NAAQS beyond the boundary. The predicted maximum impacted area is projected for the maximum disposal facility foot-print without any mitigation of dust emissions. The scale impact of the disposal facility on the ground-level $PM_{2.5}$ concentrations is likely to be similar to $PM_{10}$ concentrations. The impacts of the proposed disposal facility, under unmitigated operation, have a ***high probability*** to result in impacts of MODERATE significance at *local* scale over the ***long-term***, resulting in **MODERATE** impact risk.

## 7.3 Cumulative Impact

The cumulative impact of proposed disposal facility – when dust emissions are unmitigated – is likely to result in regular exceedances of the NAAQS for $PM_{10}$ and $PM_{2.5}$. These impacts will be of HIGH significance at a *regional* scale. The ***high probability*** will result in **HIGH** impact risk.

## 7.4 Mitigation Measures

Effective mitigation of particulate emissions will include:

- Regular wetting of the exposed areas of disposed ash
- Stabilisation of the exposed areas of ash with a top-soil covering

- Wetting of exposed top-soil for additional mitigation of dust emissions from the top-soil layer
- Re-vegetation of ash disposal facility through application of a deeper top-soil layer and seeding with appropriate grass seeds.

## 7.5 Residual Impact

The residual impact of the ash disposal facility with frequent watering and progressive re-vegetation of the exposed areas the impact of the disposal facility is predicted to reduce substantially. The impacts are reduced to within NAAQS, even on-site. The impacts have thus, similar to the status quo impacts, a *high probability* to be of MODERATE-HIGH significance at a *regional* scale over the long-term, resulting in **MODERATE-HIGH** impact risk.

## 7.6 Impact Significance

The impacts identified and discussed in Table 6-2 and Table 6-3 have been rated according to the impact assessment methodology described in Table 6-1.

## 7.7 Environmental Management Planning

The identified impacts should be mitigated through the implementable actions proposed in Section 7.4. These mitigation measures are presented in the proposed Environmental Management Planning (Table 7-1).

### Table 7-1: Environmental Management Planning - Air quality

| **Management / Environmental Component:** | **EMPr Reference Code:** | | |
|---|---|---|---|
| Air quality | EMPr-Air | | |
| **Primary Objective:** | | | |
| Reduce particulate emissions from the ash disposal facility through effective dust suppression | | | |
| **Implementation** | **Responsibility** | **Resources** | **Monitoring / Reporting** |
| 1) Regular watering of exposed ash by maintaining surface ash to approximately 5% water content | Environmental manager | Water and watering infrastructure | Weekly |
| 2) Covering exposed ash with topsoil to stabilise surface ash (approximately 50 mm) | Environmental manager | Topsoil stockpile | Monthly |
| 3) Re-vegetation of ash disposal facility with deeper top soil layer and supplemented seed bank | Environmental manager | Appropriate seed stock | Monthly |
| 4) Monitoring of dust-fall rates (via dust bucket network) and ambient air quality (via $PM_{10}$ monitoring) | Environmental manager | Dust buckets, stands, personnel, $PM_{10}$ monitoring equipment | Monthly (dust fallout)<br>Hourly ($PM_{10}$) |
| 5) Inspection of re-vegetated areas to document areas needing attention | Environmental manager | Camera, GPS | Quarterly |
| **Existing management plans / procedures:** | | | |
| **Similar to other, operating, Eskom Power Stations:** | | | |
| Dust suppression by watering | | | |
| Re-vegetation process | | | |
| Ambient air quality monitoring | | | |

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# APPENDIX A: 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 (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. 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) |

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), estimated based on the equations proposed by Marticorena and Bergametti (1995), is illustrated in Figure A-1.

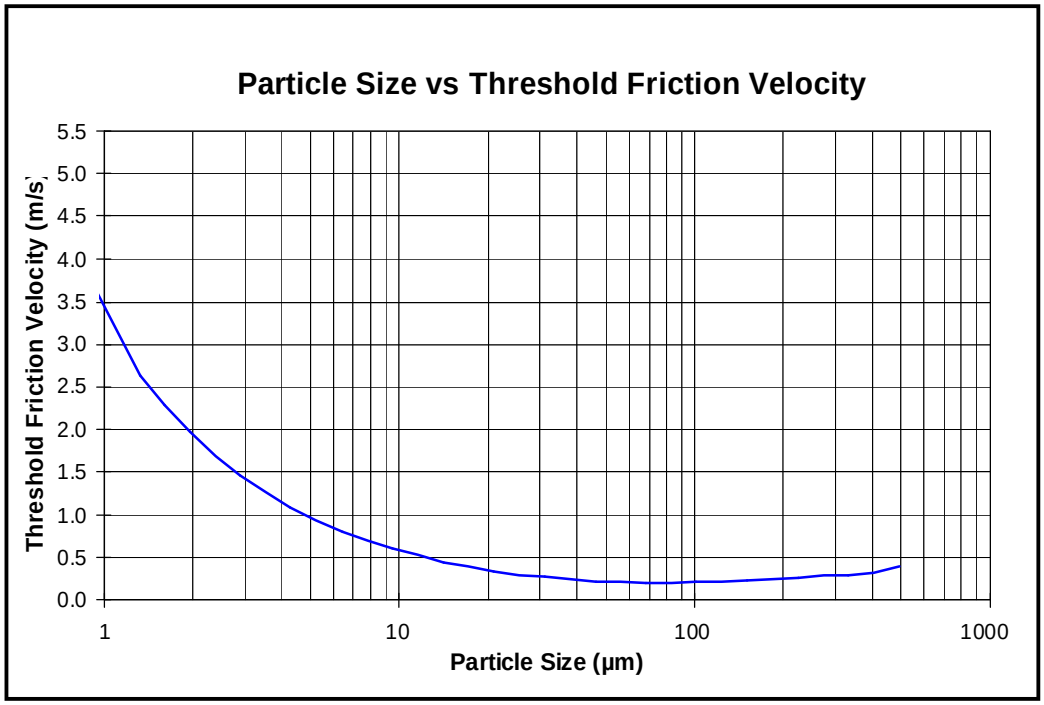


**Figure A-1: Relationship between particle sizes and threshold friction velocities using the calculation method proposed by Marticorena and Bergametti (1995)**