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Zitholele Consulting

Continuous Disposal of Ash at Kusile Power Station

Air Quality Basic Evaluation

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REPORT DETAILS

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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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EXECUTIVE SUMMARY

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

The ash disposal site alternatives are located within a 15 km radius of the Kusile Power Station, approximately 20 km from the towns of Bronkhorstspruit (to the north-west) and Ogies (to the south-east). Kusile Power Station and the ash 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 ash 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 Kendal Power Station from January 2009 to October 2012, was used. The dominant wind direction is west-north-west 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 wind—blown dust emissions from the ash disposal facility: (1) unmitigated emissions; (2) mitigation through re-vegetation (to 80% of the facility area); (3) mitigation through wetting of surface layer of exposed ash (assuming a moisture content of 5%); and, (4) mitigation through both re-vegetation and wetting.

The ash disposal facility alternatives were compared on the basis of four criteria: (a) the number of sensitive receptors at which the annual PM_{10} NAAQS were exceeded (for each alternative); (b) the area around each alternative where the annual PM_{10} exceeded the NAAQS; (c) the number of sensitive receptors at which the annual $PM_{2.5}$ NAAQS were exceeded (for each alternative); and, (d) the area around each alternative where the maximum dust-fall rate exceeded 400 $mg.m^{-2}.day^{-1}$ (likely to result in impact to agriculture).

ASSUMPTIONS AND LIMITATIONS

The following Assumptions and Limitations should be considered when interpreting the findings from the air quality assessment for the preferred ash disposal facility alternative.

- 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 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 was representative of the site.
- A comprehensive list of sensitive receptors was not available. As such, schools - primary farm schools, primary schools and high schools – were identified via aerial photography (using Google Earth™) and used as identified sensitive receptors around the ash disposal facility alternatives. Schools were selected on the basis of sensitivity of children to airborne dust and that they are indicative of residences in the near vicinity.

- No sensitive receptors were identified near Alternative C, possibly due to the age of the aerial photograph consulted. It is understood that families (and individuals) that were displaced by the construction of the Kusile Power Station were relocated to Alternative C but the exact locations were unavailable for our assessment. The lack of identified sensitive receptors near alternative C was taken into account for the overall site alternative preference, by conservatively ranking Alternative C after other alternatives with a similar spatial impact.

- 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 between -50% and 200%. There will always be some error in any geophysical model, but it is desirable to structure the model in such a way to minimise the total error. A model represents the most likely outcome of an ensemble of experimental results. The total uncertainty can be thought of as the sum of three components: the uncertainty due to errors in the model physics; the uncertainty due to data errors; and the uncertainty due to stochastic processes (turbulence) in the atmosphere.
- The selection of a modelling domain takes account of the expected impacts and it is possible that the impacts, when modelled, extend beyond the modelling domain. This occurred for Alternative B. Although the impacts extend beyond the modelling domain, it was possible to estimate the extent of the impacts outside of the modelling domain. It is expected that the area of impact will likely be similar to alternatives A and C. The model domain was later expanded to include Bronkhorstspruit as a sensitive receptor of elevated PM_{10} and $PM_{2.5}$ concentrations should Alternative B be selected the preferred alternative
- Increased life-time cancer risk was calculated at the identified sensitive receptors for arsenic, nickel and chromium.
    - Carcinogenic trivalent arsenic (As^{3+}) was assumed to account for 10% of the total arsenic in the ash sample.
        - The US-EPA unit risk factor (URF), 4.3×10^{-3}, was used to calculate the increased cancer risk, due to the fact that it is more conservative than the WHO unit risk factor.
    - There is much uncertainty in the literature regarding the species and the mechanisms through which nickel is toxic. A conservative estimate of increased life-time cancer risk was calculated assuming:
        - All forms of nickel present in the ash sample are carcinogenic.
        - The US-EPA IRIS unit risk factor (URF) of cancer as a result of exposure to nickel used was 2.4×10^{-4} $(\mu g.m^{-3})^{-1}$.
    - 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 1.1×10^{-2} $(\mu g.m^{-3})^{-1}$ to 13×10^{-2} $(\mu g.m^{-3})^{-1}$ as specified by the WHO. The US-EPA URF of 1.2×10^{-3} $(\mu g.m^{-3})^{-1}$ was used in the estimation of increased life-time cancer risk compensating for conservative approach followed in the estimation of Cr^{6+} emissions and impacts.

KEY FINDINGS

The model output shows that in the unmitigated scenario annual PM_{10} concentrations exceed the NAAQS well beyond the boundary of each alternative; however alternatives B, C and A (in order of significance) show the smallest area of impact. In relation to sensitive receptors, exceedances of the annual PM_{10} NAAQS are fewer for alternatives C and B. A similar pattern is evident for annual $PM_{2.5}$ concentrations. Dust-fall rates exceeding 400 $mg.m^{-2}.day^{-1}$ affect an area less than 20 000 ha for Alternatives A, B and C, for the unmitigated scenario.

The life-time increased cancer risk was calculated at each of the identified sensitive receptors for exposure to inhalable arsenic, nickel and chromium. The calculations were based on the projected annual PM_{10} concentrations at each sensitive receptor, 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.

All assessments for site selection were based on the output from the unmitigated scenario. However the findings from modelling the mitigation scenarios were included to illustrate the value in effective mitigation of wind-blown dust emissions to reduce the impact of the ash disposal facilities. 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.

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

Glossary

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

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

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

"control efficiency" is the percentage by which an emissions mitigation technique reduces the emissions from a stationary source to the atmosphere

"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. 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). Kusile Power Station will dispose boiler- and fly-ash in a conditioned dry (8 to 15% moisture content conditioning) format, which will be transported by means of conveyors. The ash will be distributed onto the ash disposal facility by means of a stacker at a rate of approximately 110 tons per hour per generating unit. The ash disposal facility (within 15 km of the power station) will, at full extent (after 60 years), cover an area of approximately1 500 ha.

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

1.1 Site Description

The proposed ash disposal facility alternatives are primarily surrounded by neighbouring mining operations, the Kusile Power Station, and agricultural activities. Major residential areas in the region include Ogies (~19 km south-east) and Bronkhorstspruit (~22 km north-west). Smaller residential areas in the region include Wilge (~9 km south-east), which includes the New Largo Primary School, and Phola which hosts at least three schools. Individual residences (i.e. farm houses) are also in the immediate vicinity of the proposed operations. Five farm (primary) schools are in the near vicinity of the proposed ash disposal facility alternatives and are considered to be sensitive receptors with respect to air quality.

1.2 Air Quality Evaluation Approach

The study, thus far, has followed a qualitative approach, using available meteorological data and pollutants typically associated with the proposed activities to evaluate the potential for off-site impacts.

A quantitative assessment was undertaken based on the evaluation of existing windblown dust from ash dump studies (Burger, 1994), together with the dispersion potential of the site and magnitude of expected impacts from the proposed activities. Based on the qualitative evaluation, a quantitative assessment will follow and will include dispersion modelling scenarios for each of the proposed ash disposal facility alternatives.

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.
- A comprehensive list of sensitive receptors was not available. As such, schools - primary farm schools, primary schools and high schools – were identified via aerial photography (using Google Earth™) and used as identified sensitive receptors around the ash disposal facility alternatives. Schools were selected on the basis of sensitivity of children to airborne dust and that they are indicative of residences in the near vicinity.
    - No sensitive receptors were identified near Alternative C, possibly due to the age of the aerial photograph consulted. It is understood that families (and individuals) that were displaced by the construction of the Kusile Power Station were relocated to Alternative C but the exact locations were unavailable for our assessment. The lack of identified sensitive receptors near alternative C was taken into account for the overall site alternative preference, by conservatively ranking Alternative C after other alternatives with a similar spatial impact.
- 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.
- The selection of a modelling domain takes account of the expected impacts and it is possible that the impacts, when modelled, extend beyond the modelling domain. This occurred for Alternative B. Although the impacts extend beyond the modelling domain, it was possible to estimate the extent of the impacts outside of the modelling domain. It is expected that the area of impact will likely be similar to alternatives A and C. The model domain was later expanded to include Bronkhorstspruit as a sensitive receptor of elevated PM_{10} and $PM_{2.5}$ concentrations should Alternative B be selected the preferred alternative. The findings from the additional modelling are presented in Section 5.5.
- Increased life-time cancer risk was calculated at the identified sensitive receptors for arsenic, nickel and chromium.
    - Carcinogenic trivalent arsenic (As^{3+}) was assumed to account for 10% of the total arsenic in the ash sample.

- The US-EPA unit risk factor (URF), 4.3×10^{-3}, was used to calculate the increased cancer risk, due to the fact that it is more conservative than the WHO unit risk factor.

- There is much uncertainty in the literature regarding the species and the mechanisms through which nickel is toxic. A conservative estimate of increased life-time cancer risk was calculated assuming:
  - All forms of nickel present in the ash sample are carcinogenic.
  - The US-EPA IRIS unit risk factor (URF) of cancer as a result of exposure to nickel used was 2.4×10^{-4} $(\mu g.m^{-3})^{-1}$.
- 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 1.1×10^{-2} $(\mu g.m^{-3})^{-1}$ to 13×10^{-2} $(\mu g.m^{-3})^{-1}$ as specified by the WHO. The US-EPA URF of 1.2×10^{-3} $(\mu g.m^{-3})^{-1}$ was used in the estimation of increased life-time cancer risk compensating for conservative approach followed in the estimation of Cr^{6+} emissions and impacts.

1.4 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 ash disposal facility on the air quality in the vicinity. The main findings, thus far, are outlined in Section 5 and the significance rating for all alternatives in Section 6. An environmental impact statement for the preferred alternative is presented in Section 7. The references are provided in Section 8. Appendices A – C are in Sections 9 – 11.

2 LEGISLATIVE CONTEXT

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 1). The $PM_{2.5}$ national ambient air quality standards were recently finalised and gazetted (Government Gazette no. 35463, #486) on the 29th June 2012 with lowering concentration limits over three commitment periods.

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

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

[1]The number of averaging periods where exceedance of limit is acceptable within a calendar year. For example, 4 days in a
where the PM_{10} exceeds 75 $\mu g.m^{-3}$.

[2]Date after which concentration limits become enforceable.

[3]National Ambient Air Quality Standard for Particulate Matter with aerodynamic diameter less than 2.5 micron metres ($PM_{2.5}$), as
G35463 of 29 June 2012.

2.2 National Dust Control Regulations

Draft National Dust Control Regulations were published on the 7th December 2012 with the dust fallout standards published on the 1st November 2013 (Government Gazette No. 36974). The purpose of the regulations is to prescribe general measures for the control of dust in all areas including residential and light commercial areas.

In addition to the dust fall limits, the National Dust Control Regulations prescribe monitoring procedures and reporting requirements.

The acceptable dust fall rates as measured (using ASTM D1739:1970 or equivalent) at and beyond the boundary of the premises where dust originates are given in Table 2.

Table 2: Draft dust fallout standards

Restriction area	Dust fallout rate ($mg.m^{-2}.day^{-1}$, 30-d average)	Permitted frequency of exceeding dust fallout rate
Residential area	D < 600	Two within any year, non-sequential months.
Non-residential area	600 < D < 1 200	Two within any year, non-sequential months.

2.3 Effect of Dust on Vegetation, Animals and Susceptible Human Receptors

2.3.1 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 m^{-2} day^{-1}. Little direct evidence of the effects of dust-fall on South African vegetation, including crops, exists.

2.3.2 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 m^{-3}), greatly exceeding levels reported in the ambient environment. Exposure resulted in significant compromises in various lung functions similar to those seen in the acute studies, but including also:

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

The epidemiological finding of an association between 24-hour ambient particle levels below 100 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^{-1}), using continuous exposure to concentrated ambient particles.

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

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

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

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

2.3.3 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 3). 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 3: 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)

2.4 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 4), 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. The risks contextualised in Table 4 are for the types of cancer that may develop as a result of long-term exposure to the coal ash. After metal analysis of an ash sample (from Kendal Power Station), increased life-time cancer risk was calculated for the three most abundant metals likely to result in increased risk of cancer, where the increased risk of cancer, as a result of exposure to ash from the Kusile Ash Disposal Facility, was estimated to be 1 in 10 000 or less (detailed further in Section 5.4)..

Table 4: 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

2.4.1 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 from 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 $ng.m^{-3}$ to 3 $ng.m^{-3}$ in remote areas, whereas the background levels in urban area have been found to be an order of magnitude higher, i.e. 20 to 30 $ng.m^{-3}$. Concentrations can reach several hundred nanograms

per cubic metre in some cities and exceed 1000 ng.m^{-3} (1 µg.m^{-3}) near nonferrous metal smelters (WHO, 1981) and some power plants, depending on the arsenic content of the coal.

Arsenic is toxic to human health and is considered a carcinogen. The exposure of humans to arsenic affects several organs and may interfere in the immune system (Duker *et al.*, 2005). Inorganic arsenic can have acute, sub-acute and chronic affects which may be either local or systemic. Lung cancer is considered to be the critical effect following inhalation. An increased incidence in lung cancer has been seen in several occupational groups exposed to inorganic arsenic. Some studies show that populations near emissions sources of inorganic arsenic, such as smelters, have a moderately elevated risk of lung cancer (Blot *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.m^3)$^{-1}$. The US-EPA Integrated Risk Information System (IRIS) recommends a more conservative 4.3 x 10^{-3} (µg.m^3)$^{-1}$ URF for arsenic. It was decided to use the more conservative URF to estimate increased cancer risk through exposure to ash from the 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.

2.4.2 Nickel

Nickel (Ni) is used in many industrial and commercial applications including: in stainless steel, nickel alloys, catalysts, batteries, pigments and ceramics. According to the US-National Toxicology Program

of the Department of Health and Human Services, nickel compounds are classed as known human carcinogens, while metallic nickel is classed as '*reasonably anticipated to be a human carcinogen*'. Evidence suggests that the genotoxic agent, and probable carcinogenic agent, is the Ni^{2+} ion although the potency of nickel compounds is highly variable, based on solubility and chemical speciation. The US-EPA IRIS (Integrated Risk Information System) therefore defines risk profiles for nickel carbonyl, nickel subsulfide and soluble nickel salts. Inhalation, ingestion and dermal contact are the mechanisms via which exposure to Ni occurs. Most people are exposed to low levels of environmental Ni, in air (with ambient concentrations generally less than 2.5 $ng.m^{-3}$ – Sivulka, 2005), water, food and consumer products. Occupational exposure through inhalation of dust particles and fumes has the greatest cancer risk (Sivulka, 2005), potentially results in the development of cancers of the lung and / or nasal passages, with a possibility of extra-pulmonary tumours. The unit risk (URF) for lung cancer based on life-time exposure to 1 $\mu g.m^{-3}$ of Ni compounds ranges between 2.1×10^{-4} $(\mu g.m^{-3})^{-1}$ and 37×10^{-4} $(\mu g.m^{-3})^{-1}$. The recommended inhalation URF for exposure to Ni refinery dust is 2.4×10^{-4} $(\mu g.m^{-3})^{-1}$ and for exposure to Ni subsulfide is 4.8×10^{-4} $(\mu g.m^{-3})^{-1}$. Haney *et al.* (2012) recently presented a weighted URF of 1.74×10^{-4} $(\mu g.m^{-3})^{-1}$, translating into an ambient Ni concentration of 0.059 $\mu g.m^{-3}$ for the increased lung cancer risk of 1 in 100 000. The revised URF presented by Hanley *et al.* (2012) is, however, most appropriate for the low sulfidic nickel emissions from Texas (USA) refineries.

The increased life-time cancer risk as a result of long-term exposure to Ni in ash from the Kusile Power Station was calculated from the annual PM_{10} concentrations at the identified sensitive receptors using the URF of 2.4×10^{-4} $(\mu g.m^{-3})^{-1}$, 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.

2.4.3 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).

2.4.3.1 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 µg.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.

2.4.3.2 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 µg.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 1.2×10^{-2} $(\mu g.m^{-3})^{-1}$. Using the US-EPA cancer unit risk factor, a concentration of 0.0008 µg $Cr^{6+}.m^{-3}$ in air would be associated with an excess cancer risk of one in a hundred thousand. The WHO cancer unit risk factor for hexavalent chromium is stated in the range 1.1 to 13×10^{-2} $(\mu g.m^{3})^{-1}$. Using the lower factor, a concentration of 0.000091 µg $Cr^{6+}.m^{-3}$ in air would be associated with an excess cancer risk of one in a million.

The risk calculations above are generic and simplified, based on assumptions that are not always applicable. For example, the estimates have not considered the greater vulnerability of children to such exposures. Furthermore, it is assumed that individuals would be exposed to all the hexavalent

chromium in the particulates. This may be conservative, as particulates with aerodynamic diameter above 10 µm are largely trapped in the nasopharyngeal region of the respiratory system, from where they may be washed out for ingestion through mucociliary action. This is an important consideration in assessing exposure and risk, because carcinogenicity of hexavalent chromium by the oral route of exposure has not been shown.

Since not all combustion processes result in release of Cr^{6+} it is valuable, in assessing the increased life-time cancer risk as a result of inhalation, to understand the contribution of Cr^{6+} to total Cr in ash, and especially in the PM_{10} (inhalable) fraction. In two recent studies of Cr in ash from Australian coal-fired power stations, it was found that a small proportion of total Cr occurs as Cr^{6+} (Shah *et al.*, 2008; 2012). The focus of the earlier study (Shah *et al.*, 2008) was on the speciation of trace metals (As, Cr and selenium) in the coal ash from a single power station in New South Wales using bituminous rank coal. The authors found that Cr^{6+} accounted for only 2.7% of the total Cr in coal fly-ash. The later investigation (Shah *et al.*, 2012) focussed on the Cr speciation in bituminous rank coal and ash by-product from four coal-fired power stations across Australia. The range of contribution of Cr^{6+} to total Cr in ash products ranged between 0.9 and 1.6%. Further analyses showed that in the PM_{10} fraction, only 1.1% of total Cr was in the toxic Cr6+ 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.

2.4.4 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 5). 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 5: 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 3.2).

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 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).

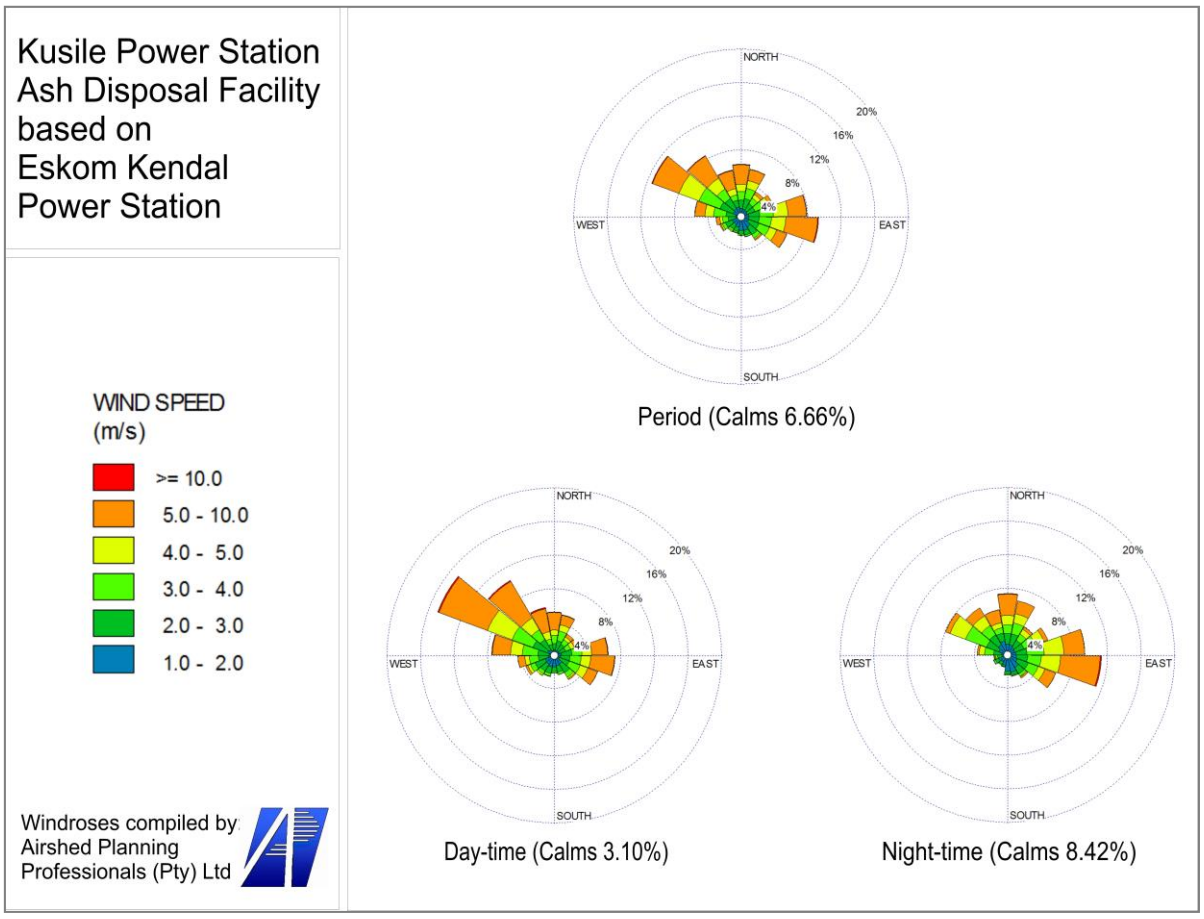

Figure 1: Period, day-time and night-time wind roses for Kendal Power Station (January 2009 – October 2012)

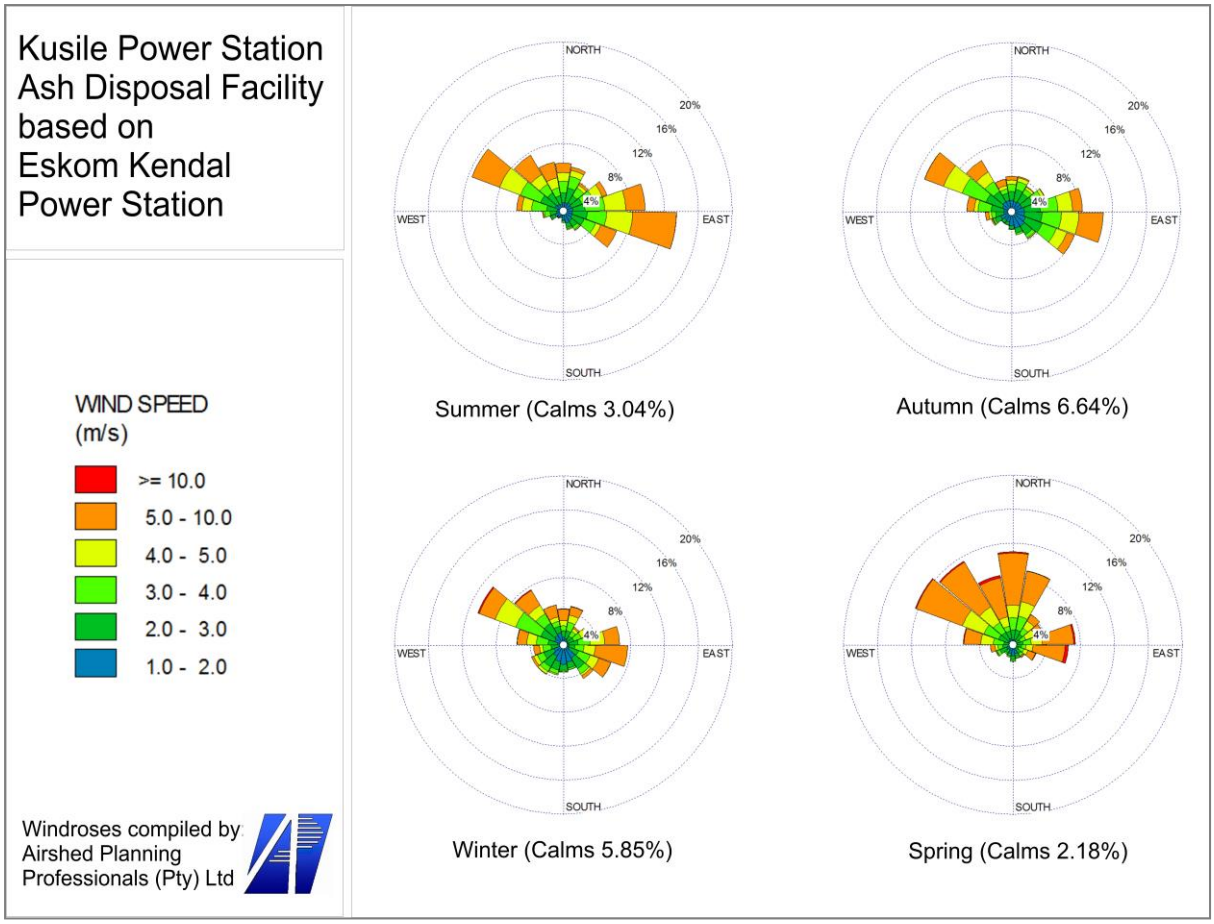

Figure 2: Seasonal wind roses for Kendal Power Station (January 2009 – October 2012)

During summer months (Figure 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. 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).

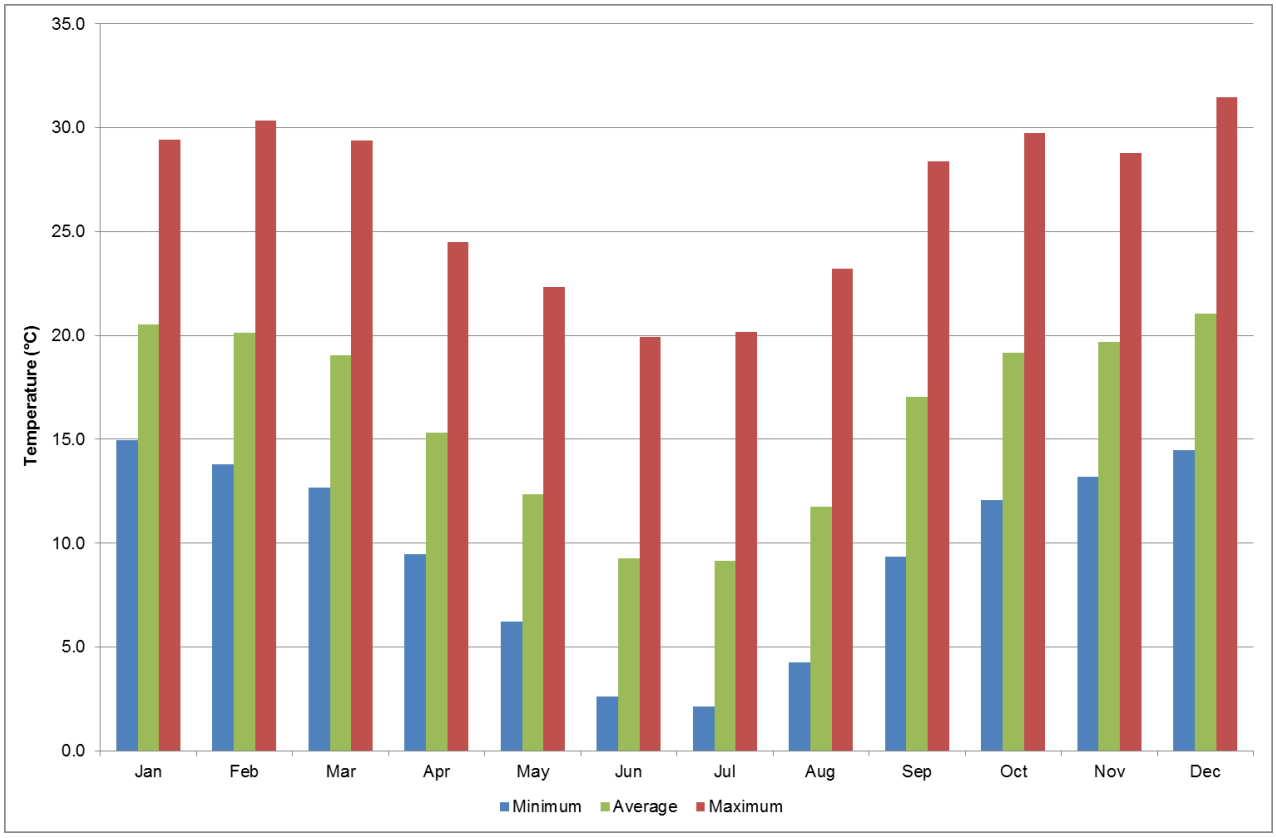

Figure 3: Minimum, maximum and average monthly temperatures near Kendal Power Station during the period January 2009 – October 2012

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 Kendal 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 6). Rain falls mainly in summer from October to April, with the peak for the region being in January.

Table 6: 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 vertical component of dispersion is a function of the extent of thermal turbulence and the depth of the surface mixing layer. Unfortunately, the mixing layer is not easily measured, and must therefore often be estimated using prognostic models that derive the depth from some of the other parameters that are routinely measured, e.g. solar radiation and temperature. 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. The mixing layer ranges in depth from ground level (i.e. only a stable or neutral layer exists) during night-times to the base of the lowest-level elevated inversion during unstable, day-time conditions.

Atmospheric stability is frequently categorised into one of six stability classes. These are briefly described in Table 7.

Table 7: Atmospheric Stability Classes

A	very unstable	calm wind, clear skies, hot daytime conditions
B	moderately unstable	clear skies, daytime conditions
C	unstable	moderate wind, slightly overcast daytime conditions
D	neutral	high winds or cloudy days and nights
E	stable	moderate wind, slightly overcast night-time conditions
F	very stable	low winds, clear skies, cold night-time conditions

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 5-6 hours after sunrise. This situation is more pronounced during the winter months due to strong night-time inversions and a 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 low level releases, such as due to vehicle entrainment from unpaved roads, the highest ground level concentrations will occur during weak wind speeds and stable (night-time) atmospheric conditions. Wind erosion, on the other hand, requires strong winds together with fairly stable conditions to result in high ground level concentrations i.e. neutral conditions.

3.2 Ambient Air Quality near Kusile Ash Disposal Facility

3.2.1 Highveld Priority Area

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

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

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

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

The Kusile Ash Disposal Facility Alternative A falls within the HPA. The other alternatives either fall partially within (Alternatives C, F, and G) or completely outside (Alternative B) the HPA. However given their proximity to the boundary the particulate emissions from the facility are likely to contribute to the air quality of the HPA. The alternatives are located in the vicinity of the Emalahleni Hot Spot (HPA, 2011) and the ambient air quality, with particular reference to particulates, is outlined below.

3.2.1.1 Emalahleni Hot Spot

The poor ambient air quality in the Emalahleni 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 Emalahleni 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 4). 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 average of ~83 $\mu g.m^{-3}$ for Witbank 2.

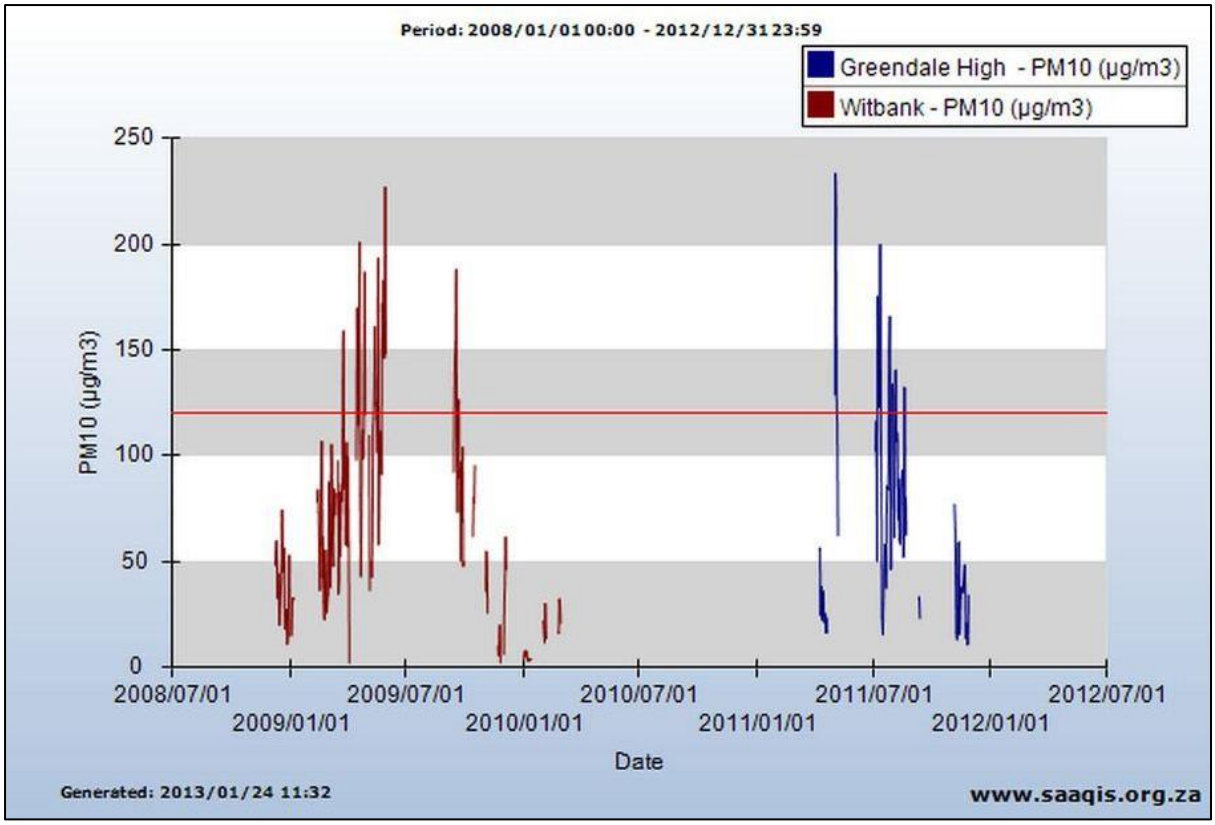

Figure 4: Daily PM_{10} concentrations monitored at two stations in the Emalahleni Hot Spot between 2008 and 2012 (from www.saaqis.org.za). The horizontal red line indicates the current daily limit of 120 µg.m^{-3}.

3.2.1.2 The proposed New Largo Colliery

The proximity of the New Largo Colliery to the Kusile Power Station and Ash Disposal Facility prompted an enquiry into the cumulative effect of the sources on local air quality, given that the background air quality is likely to be poor. Although it was not possible to quantify the cumulative impact of the mining and ash disposal facility, some findings from the New Largo Colliery Environmental Impact Assessment are included here.

The New Largo Colliery is likely to result in local cumulative impacts when combined with alternatives A, F, and G. Annual PM_{10} concentrations were modelled to exceed the NAAQS, for unmitigated operations, outside of the mine boundary during the maximum production phase, characterised by operational year 2041 (Figure 5). Mitigation of emissions from the operational process will restrict PM_{10} annual exceedances to be within the mine boundary (Figure 6).

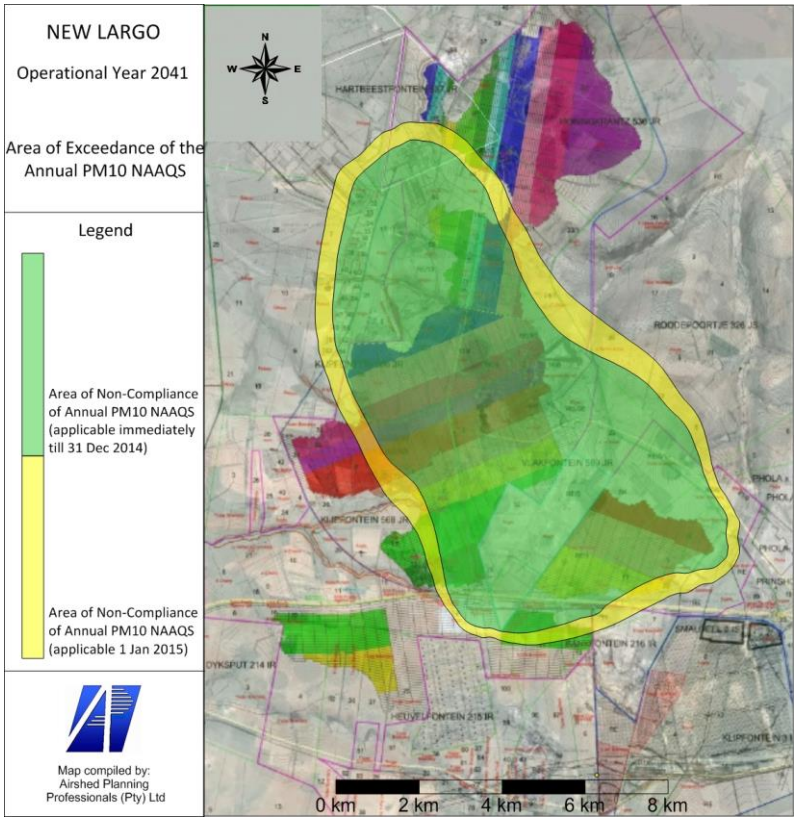

Figure 5: Area of exceedance of annual PM_{10} NAAQS due to operations at the proposed New Largo Colliery for the period 2041 - unmitigated operations (Synergistics, 2012)

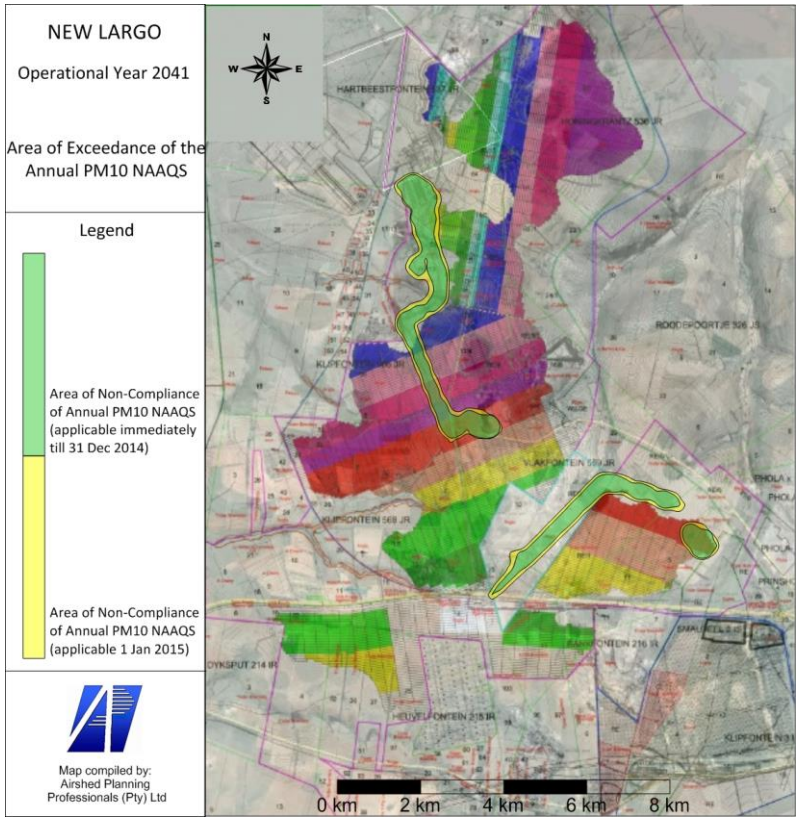

Figure 6: Area of exceedance of annual PM_{10} NAAQS due to operations at the proposed New Largo Colliery for the period 2041 - mitigated operations (Synergistics, 2012)

4 METHODOLOGY

4.1 Source Identification

The project includes the disposal of ash from the Kusile Power Station at one (or two) ash disposal facilities within 15 km of the power station. The main pollutant of concern associated with the proposed operations is particulate matter. Particulates are divided into different particle size categories with Total Suspended Particulates (TSP) associated with nuisance impacts and the finer fractions of PM_{10} (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 8) 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;
- movement of vehicles across exposed soil or ash, will also be a source of pollution; and,
- transport to, and disposal of ash on, ADF.

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

Table 8: 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
Continuous ash disposal		
Particulates	Wind erosion from ash disposal facility	Exposed dried out portions of the ash disposal facility
	Emissions associated with conveyor transport of ash	Wind-blown emissions and tipping of the ash transported on the conveyor from the power station to the disposal facility. Note that ash is usually conditioned to a moisture content of 8% to 15% prior to conveyor transport and disposal. The increased moisture content will limit the particulate emissions from these sources.
	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 is relevant as the ash disposal facility is established and during continuous ash disposal, as this would normally comprise a series of different operations including land clearing, topsoil removal, road grading, material loading and hauling, stockpiling, compaction, etc. Each of these operations has a distinct duration and potential for dust generation. It is anticipated that the extent of dust emissions would vary substantially from day to day depending on the level of activity, the specific operations, and the prevailing meteorological conditions.

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

4.1.2 Continuous ash disposal

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

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

Estimating the amount of windblown particles to be generated from the proposed ash disposal facility is not a trivial task and requires detailed information on the particle size distribution, moisture content, silt content and bulk density (explained in Appendix 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 9).

Table 9: Annual emissions for each site alternative for each of the modelled scenarios

Scenario	Particulate fraction	Annual emissions (tpa)				
		Alt A	Alt B	Alt C	Alt F	Alt G
		1 627 ha	1 330 ha	1 800 ha	2 859 ha	2 001 ha
Unmitigated	TSP	217 294	177 628	240 399	763 667	534 468
	PM_{10}	86 394	70 623	95 580	303 627	212 507
	$PM_{2.5}$	24 898	20 353	27 546	87 503	61 243
Re-vegetation CE = 97%	TSP	6 536	5 343	7 231	22 970	16 077
	PM_{10}	2 598	2 124	2 875	9 132	6 391
	$PM_{2.5}$	749	612	828	2 632	1 842
Wetting CE = 74%	TSP	56 513	46 196	62 522	198 611	139 007
	PM_{10}	22 349	18 269	24 726	78 545	54 973
	$PM_{2.5}$	6 440	5 264	7 125	22 634	15 841
Both (re-vegetation & wetting) CE = 99%	TSP	1 699	1 389	1 880	5 973	4 180
	PM_{10}	672	549	743	2 362	1 653
	$PM_{2.5}$	194	158	214	680	476

4.1.3 Rehabilitation

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

It is assumed that all ash disposal activities will have ceased during closure phase, when the power station has reached end of life. Because most of the rehabilitation is undertaken during the operations, the ash disposal facility should be almost completely rehabilitated by the closure phase. The potential for impacts after closure will depend on the extent of continuous rehabilitation efforts on the ash disposal facility.

The significance of the rehabilitation activities is likely to be linked to impacts from windblown dust from the exposed dried out ash, topsoil and vehicle entrainment during the rehabilitation process. Windblown dust is likely to only impact off-site under conditions of high wind speed with no mitigation in place. If rehabilitation as indicated takes place, i.e. vegetation cover, the impacts should be limited to be within the 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) and National Dust Control Regulations are based on human exposure to specific criteria pollutants and as such, possible sensitive receptors

were identified where the public is likely to be unwittingly exposed. NAAQS are enforceable outside of power station and ash disposal facility boundaries and therefore a number of sensitive receptors have been identified (Figure 4; Table 10). These sensitive receptors are schools – and associated residential areas – in the close vicinity of the proposed ash disposal facility alternatives. The modelled ground-level concentrations of total suspended particulates (TSP), PM_{10} and $PM_{2.5}$ were compared to National Standards and Guidelines at these sensitive receptors (Section 5).

No sensitive receptors were identified near Alternative C, possibly due to the age of the aerial photograph consulted. It is understood that families (and individuals) that were displaced by the construction of the Kusile Power Station were relocated to Alternative C but the exact locations were unavailable for our assessment. The lack of identified sensitive receptors near alternative C was taken into account for the overall site alternative preference, by conservatively ranking Alternative C after other alternatives with a similar spatial impact.

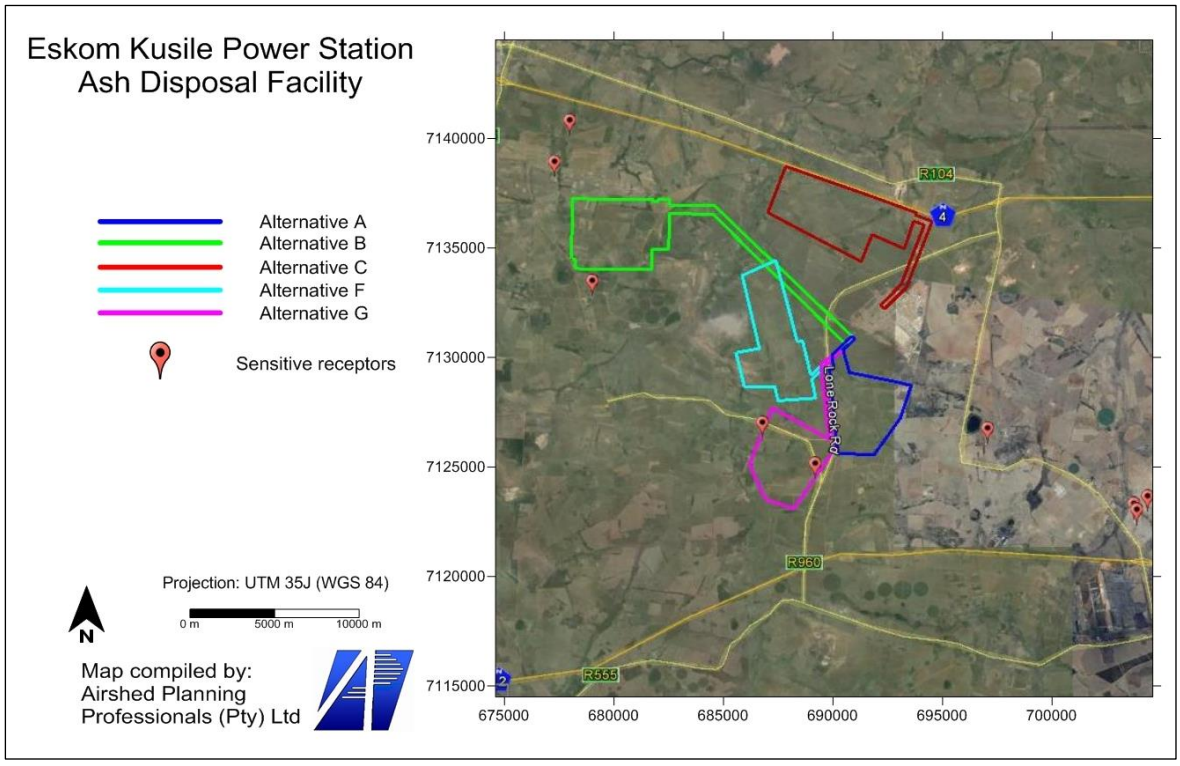

Figure 7: Aerial map (from Google Earth™ - image date 2012) of the Kusile Power Station (under construction), the proposed alternative sites for ash disposal with conveyor corridors and the sensitive receptors.

Table 10: Location of the sensitive receptors (Projection: WGS 84, UTM 35J, units are meters (m))

Receptor name	Easting	Northing
Kelvin Primary Farm school	686733	7126259
New Largo Primary school	696813	7125848
Hlangu Phala Primary school	703475	7121989
Mabande Comprehensive High school	703344	7122269
Siyathokoza Primary school	703967	7122599
Ezinkukhwini Primary Farm school	677550	7138489
Ncedanani Primary Farm School	678238	7140436
Thereso Primary Farm School	679175	7132937
Dwaalfontein Primary School	689074	7124331

4.3 Compliance analysis and impact assessment

The current air quality in the vicinity of the proposed sites is discussed in Section 3.2. The ash disposal facility will continue to give rise to dust generation as the ash disposal operations are initiated and continue through the life of the power station (60 years). These operations, as discussed under Section 4.1.2, are low level release sources meaning that the dust gets generated at heights of between 0.5 and 1 m from the ash disposal facility surface.

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

Wind erosion, will occur during strong wind conditions when wind speeds exceed the critical threshold required to lift and suspend the ash particles. This threshold is determined by the parameters that resist removal such as the particle size distribution of the bed material, moisture content and vegetation. A typical wind speed threshold is given as 5.4 $m.s^{-1}$ 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 $m.s^{-1}$ and a maximum of 15.2 $m.s^{-1}$, 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 to 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 ash disposal facility, as the focus of this report, was the only source considered during model simulations; however, the impact of all six alternatives was simulated. Due to the fact that high ambient PM_{10} concentrations (compared to SA NAAQS) were expected, generic mitigation measures were also modelled. These included wetting of the ash by water sprays and re-vegetation. A total of four scenarios were simulated:

- unmitigated (disposal of conditioned ash but allowed to dry out);
- mitigation by means of re-vegetation covering 80% of the ash disposal facility (control efficiency of: 97%);
- mitigation by means of water sprays to maintain ash moisture content at 5% (about half of the moisture content when ash deposited at disposal facility – control efficiency of: 74%); and,
- mitigation by means of re-vegetation of 80% of ash disposal facility and watering to maintain ash moisture content at 5% (control efficiency of: 99%).

All alternative sources were modelled at full size as ADMS is not capable to model real-time changes in ash disposal facility size. 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 11) and elemental content (Table 12).

Table 11: 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

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.

The model domain was later expanded to include Bronkhorstspruit as a sensitive receptor of elevated PM_{10} and $PM_{2.5}$ concentrations should Alternative B be selected the preferred alternative (Section 5.5).

Table 12: 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

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 has, however, generally been found that the accuracy of dispersion models improves with increased averaging periods. The accurate prediction of instantaneous peaks are the most difficult and are normally performed with more complicated dispersion models specifically fine-tuned and validated for the location. For the purposes of this study and for selecting a preferred alternative site, the averaging period presented in this report is annual. It should be noted that the ground-level concentration isopleths depicted present interpolated values from the concentrations predicted by ADMS 4 for each of the receptor grid points specified.

The model domain was later expanded to include Bronkhorstspruit as a sensitive receptor of elevated PM_{10} and $PM_{2.5}$ concentrations should Alternative B be selected the preferred alternative. The findings from the additional modelling are presented in Section 5.5.

5.1 Dust fall-out

Dust fall-out in the unmitigated scenario is likely to exceed the residential guideline over large areas surrounding any of the alternative ash disposal facility locations (Figure 8). Although reduced in area exceedances of the guideline are also expected if mitigation is limited to water sprays. However, dust fall-out under the re-vegetation and combination mitigation strategies falls within the residential guideline (Figure 8). The potential impact of dust-fall on agricultural crops near the ash disposal facility was plotted (Figure 9) at the 400 $mg.m^{-2}.day^{-1}$ guideline (Section 2.3.1). The predicted areas of impact where dust-fall rates are above the agricultural guideline, for the unmitigated scenario, are lowest for Alternative B, followed by Alternatives A and C (Table 13).

Table 13: Area of impact (ha) for dust fall-out rates and annual PM_{10} from each site alternative

Scenario	Receptor name	Area of impact (ha)*	
		Dust fall-out >400 $mg.m^{-2}.day^{-1}$	Annual PM_{10}
Unmitigated	Alternative A	18 047	6 647
	Alternative B	9 272	4 501
	Alternative C	18 848	7 061
	Alternative F	30 671	14 989
	Alternative G	21 842	10 474
Re-vegetation	*No impact predicted off-site for any alternative*		
Wetting	Alternative A	6 686	864
	Alternative B	3 377	689
	Alternative C	6 902	944
	Alternative F	14 894	1 602
	Alternative G	9 626	1 433
Both (re-vegetation and wetting)	*No impact predicted off-site for any alternative*		

* excluding ash disposal facility foot-print

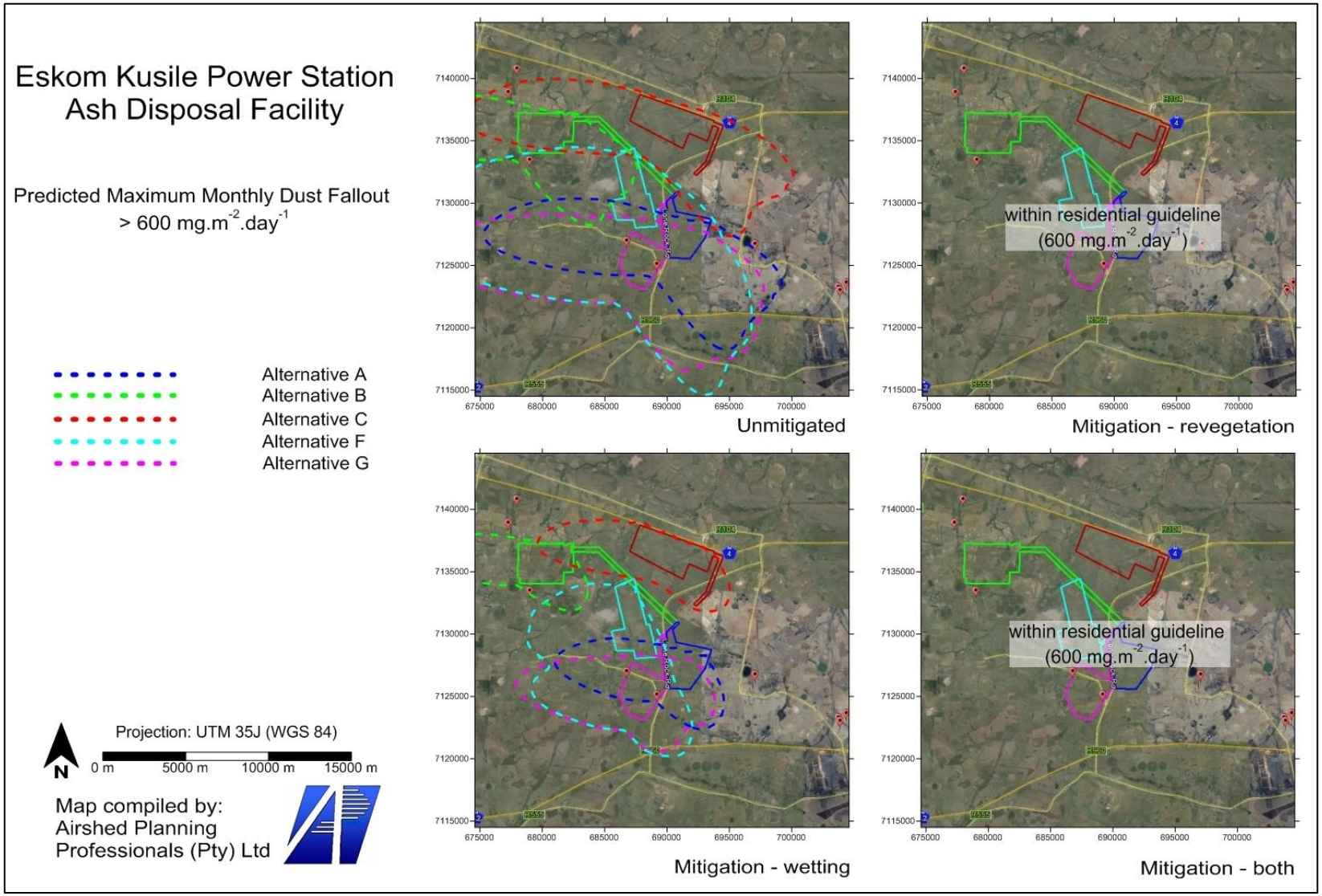

Figure 8: Predicted maximum monthly dust fall-out as a result of each of the six alternative ash disposal facilities at Kusile Power Station

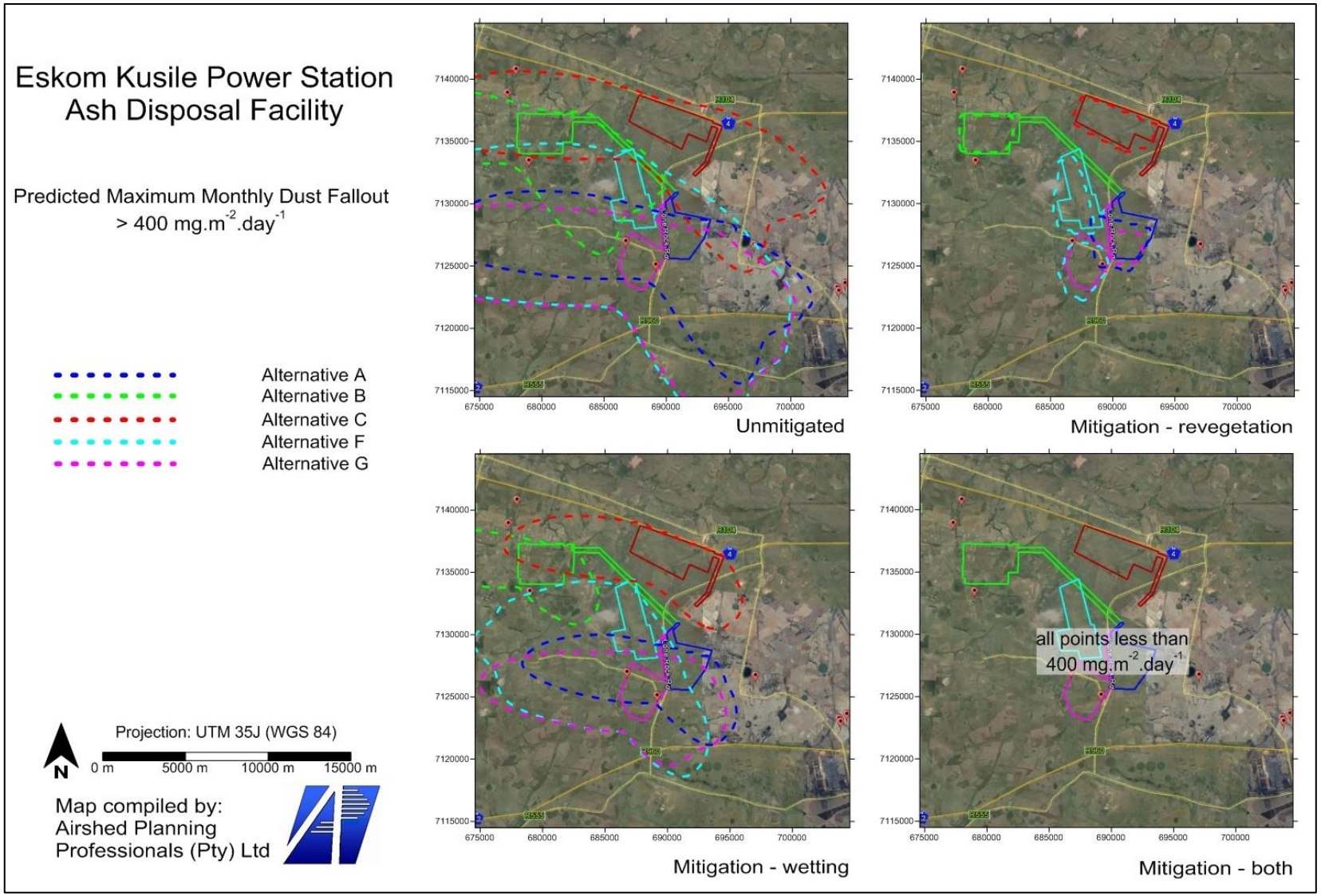

Figure 9: Areas impacted by dust fall-out rates exceeding 400 mg.m^{-2}.day^{-1}, as a result of each of the six alternative ash disposal facilities at Kusile Power Station

5.2 PM_{10} ground-level concentrations

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

The areas impacted by elevated annual PM_{10} concentrations as a result of unmitigated wind-blown dust are predicted to be the lowest for Alternative B, followed by Alternatives A and C (Table 13), although areas can be drastically reduced by introducing mitigation techniques.

Exceedances of the annual NAAQS for PM_{10} are likely to be limited to three of the local schools identified as sensitive receptors (Table 14) however improvements are likely with effective mitigation. On the basis of the unmitigated scenario, Alternatives C and B affect the fewest sensitive receptors (Table 14).

5.3 $PM_{2.5}$ ground-level concentrations

Despite the large fraction in fine material expected for the Kusile ash, impact for $PM_{2.5}$ is more restricted than PM_{10}. However, exceedances with the annual standard are expected under the unmitigated scenario, irrespective of the location of the ash disposal facility (Figure 11). The area affected by exceedances of the annual limits can be reduced through mitigation via watering and controlled within the annual limits via re-vegetation and a combination mitigation strategy (Figure 11).

Non-compliance with annual $PM_{2.5}$ NAAQS is expected at two of the sensitive receptors without mitigation of dust emissions from Alternatives A, G, and F (Table 15). Alternatives B and C have the no exceedances in the unmitigated scenario.

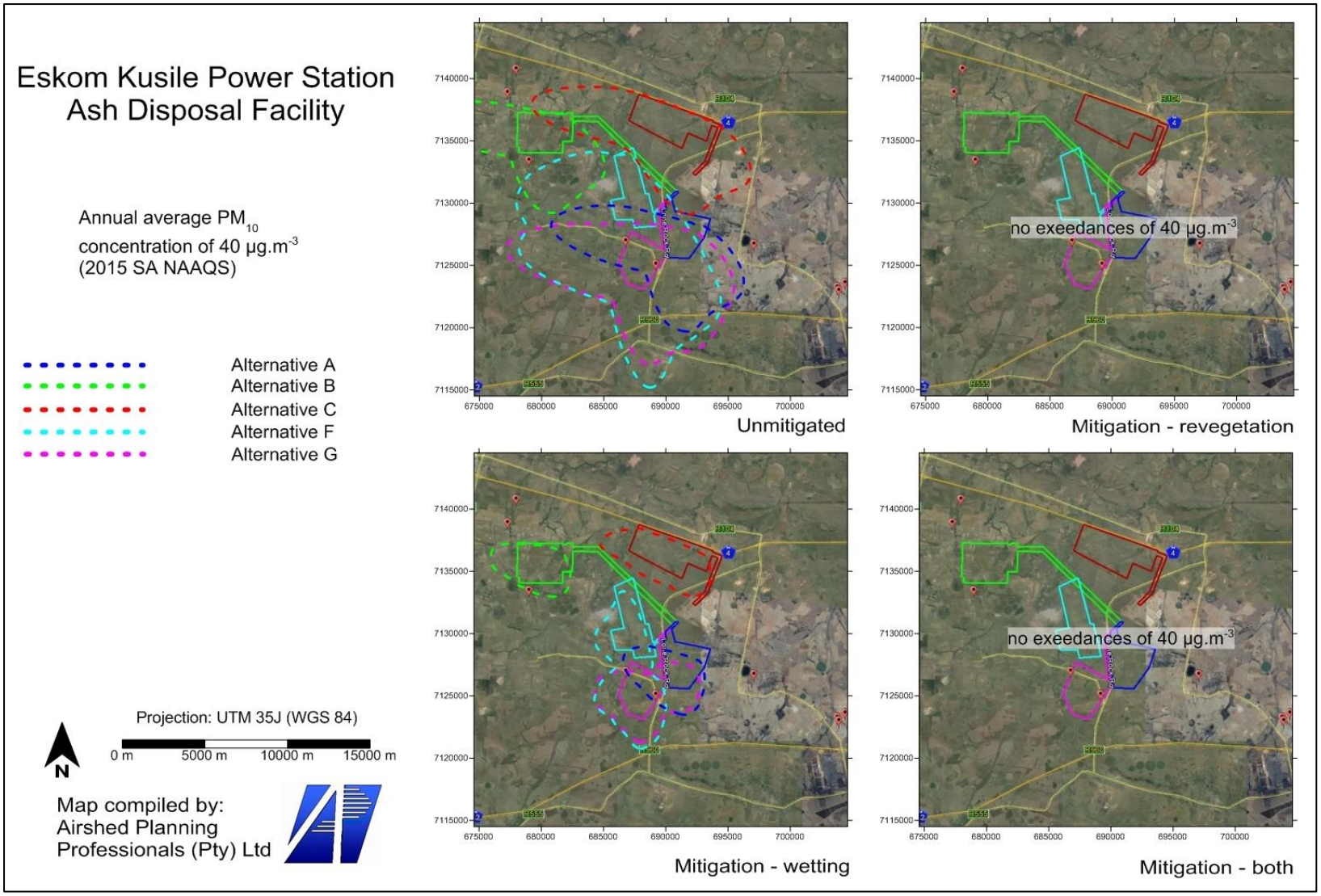

Figure 10: Predicted annual average PM_{10} concentration as a result of the six alternative ash disposal facilities at Kusile Power Station

Table 14: Annual average PM_{10} ground-level concentration at sensitive receptors where exceedances (NAAQS limit value: 40 µg.m^{-3}) are predicted as a result of wind-blown emissions from the alternative ash disposal facilities

Scenario	Receptor name	Annual average (µg.m^{-3})				
		Alt A	Alt B	Alt C	Alt F	Alt G
Unmitigated	Kelvin PFS	109.91			310.63	266.78
	New Largo PS					
	Hlangu Phala PS					
	Mabande CHS					
	Siyathokoza PS					
	Ezinkukhwini PFS					
	Ncedanani PFS					
	Thereso PFS		110.85			
	Dwaalfontein PS	107.02			324.94	291.51
Re-vegetation	Kelvin PFS					
	New Largo PS					
	Hlangu Phala PS					
	Mabande CHS					
	Siyathokoza PS					
	Ezinkukhwini PFS					
	Ncedanani PFS					
	Thereso PFS					
	Dwaalfontein PS					
Wetting	Kelvin PFS				93.59	79.23
	New Largo PS					
	Hlangu Phala PS					
	Mabande CHS					
	Siyathokoza PS					
	Ezinkukhwini PFS					
	Ncedanani PFS					
	Thereso PFS					
	Dwaalfontein PS				92.34	80.75
Both (re-vegetation & wetting)	Kelvin PFS					
	New Largo PS					
	Hlangu Phala PS					
	Mabande CHS					
	Siyathokoza PS					
	Ezinkukhwini PFS					
	Ncedanani PFS					
	Thereso PFS					
	Dwaalfontein PS					

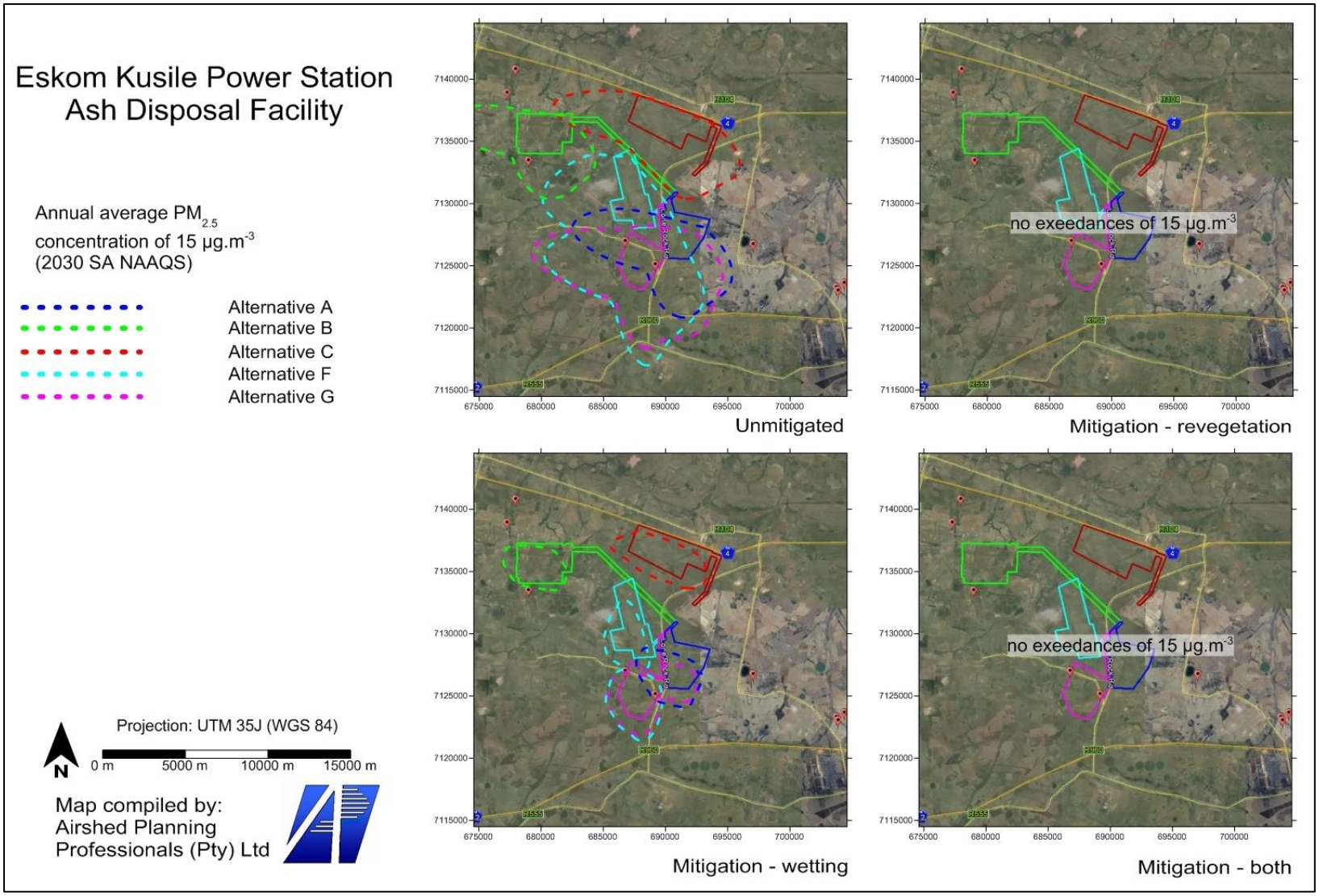

Figure 11: Predicted annual average $PM_{2.5}$ concentration as a result of the six alternative ash disposal facilities at Kusile Power Station

Table 15: Annual average $PM_{2.5}$ ground-level concentration at sensitive receptors where exceedances are predicted (NAAQS limit value: 15 µg.m^{-3}) as a result of wind-blown emissions from the alternative ash disposal facilities

Scenario	Receptor name	Annual average (µg.m^{-3})				
		Alt A	Alt B	Alt C	Alt F	Alt G
Unmitigated	Kelvin PFS	31.68			89.52	76.89
	New Largo PS					
	Hlangu Phala PS					
	Mabande CHS					
	Siyathokoza PS					
	Ezinkukhwini PFS					
	Ncedanani PFS					
	Thereso PFS					
	Dwaalfontein PS	30.84			93.64	84.01
Re-vegetation	Kelvin PFS					
	New Largo PS					
	Hlangu Phala PS					
	Mabande CHS					
	Siyathokoza PS					
	Ezinkukhwini PFS					
	Ncedanani PFS					
	Thereso PFS					
	Dwaalfontein PS					
Wetting	Kelvin PFS				26.97	22.83
	New Largo PS					
	Hlangu Phala PS					
	Mabande CHS					
	Siyathokoza PS					
	Ezinkukhwini PFS					
	Ncedanani PFS					
	Thereso PFS					
	Dwaalfontein PS				26.61	23.27
Both (re-vegetation & wetting)	Kelvin PFS					
	New Largo PS					
	Hlangu Phala PS					
	Mabande CHS					
	Siyathokoza PS					
	Ezinkukhwini PFS					
	Ncedanani PFS					
	Thereso PFS					
	Dwaalfontein PS					

5.4 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 16). These estimates are based on the annual PM_{10} concentrations for the *unmitigated* scenario (Table 14). Cancer risk as a result of exposure to nickel in the PM_{10} fraction of the ash shows the most variability and the highest number of 'low' cancer risk. The uncertainty with respect to the nickel compounds, and their proportion of total nickel in the ash, results in a more conservative cancer risk calculation. This conservative estimation of cancer risk adds support to the need for effective dust emission control through mitigation strategies, which will reduce the cancer risk further.

Table 16: 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 ash disposal facility

<table>
<tr><th rowspan="2">Sensitive receptor</th><th colspan="5">Ash disposal facility alternative</th></tr>
<tr><th>A</th><th>B</th><th>C</th><th>G</th><th>F</th></tr>
<tr><td colspan="6">Arsenic</td></tr>
<tr><td>Kelvin PFS</td><td colspan="5" rowspan="9">Very low</td></tr>
<tr><td>New Largo PS</td></tr>
<tr><td>Hlangu Phala PS</td></tr>
<tr><td>Mabande CHS</td></tr>
<tr><td>Siyathokoza PS</td></tr>
<tr><td>Ezinkukhwini PFS</td></tr>
<tr><td>Ncedanani PFS</td></tr>
<tr><td>Thereso PFS</td></tr>
<tr><td>Dwaalfontein PS</td></tr>
<tr><td colspan="6">Nickel</td></tr>
<tr><td>Kelvin PFS</td><td rowspan="4">Low</td><td>Low</td><td>Very low</td><td rowspan="2">Low</td><td rowspan="3">Low</td></tr>
<tr><td>New Largo PS</td><td rowspan="3">Very low</td><td rowspan="4">Low</td></tr>
<tr><td>Hlangu Phala PS</td></tr>
<tr><td>Mabande CHS</td><td rowspan="4">Very low</td></tr>
<tr><td>Siyathokoza PS</td><td rowspan="4">Very low</td><td>Low</td><td rowspan="3">Very low</td></tr>
<tr><td>Ezinkukhwini PFS</td><td>Low</td></tr>
<tr><td>Ncedanani PFS</td><td>Very low</td><td rowspan="2">Very low</td></tr>
<tr><td>Thereso PFS</td><td rowspan="2">Low</td><td>Very low</td><td rowspan="2">Low</td></tr>
<tr><td>Dwaalfontein PS</td><td>Low</td><td>Low</td><td>Low</td></tr>
<tr><td colspan="6">Chromium</td></tr>
<tr><td>Kelvin PFS</td><td>Low</td><td rowspan="8">Very low</td><td rowspan="9">Very low</td><td>Low</td><td>Low</td></tr>
<tr><td>New Largo PS</td><td rowspan="8">Very low</td><td rowspan="8">Very low</td><td rowspan="8">Very low</td></tr>
<tr><td>Hlangu Phala PS</td></tr>
<tr><td>Mabande CHS</td></tr>
<tr><td>Siyathokoza PS</td></tr>
<tr><td>Ezinkukhwini PFS</td></tr>
<tr><td>Ncedanani PFS</td></tr>
<tr><td>Thereso PFS</td><td>Low</td></tr>
<tr><td>Dwaalfontein PS</td><td>Low</td><td>Very low</td><td>Low</td><td>Low</td></tr>
</table>

5.5 Expanded domain assessment for Alternative B

The selection of a modelling domain takes account of the expected impacts and it is possible that the impacts, when modelled, extend beyond the modelling domain. The modelling domain where impacts were expected was not large enough to include the full scale impact of site Alternative B. Although the impacts extend beyond the modelling domain, it was however expected that the extent of the impacts of site Alternatives B would be similar to that of Alternatives A and C.

To assess the full impact of Alternative B, the domain was later increased and the model re-run. The larger domain included Bronkhorstspruit as a sensitive receptor. The domain was extended to 35 km x 30 km to include at least two points indicating the boundary of Bronkhorstspruit. The dispersion model was re-run for annual PM_{10} and $PM_{2.5}$ for the unmitigated scenario as a worst case impact on air quality within the expanded domain. Only site Alternative B was considered in the re-modelling exercise.

The re-modelling exercise showed that although impacts are likely to extend into the extended domain (Figure 12), towards the Bronkhorstspruit Dam, the impacts are unlikely to affect the town directly (Table 17 and Table 18).

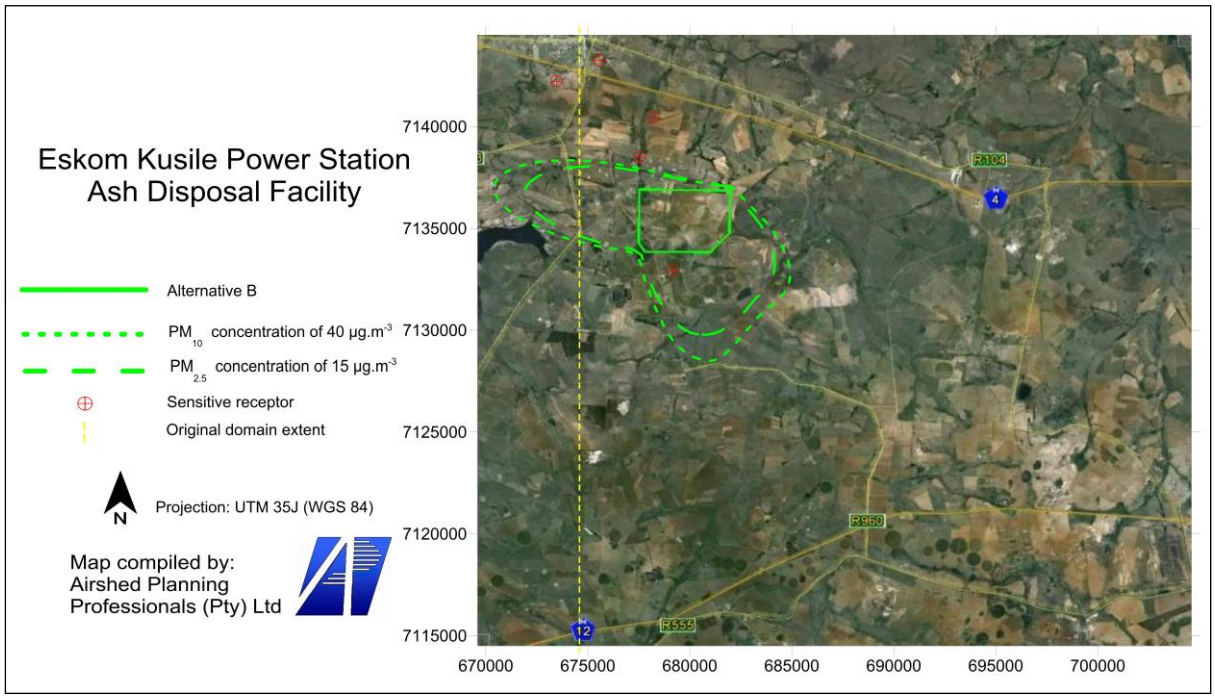

Figure 12: Annual average PM_{10} and $PM_{2.5}$ for Alternative B in an extended modelling domain

Table 17: Area of impact (ha) for annual PM_{10} and $PM_{2.5}$ for Alternative B in the extended domain.

Scenario	Receptor name	Area of impact (ha)*	
		Annual PM_{10}	Annual $PM_{2.5}$
Unmitigated	Alternative B	6 002	4 319

* excluding ash disposal facility foot-print

Table 18: Non-compliance with annual standards and exceedance of daily PM_{10} and $PM_{2.5}$ limit concentrations at sensitive receptors in the vinicity of Alternative B

Scenario	Receptor name	Annual average ($\mu g.m^{-3}$)		Number of daily exceedances (days)	
		Annual PM_{10} (standard 40 $\mu g.m^{-3}$)	Annual $PM_{2.5}$ (standard 15 $\mu g.m^{-3}$)	PM_{10} (limit: 75 $\mu g.m^{-3}$)	$PM_{2.5}$ (limit: 25 $\mu g.m^{-3}$)
Unmitigated	Ezinkukhwini PFS			14	12
	Ncedanani PFS				
	Thereso PFS	127.84	36.84	62	60
	Bronkhorstspruit 1				
	Bronkhorstspruit 2				

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. Because longer-term (annual) modelled estimates are more confidently projected, the comparison focussed on these findings, especially at the identified sensitive receptors. Because national standards are defined for PM_{10} and $PM_{2.5}$, due to potential human health impacts, these criteria were assigned more weight in the overall comparison. The impact of dust fall-out on agriculture, where dust fall-out rates exceed >400 $mg.m^{-2}.day^{-1}$, was also included as an assessment criteria.

The air quality impact assessment suggests Alternatives A, B or C, based on area impacted and the number of sensitive receptors impacted during the operational phase, are equally suitable as the preferred site. The significance rating of all of the alternatives is presented in Table 19. All sites are equally rated during the Construction, Closure and Post-closure phases.

During the Air Quality Impact Assessment for the Kusile 60-year ash disposal facility (ADF), sites A, B and C were considered equally suitable locations. After elimination of Site C (due to off-set mitigation restrictions), Site A had the lowest significance score for the operational phase. Site B had the next lowest significance score for the operational phase. There was no site preference identified for the construction, closure and post-closure phases.

The scale of impact on air quality was correlated with footprint size of the ADF alternative. In addition, the influence of effective mitigation on minimising impact was noticed between the four scenarios used during atmospheric dispersion modelling. The impacts as a result of the ADF are considered to be probable. The uncertainty is based on inherent assumptions within the atmospheric dispersion modelling process.

Table 19: Significance rating table for each alternative for each project phase

	Site Alternative				
	A	B	C	F	G
Construction phase					
Before mitigation*	1.9	1.9	1.9	1.9	1.9
After mitigation	2.4	2.4	2.4	2.4	2.4
Status quo	3.8	3.8	3.8	3.8	3.8
Cumulative impact	3.8	3.8	3.8	3.8	3.8
Residual impact	3.2	3.2	3.2	3.2	3.2
Operational phase					
Before mitigation*	4.4	4.6	4.1	4.7	4.7
After mitigation	2.1	2.1	2.1	2.1	2.1
Status quo	3.8	3.8	3.8	3.8	3.8
Cumulative impact	4.7	4.7	4.7	4.7	4.7
Residual impact	3.8	3.8	3.8	3.8	3.8
Closure phase					
Before mitigation*	1.8	1.8	1.8	1.8	1.8
After mitigation	1.8	1.8	1.8	1.8	1.8
Status quo	3.8	3.8	3.8	3.8	3.8
Cumulative impact	3.8	3.8	3.8	3.8	3.8
Residual impact	3.2	3.2	3.2	3.2	3.2
Post-closure phase					
Before mitigation*	1.1	1.1	1.1	1.1	1.1
After mitigation	1.5	1.5	1.5	1.5	1.5
Status quo	3.8	3.8	3.8	3.8	3.8
Cumulative impact	3.8	3.8	3.8	3.8	3.8
Residual impact	3.5	3.5	3.5	3.5	3.5

* combined weighted rating

The aspects **for** and *against* each of the remaining alternatives (Alternatives A, B, F and G) are re-iterated below.

- **For**:
  - **Alternative sites A, F and G** are closer to the power station terrace
    - The proximity to the power station terrace allows for easier access to the ADF for maintenance and mitigation, as well as reduced potential for emissions from the conveyor system and accumulated conveyor spills.

- **Alternative B** has fewer sensitive receptors affected by operations at the ADF.

- *Against*:
  - *Alternatives F, G and B* have larger foot-print areas
    - Larger foot-print areas are likely to result in more emissions, if mitigation measures are not effectively applied, and hence resulting in larger areas affected by operational activities.
  - *Alternatives A, F and G* would result in more sensitive receptors affected by operations at the ADF.

Alternative A is the preferred site for the Kusile 60-year ADF on the basis of air quality. Alternative B would be acceptable, but is not preferred due to the foot-print and the distance from the power station terrace.

Irrespective of the location of the ash disposal facility the model simulations show that mitigation of dust emissions will be critical to maintain PM_{10} concentrations with the South African NAAQS. In order to ensure that mitigation is effective it is recommended that dust fall monitoring is implemented around the perimeter of the ash disposal facility, especially in the direction of the prevailing winds and near any sensitive receptors. It is also recommended that PM_{10} be monitored near the ash disposal facility, especially if this is away from any monitoring undertaken by the power station. The PM_{10} filters and dust fall-out can further be analysed for heavy metals. Details of ambient monitoring options are detailed in Appendix B.

7 ENVIRONMENTAL IMPACT STATEMENT

The environmental impact statement that follows applies to the operational phase of the Ash Disposal Facility located at the preferred alternative site A. 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**. The assessment methodology is included in Appendix C.

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 Emalahleni Hot Spot. The Emalahleni 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 *district* scale. The impacts of the status quo are *very-likely* in the long-term and result in a **MODERATE-HIGH** impact risk.

7.2 Project Impact – Unmitigated

Impacts from the operational ash disposal facility will probably result in elevated annual average ground-level PM_{10} concentrations, exceeding the annual NAAQS, across an area of approximately 6 647 ha, affecting two of the identified sensitive receptors, Kelvin Primary Farm School and Dwaalfontein Primary School. This area is projected for the maximum ash disposal facility foot-print (1 627 ha) 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 ash facility, under unmitigated operation, are *very-likely* to result in impacts of VERY HIGH significance at *district* scale over the long-term, resulting in **HIGH** impact risk.

7.3 Cumulative Impact

The cumulative impact of proposed ash 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 permanent impacts will be of HIGH significance at a *provincial* scale. The *very-likely* 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 (after mitigation)

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

7.6 Impact Matrix

The impacts identified and discussed above have been rated (Table 20) according to the impact assessment methodology described in Appendix C.

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 21).

Table 20: Impact matrix for the operational phase of ash disposal facility at the preferred Alternative A

IMPACT DESCRIPTION		Direction of Impact	**Degree of Certainty**	Magnitude	Spatial	Temporal	Probability	**Impact Risk**
OPERATIONAL PHASE								
STATUS QUO	INITIAL BASELINE IMPACTS TO ENVIRONMENT	Negative	**Definite**	4	5	4	4	**-3.8**
				MODH	DIS	LONG	VLIKE	**MODH**
Project Impact 1	Non-compliance with annual PM_{10} standards at sensitive receptors	Negative	**Probable**	6	5	4	4	**-4.4**
				VHIGH	DIS	LONG	VLIKE	**HIGH**
Project Impact 2	Impacted area where non-compliance with PM_{10} standards are expected	Negative	**Probable**	6	5	4	4	**-4.4**
				VHIGH	DIS	LONG	VLIKE	**HIGH**
Project Impact 3	Non-compliance with annual $PM_{2.5}$ standards and sensitive receptors	Negative	**Probable**	6	5	4	4	**-4.4**
				VHIGH	DIS	LONG	VLIKE	**HIGH**
Project Impact 4	Impacted area where dust-fall >400 $mg.m^{-2}.day^{-1}$	Negative	**Probable**	6	5	4	4	**-4.4**
				VHIGH	DIS	LONG	VLIKE	**HIGH**
CUMULATIVE IMPACT	INITIAL IMPACTS TO ENVIRONMENT + ADDITIONAL IMPACTS FROM PROJECT, **BEFORE MITIGATION**	Negative	**Probable**	5	6	5	4	**-4.7**
				HIGH	PRO	PERM	VLIKE	**HIGH**
RESIDUAL IMPACT	INITIAL IMPACTS TO ENVIRONMENT + ADDITIONAL IMPACTS FROM PROJECT, **AFTER MITIGATION**	Negative	**Probable**	4	5	4	4	**-3.8**
				MODH	DIS	LONG	VLIKE	**MODH**

Table 21: 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) 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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9 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 $m.s^{-1}$ (US-EPA, 1995b).

An hourly emissions file was created for each of these source groups. The calculation of an emission rate for every hour of the simulation period was carried out using the ADDAS model. This software is based on the dust emission models proposed by Marticorena and Bergametti (1995) and Shao (2008). The models attempt to account for the variability in source erodibility through the

parameterisation of the erosion threshold (based on the particle size distribution of the source) and the roughness length of the surface.

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

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

for

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

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

where,

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

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

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

for

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

where,

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

Dust mobilisation occurs only for wind velocities higher than a threshold value, and is not linearly dependent on the wind friction and velocity. The threshold friction velocity, defined as the minimum friction velocity required to initiate particle motion, is dependent on the size of the erodible particles and the effect of the wind shear stress on the surface. The threshold friction velocity decreases with a decrease in the particle diameter, for particles with diameters >60 µm. Particles with a diameter <60 µm result in increasingly high threshold friction velocities, due to the increasingly strong cohesion forces linking such particles to each other (Marticorena and Bergametti, 1995). The relationship between particle sizes ranging between 1 µm and 500 µm and threshold friction velocities (0.24 to 3.5 m.s^{-1}), estimated based on the equations proposed by Marticorena and Bergametti (1995), is illustrated in **Error! Reference source not found.** A13.

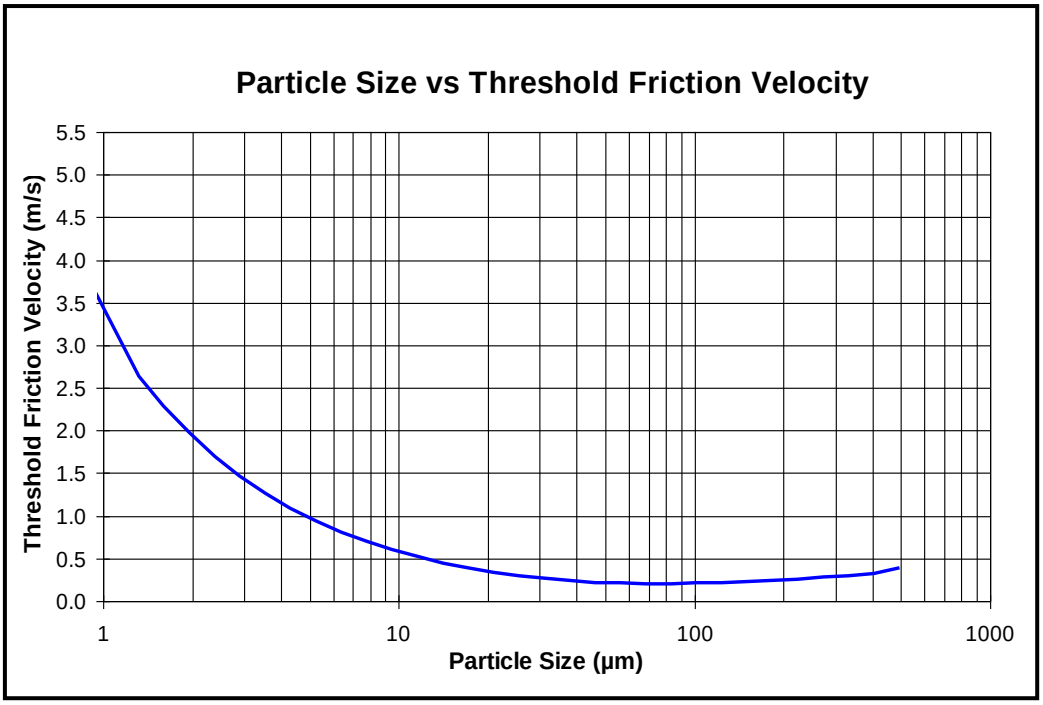

Figure A13: Relationship between particle sizes and threshold friction velocities using the calculation method proposed by Marticorena and Bergametti (1995)

10 APPENDIX B: EVALUATION OF SUSPENDED PARTICULATE SAMPLERS

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

B1: Filter-based Monitors

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

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

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

Sequential air samplers with sequential dichotomous configurations splits the PM_{10} sample stream into its fine ($PM_{2.5}$) and coarse (particles between 2.5 and 10 µm in size) fractions - collecting the fine and coarse mode particulates simultaneously on two different filters. Certain of these systems (e.g. Partisol-Plus Air Samplers, Figure B14, have capacities of up to 16 filter cassettes with an automatic filter exchange mechanism. (Filter changes can be triggered on a temporal basis or based on wind direction.) Once the 16 filters have been exposed, the filters would require collection and replacement.

Figure B14: Partisol-Plus Sequential Air Sampler

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

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

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

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

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

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

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

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

The performance of the TEOM and BAM monitors are compared in Table B22. The TEOM tends to perform better than BAMs in many respects, particularly with regard to the precision of measurements made. An additional advantage of the TEOM (14000 series) is the optional inclusion of the ACCU system. This system allows for conditional sampling by time/date, particulate concentration and/or wind speed and direction. The application of the TEOM in combination with the ACCU system could therefore allow for the assessment of an operation's contribution to particulate concentrations occurring at a site on an on-line real-time basis.

Table B22: Comparison of TEOM and BAM performance

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

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

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

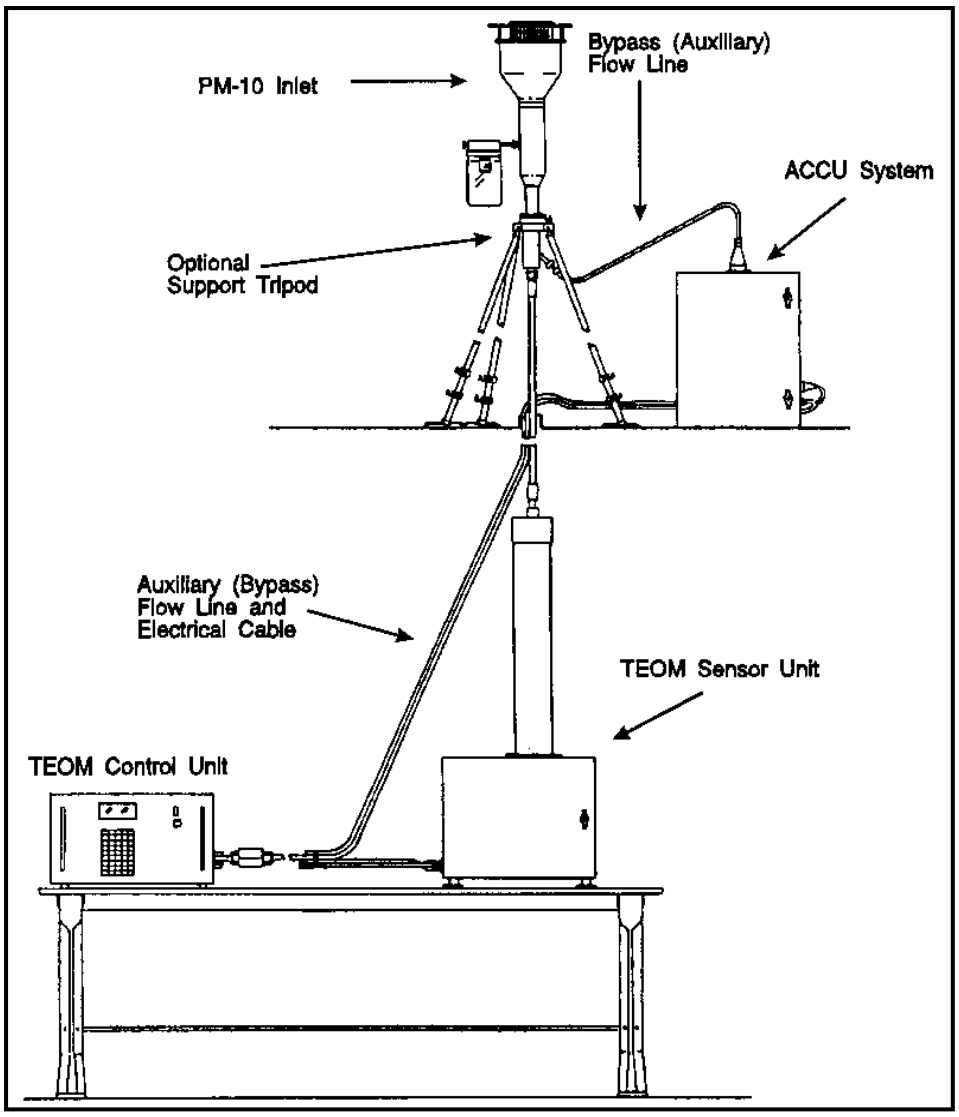

Figure B15: TEOM sampler linked to the ACCU^{TM} conditional sampling system

B2: Non-filter-based Monitors

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

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

B3: Data Transfer Options

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

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

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

B4: Sampler and Data Transfer Recommendations

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

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

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

11 APPENDIX C: IMPACT ASSESSMENT METHODOLOGY

11.1 Approach to Assessing Impacts:

- Impacts were assessed separately for the **construction**, **operational**, **closure**, and post-closure phases of the project;
- Impacts are described according to the ***Status Quo***, ***Project Impact***, ***Cumulative Impact***, ***Mitigation Measures*** and ***Residual Impact*** as follows:
  - The Status Quo assesses the existing impact on the receiving environment. The existing impact may be from a similar activity, e.g. an existing ash dump, or other activities e.g. mining or agriculture.
  - The project impact assesses the potential impact of the proposed development on an environmental element;
  - The cumulative impact on an environmental element is the description of the project impact combined with the initial status quo impacts that occur;
  - Mitigation measures that could reduce the impact risk are then prescribed; and
  - The residual impact describes the cumulative impact after the implementation of mitigation measures.
- Impacts are rated against a predetermined set of criteria including (magnitude, duration, spatial scale, probability, and direction of impact);
- A rating matrix is provided for each environmental element per project phase summarising all the aforementioned in a single table.

More detailed description of each of the assessment criteria and any abbreviations used in the rating matrix is given in the following sections.

11.1.1 Magnitude / Significance Assessment

Significance rating (importance) of the associated impacts embraces the notion of extent and magnitude, but does not always clearly define these since their importance in the rating scale is very relative. For example, the magnitude (i.e. the size) of area affected by atmospheric pollution may be extremely large (1000 km^2) but the significance of this effect is dependent on the concentration or level of pollution. If the concentration is great, the significance of the impact would be HIGH or VERY HIGH, but if it is diluted it would be VERY LOW or LOW. Similarly, if 60 ha of a grassland type are destroyed the impact would be VERY HIGH if only 100 ha of that grassland type were known. The impact would be VERY LOW if the grassland type was common. A more detailed description of the impact significance rating scale is given in Table C23.

Table C23: Description of the significance rating scale

Rating			Description
Score	**Code**	**Category**	
7	SEV	SEVERE	Impact most substantive, no mitigation possible
6	VHIGH	VERY HIGH	Impact substantive, mitigation difficult/expensive
5	HIGH	HIGH	Impact substantive, mitigation possible and easier to implement
4	MODH	MODERATE-HIGH	Impact real, mitigation difficult/expensive
3	MODL	MODERATE-LOW	Impact real, mitigation easy, cost-effective and/or quick to implement
2	LOW	LOW	Impact negligible, with mitigation
1	VLOW	VERY LOW	Impact negligible, no mitigation required
0	NO	NO IMPACT	There is no impact at all - not even a very low impact on a party or system.

11.1.2 Spatial Scale

The spatial scale refers to the extent of the impact i.e. will the impact be felt at the local, regional, or global scale. The spatial assessment scale is described in more detail in Table C24.

Table C24: Description of the spatial rating scale.

Rating			Description
Score	**Code**	**Category**	
7	NAT	*National*	The maximum extent of any impact.
6	PRO	*Provincial*	The spatial scale is moderate within the bounds of impacts possible, and will be felt at a provincial scale
5	DIS	*District*	The spatial scale is moderate within the bounds of impacts possible, and will be felt at a district scale
4	LOC	*Local*	The impact will affect an area up to 5 km from the proposed route corridor.
3	ADJ	*Adjacent*	The impact will affect the development footprint and 500 m buffer around development footprint
2	DEV	*Development footprint*	Impact occurring within the development footprint
1	ISO	*Isolated Sites*	The impact will affect an area no bigger than the servitude.

11.1.3 Duration / Temporal Scale

In order to accurately describe the impact it is necessary to understand the duration and persistence of an impact in the environment. The temporal scale is rated according to criteria set out in Table C25.

Table C25: Description of the temporal rating scale.

Rating			Description
Score	**Code**	**Category**	
5	PERM	Permanent	The environmental impact will be permanent.
4	LONG	Long term	The environmental impact identified will operate beyond the life of operation.
3	MED	Medium term	The environmental impact identified will operate for the duration of life of the line.
2	SHORT	Short-term	The environmental impact identified will operate for the duration of the construction phase or a period of less than 5 years, whichever is the greater.
1	INCID	Incidental	The impact will be limited to isolated incidences that are expected to occur very sporadically.

11.1.4 Degree of Probability

The probability or likelihood of an impact occurring will be described as shown in Table C25.

Table C26: Description of the degree of probability of an impact accruing

Score	Code	Category
5	OCCUR	*It's going to happen / has occurred*
4	VLIKE	*Very Likely*
3	LIKE	*Could happen*
2	UNLIKE	*Unlikely*
1	IMPOS	*Practically impossible*

11.1.5 Degree of Certainty

As with all studies it is not possible to be 100% certain of all facts, and for this reason a standard "degree of certainty" scale is used as discussed in Table C27. The level of detail for specialist studies is determined according to the degree of certainty required for decision-making. The impacts are discussed in terms of affected parties or environmental components.

Table C27: Description of the degree of certainty rating scale

Rating	Description
Definite	More than 90% sure of a particular fact.
Probable	Between 70 and 90% sure of a particular fact, or of the likelihood of that impact occurring.
Possible	Between 40 and 70% sure of a particular fact or of the likelihood of an impact occurring.
Unsure	Less than 40% sure of a particular fact or the likelihood of an impact occurring.
Can't know	The consultant believes an assessment is not possible even with additional research.

11.1.6 Impact Risk Calculation

To allow for impacts to be described in a quantitative manner in addition to the qualitative description, a rating scale of between 1 and 5 was used for each of the assessment criteria. Thus the total value of the impact is described as the function of significance, spatial and temporal scale as described below:

$$Impact\ Risk = \frac{\text{Significance} + \text{Spatial} + \text{Temporal}}{2.714} \times \frac{\text{Probability}}{5}$$

An example of how this rating scale is applied is shown below in Table C28:

Table C28: Example of rating scale

Impact	Magnitude	Spatial scale	Temporal scale	Probability	Rating
Greenhouse gas emissions	2	*3*	3	3	1.8
	LOW	*Local*	Medium Term	*Could Happen*	**LOW**

***Note**: The significance, spatial and temporal scales are added to give a total of 8, that is divided by 2.714 to give the criteria rating of 2.95. The probability (3) is divided by 5 to give a probability rating of 0.6. The criteria rating (2.95) is then multiplied by the probability rating (0.6) to give the final rating of 1.8; which is rounded to the first decimal.*

The impact risk is classified according to 5 classes as described in Table C29 below.

Table C29: Impact Risk Classes

Rating	Impact class	Description
6.1 - 7.0	**7**	**SEVERE**
5.1 - 6.0	**6**	**VERY HIGH**
4.1 - 5.0	**5**	**HIGH**
3.1 - 4.0	**4**	**MODERATE-HIGH**
2.1 - 3.0	**3**	**MODERATE-LOW**
1.1 - 2.0	**2**	**LOW**
0.1 - 1.0	**1**	**VERY LOW**

Therefore with reference to the example used for greenhouse gas emissions above, an impact rating of 1.8 will fall in the Impact Class 2, which will be considered to be a Low impact.

11.1.7 Notation of Impacts

In order to make the report easier to read the following notation format is used to highlight the various components of the assessment:

- Significance or magnitude- IN CAPITALS
- Spatial Scale – *in italics*
- Duration – <u>in underline</u>
- Probability – *<u>in italics and underlined.</u>*
- Degree of certainty - **in bold**