Air Quality Impact Assessment for the Proposed Spitzland Development near Roodepoort, Gauteng

Project done on behalf of **Environmental Impact Management Services (EIMS)**

Report Compiled by:
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Revision Record

Revision Number	Date	Reason for Revision
0	April 2018	Draft report for review
1	20 April 2018	Inclusion of comments
1.1	26 April 2018	Inclusion of additional comments
1.2	May 2018	Final report
1.3	31 May 2018	Final report with additional mitigated scenarios

Specialist Report Requirements (NEMA Regulation, 2017)

	A specialist report prepared in terms of the Environmental Impact Regulations of 2017 must contain:	Relevant section in report
a	details of- (i) the specialist who prepared the report; and (ii) the expertise of that specialist to compile a specialist report including a curriculum vitae;	Report details (page ii) Section 7.3 (Appendix C)
b	a declaration that the specialist is independent in a form as may be specified by the competent authority;	Report details (page ii)
c	an indication of the scope of, and the purpose for which, the report was prepared;	Section 1.1
cA	an indication of the quality and age of base data used for the specialist report;	Section 3
cB	a description of existing impacts on the site, cumulative impacts of the proposed development and levels of acceptable change;	Section 3
d	The duration, date and season of the site investigation and the relevance of the season to the outcome of the assessment;	Section 3.3
e	a description of the methodology adopted in preparing the report or carrying out the specialised process inclusive of equipment and modelling used;	Sections 1.4 and 4.1
f	details of an assessment of the specific identified sensitivity of the site related to the proposed activity or activities and its associated structures and infrastructure, inclusive of a site plan identifying site alternatives;	Section 3.1
g	an identification of any areas to be avoided, including buffers;	Section 3.1
h	a map superimposing the activity including the associated structures and infrastructure on the environmental sensitivities of the site including areas to be avoided, including buffers;	Section 1.1
i	a description of any assumptions made and any uncertainties or gaps in knowledge;	Sections 1.5, 1.6
j	a description of the findings and potential implications of such findings on the impact of the proposed activity, including identified alternatives on the environment or activities;	Sections 4.3, 5
k	any mitigation measures for inclusion in the EMPr;	Section 5
l	any conditions for inclusion in the environmental authorisation;	Section 5
m	any monitoring requirements for inclusion in the EMPr or environmental authorisation;	Section 5
n	a reasoned opinion- (i) as to whether the proposed activity, activities or portions thereof should be authorised; (iA) regarding the acceptability of the proposed activity or activities; and (ii) if the opinion is that the proposed activity, activities or portions thereof should be authorised, any avoidance, management and mitigation measures that should be included in the EMPr, and where applicable, the closure plan;	Section 5 Section 5 Sections 4.1 and 5
o	a description of any consultation process that was undertaken during the course of preparing the specialist report;	NA
p	a summary and copies of any comments received during any consultation process and where applicable all responses thereto; and	NA
q	any other information requested by the competent authority.	NA

Abbreviations

AERMIC	AMS/EPA Regulatory Model Improvement Committee
Airshed	Airshed Planning Professionals (Pty) Ltd
APPA	Air Pollution and Prevention Act
AQSR	Air Quality Sensitive Receptor
ASTM	American Society for Testing and Materials
CE	Control Efficiency
COJ	City of Johannesburg
DEA	Department of Environmental Affairs (South Africa)
GLC(s)	Ground level concentration(s)
VTAPA	Vaal Triangle Airshed Priority Area
IFC	International Finance Corporation
NAAQS	National Ambient Air Quality Standards (South Africa)
NDCR	National Dust Control Regulations
NEM:AQA	National Environmental Management Air Quality Act (South Africa)
NPI	National Pollutant Inventory (Australia)
SA	South Africa(n)
SABS	South African Bureau of Standards
TSF	Tailings Storage Facility
TSP	Total Suspended Particulates
US EPA	United States Environmental Protection Agency
WRF	The Weather Research and Forecasting Model

Glossary

Air pollution	This means any change in the composition of the air caused by smoke, soot, dust (including fly ash), cinders, solid particles of any kind, gases, fumes, aerosols and odorous substances
Ambient air	This is defined as any area not regulated by Occupational Health and Safety regulations
Atmospheric emission or emission	Any emission or entrainment process emanating from a point, non-point or mobile source that results in air pollution
Averaging period	This implies a period of time over which an average value is determined
Dispersion	The spreading of atmospheric constituents, such as air pollutants
Dust	Solid materials suspended in the atmosphere in the form of small irregular particles, many of which are microscopic in size
Frequency of Exceedance	A frequency (number/time) related to a limit value representing the tolerated exceedance of that limit value, i.e. if exceedances of limit value are within the tolerances, then there is still compliance with the standard
Mechanical mixing	Any mixing process that utilizes the kinetic energy of relative fluid motion
Oxides of nitrogen (NO_x)	The sum of nitrogen oxide (NO) and nitrogen dioxide (NO_2) expressed as nitrogen dioxide (NO_2)
Particulate Matter (PM)	These comprise 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 PM_{10} and $PM_{2.5}$ fall in the finer fraction.
PM_{10}	Particulate Matter with an aerodynamic diameter of less than 10 µm. it is also referred to as thoracic particulates and is associated with health impacts due to its tendency to be deposited in, and damaging to, the lower airways and gas-exchanging portions of the lung
$PM_{2.5}$	Particulate Matter with an aerodynamic diameter of less than 2.5 µm. it is also referred to as respirable particulates. It is associated with health impacts due to its high tendency to be deposited in, and damaging to, the lower airways and gas-exchanging portions of the lung
Vehicle Entrainment	This is the lifting and dropping of particles by the rolling wheels leaving the road surface exposed to strong air current in turbulent shear with the surface. The turbulent wake behind the vehicle continues to act on the road surface after the vehicle has passed

Symbols and Units

°C	Degrees Celsius
µg	Microgram(s)
µg/m³	Micrograms per cubic meter
km	Kilometers
m/s	Metres per second
m²	Metres squared
mg	Milligram(s)
mm	Millimeters
PM	Particulate Matter
PM_{10}	Thoracic particulate matter
$PM_{2.5}$	Respirable particulate matter
t/a	Tons per annum

Executive Summary

Introduction

Airshed Planning Professionals (Airshed) was appointed by Environmental Impact Management Services (EIMS) to update the 2013 and 2016 air quality impact assessment for the proposed Spitzland Development. Tailings storage facilities (TSFs) surrounding the proposed development could possibly impact on the proposed development.

Scope and Approach

The main purpose of this investigation was to quantify and assess the potential impact that the receiving environment may have on the proposed development area.

The air quality impact assessment included a study of the receiving environment and the quantification and assessment of the impact of the TSFs on human health and the environment. The receiving environment was described in terms of local atmospheric dispersion potential, the location of potential AQSRs in relation to proposed activities as well as existing ambient pollutant levels and dustfall rates.

An atmospheric emissions inventory was compiled for the TSFs. Pollutants quantified included particulate matter (TSP, PM_{10}, and $PM_{2.5}$). All PM emissions were quantified using the Airshed in-house model ADDAS.

Dispersion simulations to estimate ground level concentrations and dustfall rates were done using the AERMOD model.

Main Findings and Conclusions

The main findings of the assessment are summarised below:

- The receiving environment:
  - The proposed development area is dominated by winds from the northerly sector. An average wind speed of 4.1 m/s was extracted for the site from the WRF data set with wind speeds exceeding 6.7 m/s (the threshold wind speed likely to result in dust emissions from gold TSFs) 12.5% of the time.
  - Surrounding areas where ambient air quality data is available show PM_{10} concentrations exceeding the NAAQS. Simulated PM_{10} concentrations from the CoJ AQMP study also showed elevated levels for the region.
- A summary of compliance with the relevant legislation (due to the impact of the TSFs) can be seen in the table below:

Impact Description	Compliance at proposed Spitzland Development		
	Scenario 1	Scenario 2	Scenario 3
$PM_{2.5}$ daily	X	X	X
$PM_{2.5}$ annual	√	√	√
PM_{10} daily	X	X	X
PM_{10} annual	√	√	√
Nuisance effects due to dustfall deposition	X	X	X
	Active remining at TSF 1, 2 and 3 with no vegetation and no mitigation.	Post-remining at TSF 1, 2 and 3.	TSF 1, 2 and 3 remain dormant with existing vegetation cover.

Impact Description	Compliance at proposed Spitzland Development		
	Scenario 1	Scenario 2	Scenario 3
	Non-compliance area covers large portion of proposed development.	Non-compliance area covers only portion of proposed development – impacts due to TSF 4.	Non-compliance area covers small portion of proposed development – impacts mostly due to TSF 4.

In conclusion, active remining of TSF1, 2 and 3 are likely to result in the highest impacts from all three scenarios evaluated if no mitigation measures, such as water sprays, are applied. Similarly, post-remining and leaving the TSFs as is, could also have unacceptable impacts, although in smaller areas of the proposed development. Even with mitigation in place at TSF 1, 2 and 3 for any of the three scenarios, the impacts from TSF4 will still result in non-compliance at a small portion of the development. Thus, either rehabilitation of TSF4 or exclusion of the development area affected by TSF4, would be required to ensure compliance at the proposed development.

If it is assumed that the development area is decreased (due to the recommended exclusion) the summary would then be as shown below:

Impact Description	Compliance at proposed Spitzland Development		
	Scenario 1	Scenario 2	Scenario 3
$PM_{2.5}$ daily	X	√	X
$PM_{2.5}$ annual	√	√	√
PM_{10} daily	X	√	X
PM_{10} annual	√	√	√
Nuisance effects due to dustfall deposition	X	√	X
	Active remining at TSF 1, 2 and 3 with no vegetation and no mitigation. Non-compliance area covers large portion of proposed development.	Post-remining at TSF 1, 2 and 3.	TSF 1, 2 and 3 remain dormant with existing vegetation cover. Non-compliance area covers very small portion of proposed development – impacts due to TSF 1, 2 and 3.

If it is assumed that TSF 3 and 4 would be mitigated (by increasing the vegetation to 75%) the compliance at the proposed development would then be as shown below:

Impact Description	Compliance at proposed Spitzland Development (mitigated)		
	Scenario M1	Scenario M2	Scenario M3
$PM_{2.5}$ daily	X	X	√
$PM_{2.5}$ annual	√	√	√
PM_{10} daily	X	X	√
PM_{10} annual	√	√	√
Nuisance effects due to dustfall deposition	X	X	√
	Active remining at TSF 1 and 2 with no vegetation and no mitigation. Additional mitigation on TSF 3 and 4 (75%).	Post-remining at TSF 1. Active remining at TSF 2 with no vegetation and no mitigation. Additional mitigation on TSF 3 and 4 (75%).	Post-remining at TSF 1 and 2. Additional mitigation on TSF 3 and 4 (75%). TSF 5 and 6 remain dormant with existing vegetation cover.

Impact Description	Compliance at proposed Spitzland Development (mitigated)		
	Scenario M1	Scenario M2	Scenario M3
	Non-compliance area covers small portion of proposed development – impacts due to TSF 1 and 2.	Non-compliance area covers small portion of proposed development – impacts due to TSF 2.	

For the mitigated scenarios, the impact at the proposed development is significantly reduced due to proposed mitigation on TSF 3 and 4. Scenario 3 results in compliance at the proposed residential development.

Main Recommendations

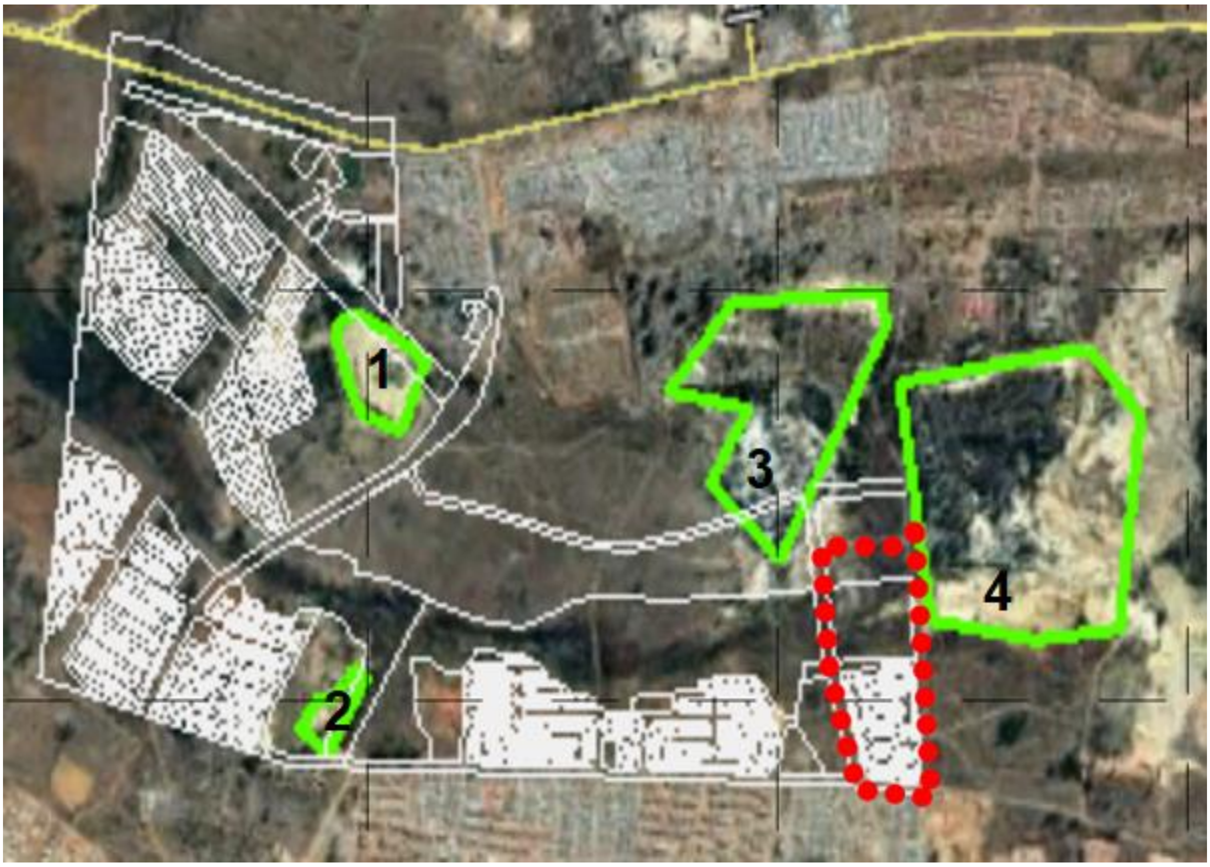
Based on the dispersion modelling results, the following phasing methodology is recommended to ensure compliance with NAAQS and NDCR within the residential development.

- Development 1: Exclude areas that fall within the restriction zones applicable to the remining of TSF 1 and 2 individually (because they will not be mined concurrently). Exclude areas that fall within the restriction zones applicable to TSF 3-6 remaining as they are.
- Development 1a: Same as phase 1 except with the restriction zones for the remining of TSF 1 and 2 adjusted to compensation for mitigation measures. The dispersion modelling conservatively assumed that during remining of the TSF, the entire area would be exposed and susceptible to wind erosion. If it is remined from one end to another the area of disturbance will be smaller and therefore the area of non-compliance will also be reduced. If additional mitigation measures are implemented, such as water suppression and nets for shielding dust, the impacted area can also be reduced.
- Development 2: expand the development 1 area into the restriction zones applicable to TSF1- assume that this TSF has been mined.
- Development 3: expand development 1 into restriction zones applicable to TSF 2- assume that this TSF has been re-mined.

If in future the remining of TSF 3 to 6 is proposed, it is recommended that the respective mining company would need to apply mitigation measures to the remining of these dumps to ensure acceptable exposure to the proposed development community.

It is the specialist opinion that the proposed development may be authorised, however it is recommended that the development area is adjusted to exclude the most eastern section directly adjacent to TSF number 4 unless TSF number 4 can be mitigated (vegetation would significantly reduce the impacts) and the development occurs in phases as discussed. See the recommended exclusion zone below (red dotted line for area of daily PM_{10} non-compliance simulated to be exceeded). This would not be necessary if additional and sufficient vegetation is included at TSF 3 and TSF 4.

It is recommended that a short term ambient monitoring campaign be carried out to verify the ambient levels at the site and also to determine if additional vegetation is sufficient to meet ambient NAAQS and NDCR at the proposed development.



Proposed exclusion zone

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Air Quality Impact Assessment for the Proposed Spitzland Development near Roodepoort, Gauteng

1 INTRODUCTION

Airshed Planning Professionals (Airshed) was appointed by Environmental Impact Management Services (EIMS) to update the 2013 and 2016 air quality impact assessment. The proposed development can be seen in Figure 1. Tailings storage facilities (TSFs) surrounding the proposed development could possibly impact on the proposed development. Since it is assumed that naturally occurring radionuclides are associated with these TSFs, one of the parameters considered as part of the air quality study was the exhalation of radon gas.

1.1 Scope of Work

The purpose of this investigation is to determine baseline air quality conditions, identify sensitive receptors and quantify and assess the potential impact that the receiving environment may have on the proposed development area.

The following tasks, typical of an air quality impact assessment, are included in the scope of work:

- A review of surrounding activities in order to identify sources of emission and associated pollutants;
- A study of regulatory requirements and inhalation thresholds for identified key pollutants against which compliance need to be assessed and health risks screened;
- A study of the environment in the vicinity of the proposed development; including:
    - The identification of potential air quality sensitive receptors (AQSRs);
    - A study of the atmospheric dispersion potential of the area taking into consideration local meteorology, land-use and topography; and
    - The analysis of all available ambient air quality information/data to determine pre-development ambient pollutant levels and dustfall rates.
- The compilation of a comprehensive emissions inventory:
    - Pollutants quantified will include particulate matter (TSP, PM_{10} and $PM_{2.5}$).
- Atmospheric dispersion modelling to simulate ambient air pollutant concentrations and dustfall rates as a result of the TSFs.
- A screening assessment to determine:
    - Compliance of simulated criteria pollutant concentrations with ambient air quality standards; and
    - Nuisance dustfall.
- The compilation of a comprehensive air quality specialist report detailing the study approach, limitations, assumption, results and recommendations.

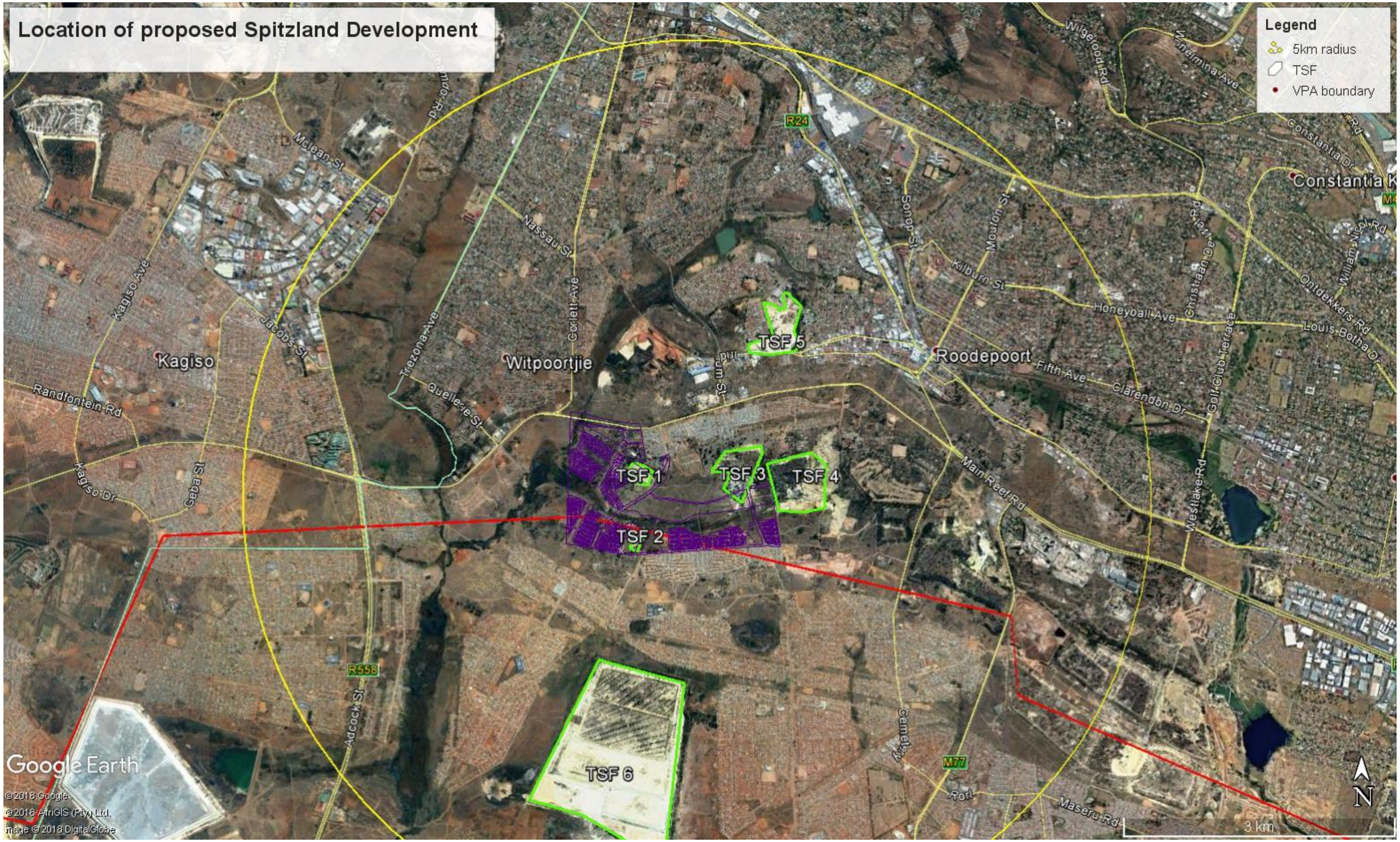

Figure 1: Locality map showing the proposed development in relation to the surrounding TSFs

1.2 Description of Project Activities from an Air Quality Perspective

The main focus of the air quality impact assessment is the impact of the TSFs on the proposed development.

Air quality impacts will be associated with the construction phase of the proposed development; however, this will be of a short duration and will not have an impact itself on the proposed development. A description of the construction phase, from an air quality impact perspective, is summarised below.

Construction will typically include land clearing of the construction footprint, general construction activities (i.e. bulk earthworks and infrastructure development for buildings and on-site roads etc.), bulldozing, loading and grading activities. These operations will likely result in fugitive[1] particulate matter (PM) emissions.

Particulate emissions often vary substantially from day to day, depending on the level of activity, the specific operations, and the prevailing meteorological conditions. A large portion of the emissions results from equipment traffic over temporary roads at the construction site (US EPA, 1995).

This report therefore only focusses on the air quality impact from the TSFs on the proposed development.

It is important to note that, in the discussion, regulation and estimation of PM emissions and impacts, a distinction is made between different particle size fractions, *viz*. TSP, PM_{10} and $PM_{2.5}$. PM_{10} is defined as particulate matter with an aerodynamic diameter of less than 10 µm and is also referred to as thoracic particulates. Respirable particulate matter, $PM_{2.5}$, is defined as particulate matter with an aerodynamic diameter of less than 2.5 µm. Whereas PM_{10} and $PM_{2.5}$ fractions are taken into account to determine the potential for human health risks, total suspended particulate matter (TSP) is included to assess nuisance effects.

1.3 Windblown Dust Sources in the Region

Active, dormant and reclaimed tailings storage facilities (TSFs) within Gauteng have been identified as potential significant sources of windblown dust, impacting on human health and the environment – CoJ AQMP of 2013 (CoJ, 2003); Gauteng province AQMP of 2009 (GDACE, 2009) and the Vaal Triangle Priority Area AQMP of 2009 (DEA, 2009). As a management measure, the Gauteng Department of Agriculture, Conservation and the Environment (GDACE) developed generic buffer zones around tailings dams. Two generic buffer zone distances were specified – best case and worst case. A worst-case buffer zone distance of 1 000 m was specified for slimes dams and ash dumps, with a best-case buffer zone of 500 m. The reasoning behind the best-case buffer zone is that at 500 m the dust can no longer be distinguished from ambient dust pollution (GDACE, 2002). **These buffer zones are merely guidelines and hence not legally enforceable**. These generic buffer zones are used by Metropolitan Municipalities within Gauteng **as guidelines specifically in the approval of new residential areas in close proximity to existing TSFs.**

A total of 380 Mine Residue Areas (MRAs) are present within the Gauteng Province, ranging from gold TSFs, waste rock dumps, coal dumps, and quarries (GDARD, 2009). These facilities are also in various operational and rehabilitation stages, with some still operational, a number of these facilities being dormant, and a few in the process of being reclaimed. There are a number of abandoned gold tailings dumps in Gauteng and specifically in the CoJ, with typically poor vegetation cover and

[1] Fugitive emissions refer to emissions that are spatially distributed over a wide area and not confined to a specific discharge point as would be the case for process related emissions (IFC, 2007).

large open areas prone to wind erosion. The active dumps have the same problems, but the surface areas are usually wet thereby reducing the potential for windblown dust.

Windblown dust from mine waste facilities can be significant sources of dust emissions with high dust concentrations reported near mining sites, affecting both the environment and human health. A number of studies have been conducted on the impact from mine tailings – specifically gold mine tailings – on residential areas around and close to the base of these tailings facilities (Ojelede *et al*., 2012; Phakedi, 2011; Annegarn, 2006; Annegarn *et al*., 2000; 2010). These studies indicated that slimes dams in close proximity to human settlements pose a health risk, with measured PM_{10} concentrations during storm events reported to be between 171 µg/m³ and 462 µg/m³ (Ojelede *et al*., 2012).

1.4 Approach and Methodology

The approach and methodology followed in the completion of tasks included in the scope of work are discussed below:

1.4.1 Project Information and Activity Review

All project related information referred to in this study was provided by EIMS.

1.4.2 The Identification of Regulatory Requirements and Screening Criteria

In the evaluation of ambient air quality impacts and dustfall rates reference was made to:

- South African National Ambient Air Quality Standards (NAAQS); and
- National Dust Control Regulations (NDCR) as set out in the National Environmental Management Air Quality Act (Act No. 39 of 2004) (NEM:AQA).

1.4.3 Study of the Receiving Environment

An understanding of the atmospheric dispersion potential of the area is essential to an air quality impact assessment. Meteorological data from the Weather Research and Forecasting model (WRF) data set used for the City of Johannesburg (CoJ) air quality management plan (AQMP) was extracted for the project site for 2014. Validation statistics for this data can be seen in the CoJ AQMP Status Quo report (CSIR Climate Studies, 2016). According to the dispersion modelling guidelines (Government Gazette, 2014) mesoscale models offer an alternative to meteorological measurements as input for Gaussian-plume models and advanced dispersion models. Mesoscale models use gridded meteorological data and sophisticated physics algorithms to produce meteorological fields at defined horizontal grid resolutions and in multiple vertical levels over a large domain. A number of meteorological model datasets covering South Africa are available from a number of vendors. The Code of Practice refrains from recommending specific datasets but encourages modellers to use data from the United Kingdom Meteorological Office Unified Model (MetUM), Weather Research and Forecasting (WRF), The Air Pollution Model (TAPM) and the 5th-generation Mesoscale Model (MM5).

1.4.4 Determining the Impact of the Project on the Receiving Environment

The establishment of a comprehensive emission inventory formed the basis for the assessment of the air quality impacts from the TSFs on the receiving environment. Emission quantification was done using the in-house model ADDAS (Burger *et al*., 1997; Burger, 2010). This model is based on the dust emission scheme of Marticorena and Bergametti (1995) referred to as MB95 (from this point forward) and Shao *et al*. (2011) (referred to as SH11).

1.4.5 Compliance Assessment

Compliance was assessed by comparing simulated ambient criteria pollutant concentrations ($PM_{2.5}$ and PM_{10}) and dustfall rates to selected ambient air quality and dustfall criteria.

1.4.6 Impact Significance

The significance of impacts was determined in line with the requirements for impact assessment as outlined in the NEMA.

1.4.7 The Development of an Air Quality Management Plan

The findings of the above components informed recommendations of air quality management measures, including mitigation and reporting.

1.5 Assumptions, Exclusions and Uncertainties

The following important assumptions, exclusions and uncertainties to the specialist study should be noted:

- Meteorological data from a data point for the project site for the period 2014 was extracted from the WRF data set used for the CoJ AQMP study.
- The impact assessment was limited to criteria particulates (including TSP, PM_{10} and $PM_{2.5}$).
- Constructional phase impacts of the proposed development were not quantified. These impacts are expected to be of short duration.
- There will always be some degree of uncertainty in any geophysical model, but it is desirable to structure the model in such a way to minimize 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. Nevertheless, dispersion modelling is generally accepted as a scientific and valuable tool in air quality management.

1.6 Gaps in Knowledge

The following was identified as gaps in knowledge during the specialist study and should be noted:

- The quantification of sources of emission was restricted to the TSFs identified in the study scope. Hence, only incremental impacts due to PM_{10} and $PM_{2.5}$, as well as incremental dustfall effects were simulated from the TSFs. Other sources in the area (e.g. domestic fuel combustion), could also be contributing to the ambient air.

2 Regulatory Requirements and Impact Assessment Criteria

Prior to assessing the impact of the TSFs on human health and the environment, reference needs to be made to the environmental regulations governing the impact of such operations i.e. emission standards, ambient air quality standards and dust control regulations.

Emission standards are generally set for point sources and specify the amount of the pollutant acceptable in an emission stream and are often based on proven efficiencies of air pollution control equipment.

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 standards and guideline values indicate safe daily exposure levels for the majority of the population, including the very young and the elderly, throughout an individual's lifetime. Air quality guidelines and standards are normally given for specific averaging or exposure periods. This section summarises legislation for criteria and non-criteria pollutants relevant to the study and dustfall impacts.

2.1 Emission Standards

The NEM:AQA (Act No. 39 of 2004 as amended) mandates the Minister of Environment to publish a list of activities which result in atmospheric emissions and consequently cause significant detrimental effects on the environment, human health and social welfare. All scheduled processes as previously stipulated under the Air Pollution Prevention Act (APPA) are included as listed activities with additional activities added to the list. The updated Listed Activities and Minimum National Emission Standards were published on the 22nd November 2013 in Government Gazette No. 37054 (Government Gazette, 2013).

According to the project description, none of the activities are expected to trigger the MES's or the need for an AEL application.

2.2 Ambient Air Quality Standards for Criteria Pollutants

Criteria pollutants are considered those pollutants most commonly found in the atmosphere, that have proven detrimental health effects when inhaled and are regulated by ambient air quality criteria. In the context of this project, these include $PM_{2.5}$ and PM_{10}.

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}, $PM_{2.5}$, dustfall, SO_2, NO_2, ozone (O_3), CO, lead (Pb) and benzene (C_6H_6). The final revised NAAQSs were published in the Government Gazette on 24 of December 2009 (Government Gazette, 2009) and included a margin of tolerance (i.e. frequency of exceedance) and implementation timelines linked to it. NAAQS for $PM_{2.5}$ were published on 29 July 2012 (Government Gazette, 2012). The NAAQSs referred to in this study are listed in Table 1.

Table 1: Air quality standards for criteria pollutants (SA NAAQS)

Pollutant	Averaging Period	Limit Value (µg/m³)	Limit Value (ppb)	Frequency of Exceedance	Compliance Date
PM_{10}	24 hour	75	-	4	Currently in effect
	1 year	40	-	0	Currently in effect
$PM_{2.5}$	24 hour	40	-	4	1 Jan 2016 – 31 Dec 2029
	1 year	20	-	0	1 Jan 2016 – 31 Dec 2029

2.3 National Dust Control Regulations

The National Dust Control Regulations (NDCR) were published on the 1st of November 2013 (Goverment Gazette, 2013). The purpose of the regulation is to prescribe general measures for the control of dust in all areas including residential and non-residential areas. Acceptable dustfall rates according to the regulation are summarised in Table 2.

Table 2: Acceptable dustfall rates

Restriction areas	Dustfall rate (D) in mg/m^2-day over a 30 day average	Permitted frequency of exceedance
Residential areas	D < 600	Two within a year, not sequential months.
Non-residential areas	600 < D < 1 200	Two within a year, not sequential months.

The regulation also specifies that the method to be used for measuring dustfall and the guideline for locating sampling points shall be ASTM D1739 (1970), or equivalent method approved by any internationally recognized body. It is important to note that dustfall is assessed for nuisance impact and not inhalation health impact. It should be noted that the requirements of the regulations only become applicable to a specific installation or site after a written notice has been given to the site/installation by the local Air Quality Officer.

The management of air pollution is the responsibility of the local Ari Quality Officer. If the landowners are requested by the local authority to assess dustfall and are found to be exceeding the regulations, then the landowner will be required to take measures aimed at the control of dust. Section 32 of the NEMA will be applicable, the control of dust.

2.4 Regulations Regarding Air Dispersion Modelling

Air dispersion modelling provides a cost-effective means for assessing the impact of air emission sources, the major focus of which is to determine compliance with the relevant ambient air quality standards. Regulations regarding air dispersion modelling were promulgated in Government Gazette No. 37804 vol. 589; 11 July 2014, (Government Gazette, 2014) and recommend a suite of dispersion models to be applied for regulatory practices as well as guidance on modelling input requirements, protocols and procedures to be followed. The Regulations regarding Air Dispersion Modelling are applicable –

(a) in the development of an air quality management plan, as contemplated in Chapter 3 of the NEM:AQA;
(b) in the development of a priority area air quality management plan, as contemplated in section 19 of the NEM:AQA;
(c) in the development of an atmospheric impact report, as contemplated in section 30 of the NEM:AQA; and,
(d) in the development of a specialist air quality impact assessment study, as contemplated in Chapter 5 of the NEM:AQA.

The Regulation has been applied to the development of this report. The first step in the dispersion modelling exercise requires a clear objective of the modelling exercise and thereby gives clear direction to the choice of the dispersion model most suited for the purpose. Chapter 2 of the Regulations present the typical levels of assessments, technical summaries of the prescribed models (SCREEN3, AERSCREEN, AERMOD, SCIPUFF, and CALPUFF) and good practice steps to be taken for modelling applications. The proposed operation falls under a Level 2 assessment which is described as follows;

- The distribution of pollutant concentrations and deposition are required in time and space.
- Pollutant dispersion can be reasonably treated by a straight-line, steady-state, Gaussian plume model with first order chemical transformation. The model specifically to be used in the air quality impact assessment is AERMOD.

- Emissions are from sources where the greatest impacts are in the order of a few kilometers (less than 50 km) downwind.

Dispersion modelling provides a versatile means of assessing various emission options for the management of emissions from existing or proposed installations. Chapter 3 of the Regulation prescribe the source data input to be used in the model. Dispersion models are particularly useful under circumstances where the maximum ambient concentration approaches the ambient air quality limit value and provide a means for establishing the preferred combination of mitigation measures that may be required.

Chapter 4 of the Regulation prescribe meteorological data input from on-site observations to simulated meteorological data. The chapter also gives information on how missing data and calm conditions are to be treated in modelling applications. Meteorology is fundamental for the dispersion of pollutants because it is the primary factor determining the diluting effect of the atmosphere.

Topography is also an important geophysical parameter. The presence of terrain can lead to significantly higher ambient concentrations than would occur in the absence of the terrain feature. In particular, where there is a significant relative difference in elevation between the source and off-site receptors large ground level concentrations can result.

The modelling domain would normally be decided on the expected zone of influence; the extent being defined by simulated ground level concentrations from initial model runs. The modelling domain must include all areas where the ground level concentration is significant when compared to the air quality limit value (or other guideline). Air dispersion models require a receptor grid at which ground-level concentrations can be calculated. The receptor grid size should include the entire modelling domain to ensure that the maximum ground-level concentration is captured and the grid resolution (distance between grid points) sufficiently small to ensure that areas of maximum impact adequately covered.

Chapter 5 provides general guidance on geophysical data, model domain and coordinates system requirements, whereas Chapter 6 elaborates more on these parameters as well as the inclusion of background air pollutant concentration data. Chapter 6 also provides guidance on the treatment of NO_2 formation from NOx emissions, chemical transformation of SO_2 into sulfates and deposition processes. Chapter 7 of the Regulation outlines how the plan of study and modelling assessment reports are to be presented to authorities.

2.5 Air Quality Management Plans - Vaal Triangle Airshed Priority Area and Gauteng Province

With the shift of the new Air Quality Act from source control to the impacts on the receiving environment, the responsibility to achieve and manage sustainable development has reached a new dimension. The Air Quality Act has placed the responsibility of air quality management on the shoulders of provincial and local authorities that will be tasked with baseline characterisation, management and operation of ambient monitoring networks, licensing of listed activities, and emissions reduction strategies. The main objective of the act is to ensure the protection of the environment and human health through reasonable measures of air pollution control within the sustainable (economic, social and ecological) development framework.

An Air Quality Management Plan for the Vaal Triangle Airshed Priority Area (VTAPA) was gazetted on the 28th of May 2009 (Government Gazette No. 32263). The plan included the establishment of emissions reduction strategies and intervention programmes based on the findings of a baseline characterisation of the area.

An Air Quality Management Plan for Gauteng Province was developed in the same period (January 2009). This plan is currently being reviewed.

The southern part of the proposed development falls within the VTAPA (see Figure 1) and therefore, the proposed development should support the goals of the VTAPA. The entire development falls within the Gauteng Province. Intervention strategies for Mine Tailings Dams included the GDACE mine tailings buffer regulation which restricted the development within a specified buffer zone around a mine tailings facility (See Section 1.3). It also supported the residential dustfall limit of 600 mg/m²/day in residential areas and that the ambient air quality limits for PM_{10} not be exceeded.

Although the proposed development will not add to the existing baseline ambient levels (with the exception of the short-term construction phase), it should be noted that the proposed development will be located in an area with already elevated ambient levels.

3 DESCRIPTION OF THE RECEIVING ENVIRONMENT

3.1 Air Quality Sensitive Receptors

Air quality sensitive receptors (AQSRs) primarily refer to places where humans reside, schools and hospitals. Ambient air quality guidelines and standards, as discussed under section 2, have been developed to protect human health. Ambient air quality, in contrast to occupational exposure, pertains to areas outside of an industrial site boundary where the public has access to and according to the Air Quality Act, excludes areas regulated under the Occupational Health and Safety Act (Act No 85 of 1993).

For this air quality impact assessment, the proposed development itself, i.e. Spitzland, is the primary AQSR. Suburbs located around the proposed residential development, include Sol Plaatje and Bram Fischerville to the south, Leratong Village to the west, Witpoortjie to the north-west and Goudrand, Matholesville and Roodepoort to the north of the proposed development. These AQSRs are illustrated in Figure 1 and Figure 2.

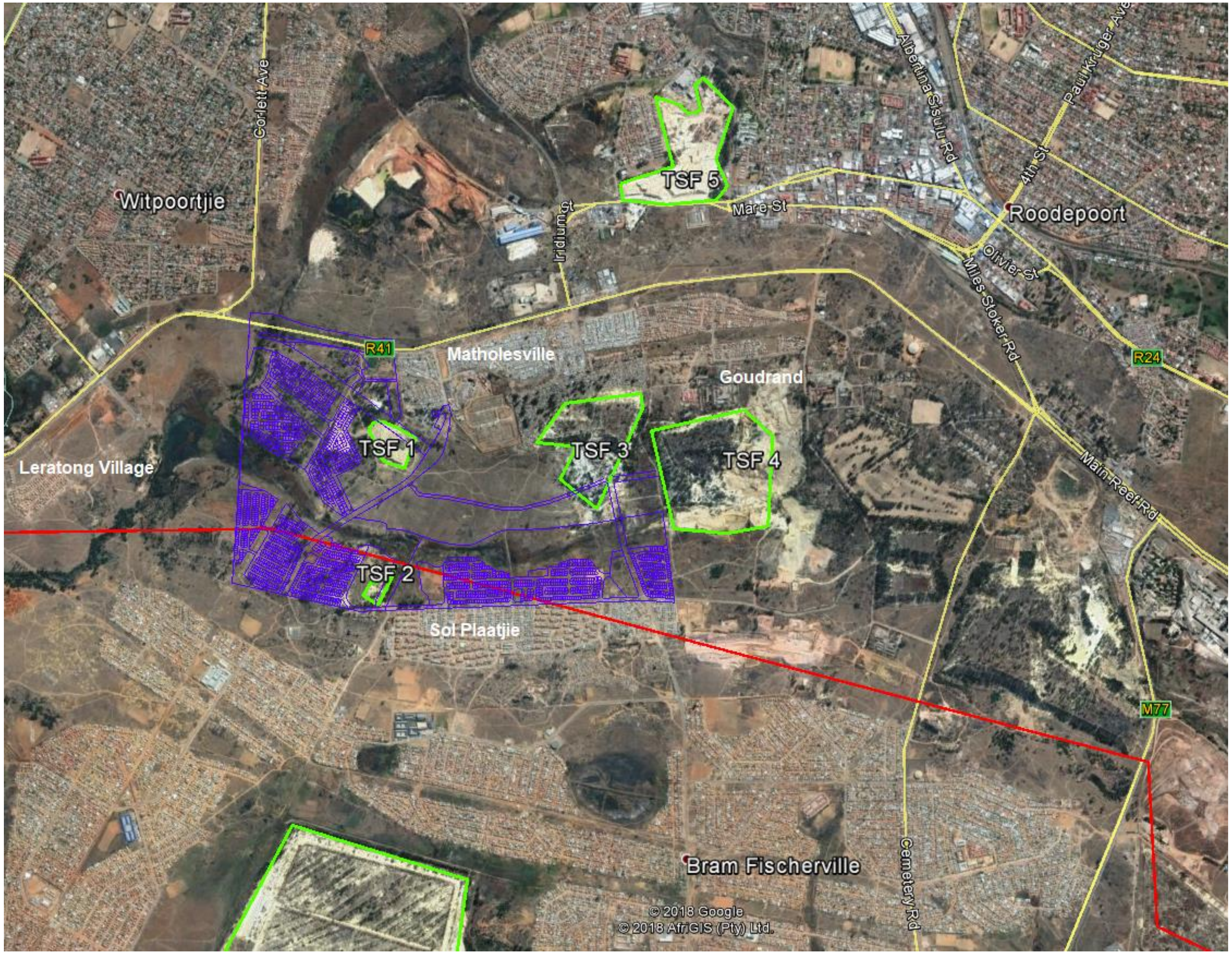

Figure 2: AQSRs surrounding the proposed development area

3.2 Atmospheric Dispersion Potential

Physical and meteorological mechanisms govern the dispersion, transformation, and eventual removal of pollutants from the atmosphere. The analysis of hourly average meteorological data is necessary to facilitate a comprehensive understanding of the dispersion potential of the site. Parameters useful in describing the dispersion and dilution potential of the site i.e. wind speed, wind direction, temperature and atmospheric stability, are subsequently discussed. Hourly meteorological data from the Weather Research and Forecasting model (WRF) data set used for the City of Johannesburg (CoJ) air quality management plan (AQMP) was extracted for the project site for 2014. Validation statistics for this data can be seen in the CoJ AQMP Status Quo report (CSIR Climate Studies, 2016).

3.2.1 Topography

The study area is characterised by a flat surface with sparse vegetation. An analysis of topographical data indicated a slope of less than 1:10 from over most of the proposed development area. Dispersion modelling guidance recommends the inclusion of topographical data in dispersion simulations only in areas where the slope exceeds 1:10 (US EPA, 2004).

3.2.2 Surface Wind Field

The horizontal dispersion of pollution is largely a function of the wind field. The wind speed determines both the distance of downwind transport and the rate of dilution of pollutants. The generation of mechanical turbulence is similarly a function of the wind speed, in combination with the surface roughness.

Period wind roses drawn from WRF data for Spitzland are shown in Figure 3. Wind roses comprise 16 spokes, which represent the directions from which winds blew during a specific period. The colours used in the wind roses below, reflect the different categories of wind speeds; the yellow area, for example, representing wind speeds between 6 and 7 m/s. The dotted circles provide information regarding the frequency of occurrence of wind speed and direction categories. The frequency with which calms occurred, i.e. periods during which the wind speed was below 1 m/s are also indicated.

The wind field for the entire period was dominated by winds from the north-northeast and from the north. The average wind speed for the WRF data set at Spitzland was 4.1 m/s.

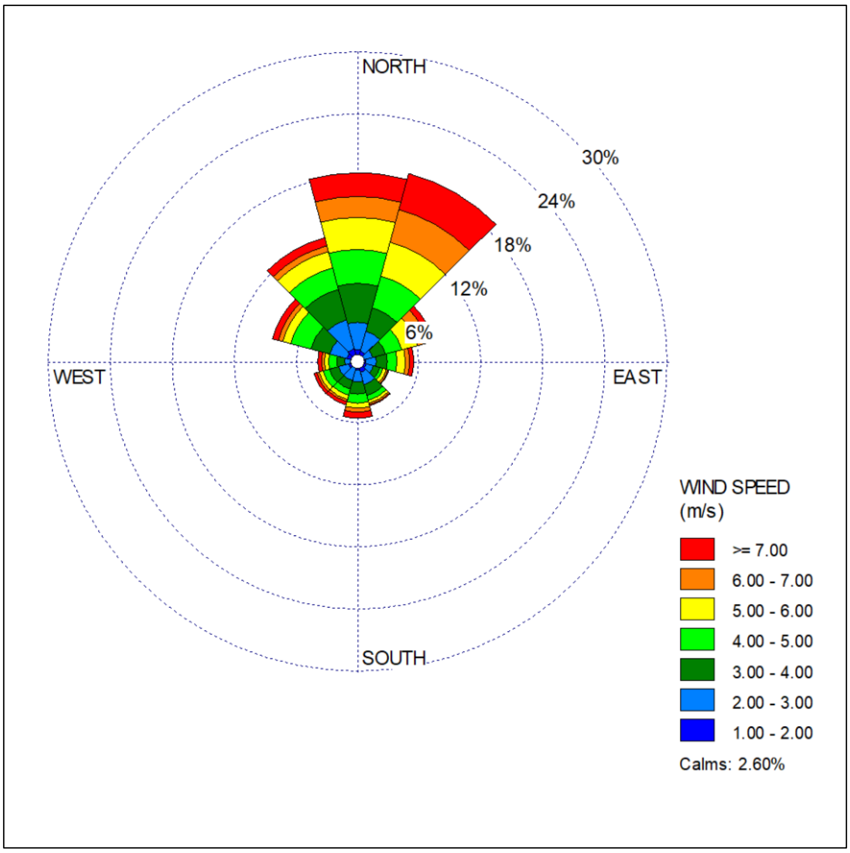

Figure 3: Period wind rose – extrapolated WRF weather data at Spitzland (2014)

3.2.3 Temperature

Air temperature provides an indication of the extent of insolation, and therefore of the rate of development and dissipation of mixing dispersion layers. Monthly maximum and minimum temperatures are given in Table 3. Monthly temperatures ranged between 3°C and 27°C.

Table 3: Monthly temperature summary – Roodepoort weather station (long term NOAA)

Monthly Minimum and Maximum Temperatures (°C)												
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Minimum	16	15	14	10	7	4	3	5	9	12	13	15
Maximum	27	27	25	23	21	18	18	21	25	26	26	27

3.3 Site Visit

A site visit was not conducted by Airshed for this air quality impact assessment, as site visits have recently been conducted in the area for other studies. Adequate project information was obtained from EIMS, as well as from previous studies done in the area.

3.4 Ambient Air Quality within the region

3.4.1 Sources of Air Pollution within the Region

Mining and industrial activities, farming and residential land-uses occur in the vicinity of the proposed development area. These land-use activities contribute to baseline pollutant concentrations via vehicle tailpipe emissions, household fuel combustion, biomass burning and various fugitive dust sources. Long-range transport of particulates, emitted from remote tall stacks and from large-scale biomass burning in countries to the north of South Africa, has been found to contribute significantly to background fine particulate concentrations within the South African boundary (Andreae, et al., 1996; Garstang, et al., 1996; Piketh, et al., 1996).

Sources of atmospheric emissions include:

- Gaseous and particulate emissions from mining and tailings recovery operations;
- Gaseous and particulate emissions from industrial operations;
- Miscellaneous fugitive dust sources including vehicle entrainment on roads and windblown dust from open areas;
- Gaseous and particulate emissions from vehicles and aircraft;
- Gaseous and particulate emissions from household fuel burning; and
- Gaseous and particulate emissions from biomass burning/veld fires (e.g. wild fires).

3.4.2 Measured Ambient Air Quality

The identification of existing sources of emission and the characterisation of ambient pollutant concentrations is fundamental to the assessment of the potential for cumulative impacts in the region. Ambient measurement data in the region from the Mogale City monitoring station operated by the West Rand District Municipality was obtained for the period 2012 to current. The station is located fairly near the site (2.4 km to the west of the site, Figure 4). Data availability was poor with huge gaps in data captured. From these figures, it can be deduced that ambient concentrations of PM_{10} exceeded the NAAQS.

Analysis of data for the period January 2012 to current is presented in Figure 6. It should also be noted that the Mogale City monitoring station is expected to reflect higher pollutant concentrations - compared to the project site - due to domestic fuel burning activities in the township, especially during winter months. The Mogale City site is considered to be most representative of ambient air quality in the proposed development area with respect to background air pollution sources and ambient air quality. There are however no TSFs influencing the Mogale City area.

There was an additional short-term monitoring campaign conducted by Royal Haskoning DHV during June 2015. Table 4 provides the monitoring results for the ambient monitoring undertaken from the 11th June until the 15th June 2015. The results indicate that monitoring site 1 (Figure 5) located on the northern edge of the property boundary exceeded the ambient limit of 75 µg/m³ for two of the days monitored. It is likely the standard will be exceeded as it allows only 4 exceedances per year, however not enough data is available to comment on compliance with standards.

Table 4: PM_{10} monitoring results (µg/m³) – June 2015 campaign

	11/12 June	12/13 June	13/14 June	14/15 June
Monitor 1	**86**	**79**	65	71
Monitor 2	44	46	38	41
Monitor 3	55	51	49	54

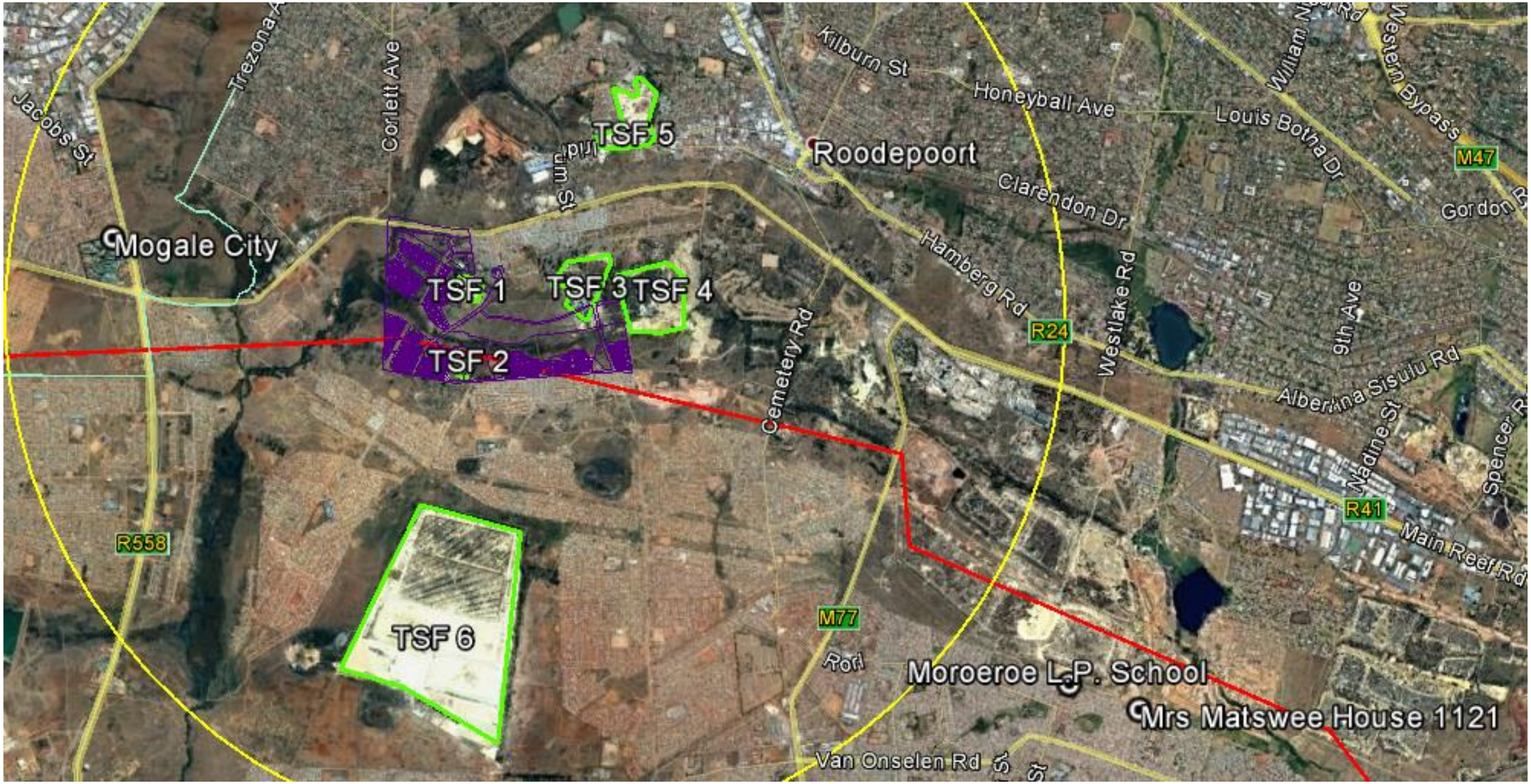

Figure 4: Location of ambient monitoring stations

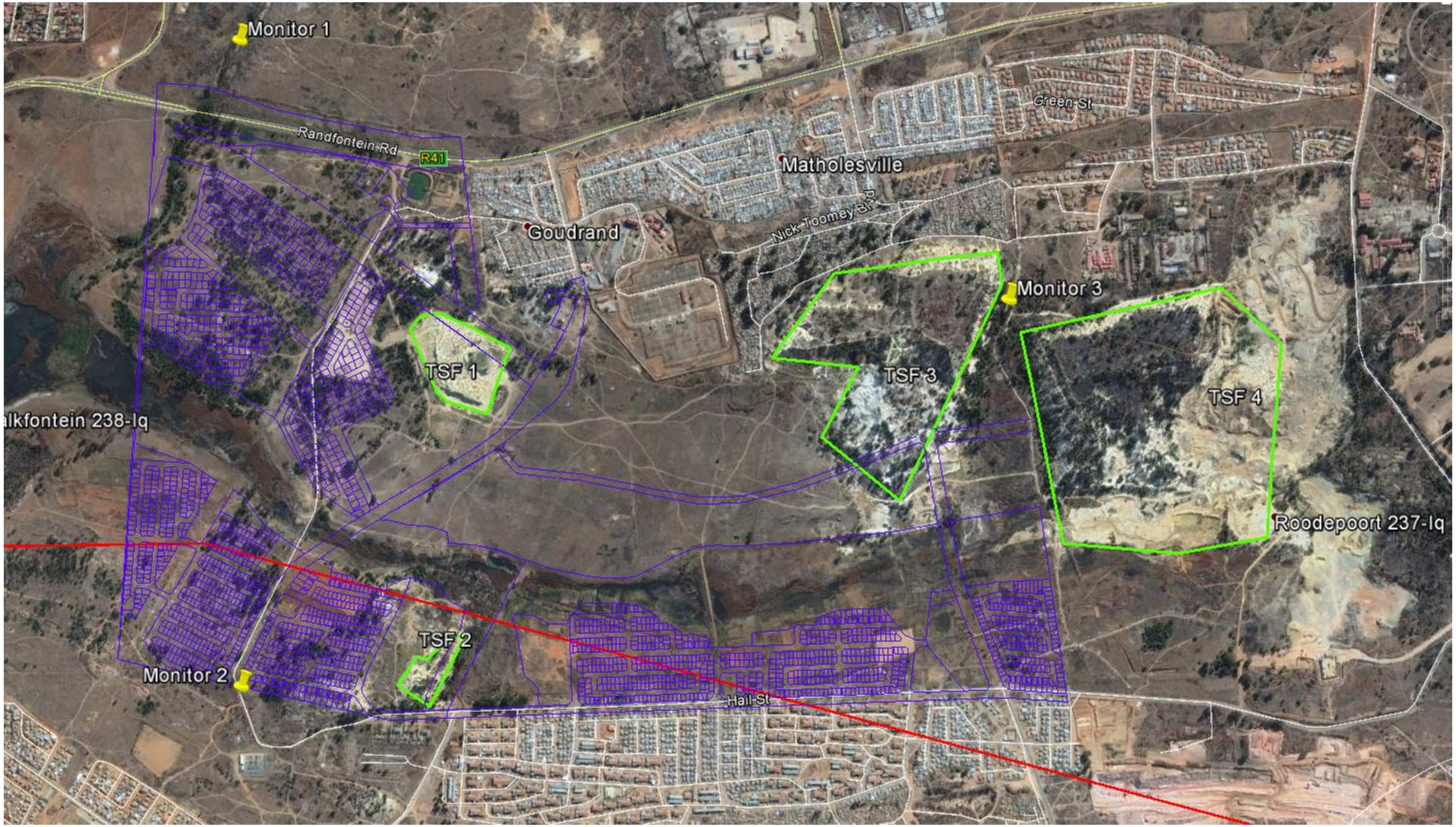

Figure 5: Location of ambient monitoring campaign locations

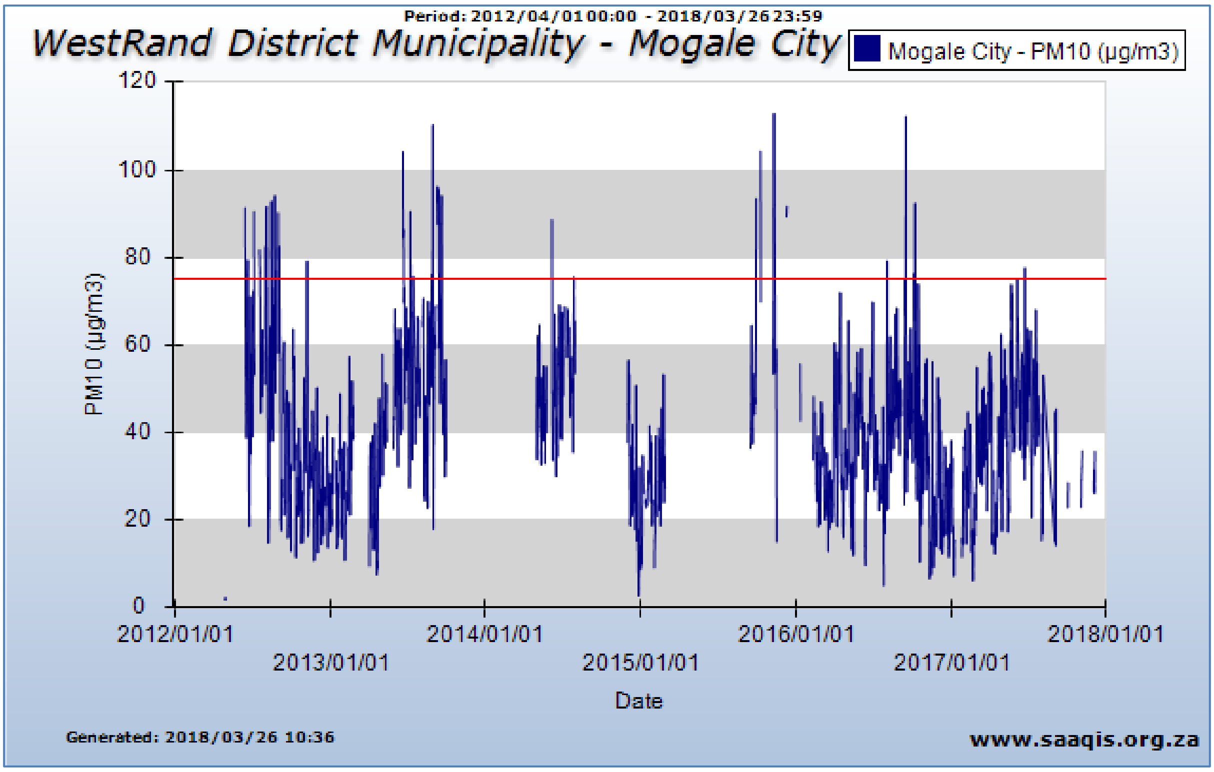

Figure 6: Daily PM_{10} concentrations, Mogale City monitoring station (Red line indicates NAAQS limit value)

Figure 7 and Figure 8 show dustfall rates for receptors, however they are not close to the proposed development site and the data is outdated (2010 to 2012). Even so, there is potential for dustfall rates to exceed the residential NDCR of 600 mg/m²/day in the vicinity of gold TSFs.

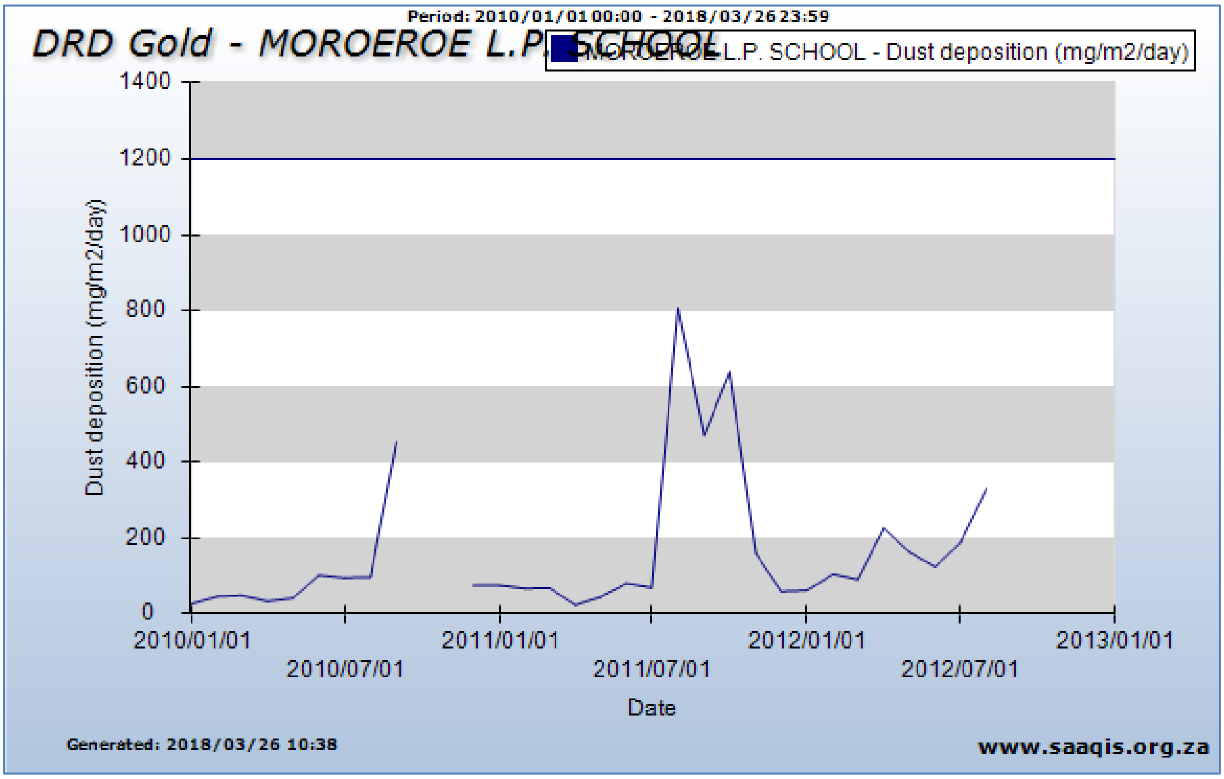

Figure 7: Monthly dustfall rate, Moroeroe L.P. School monitoring station (Blue line indicates NDCR for non-residential)

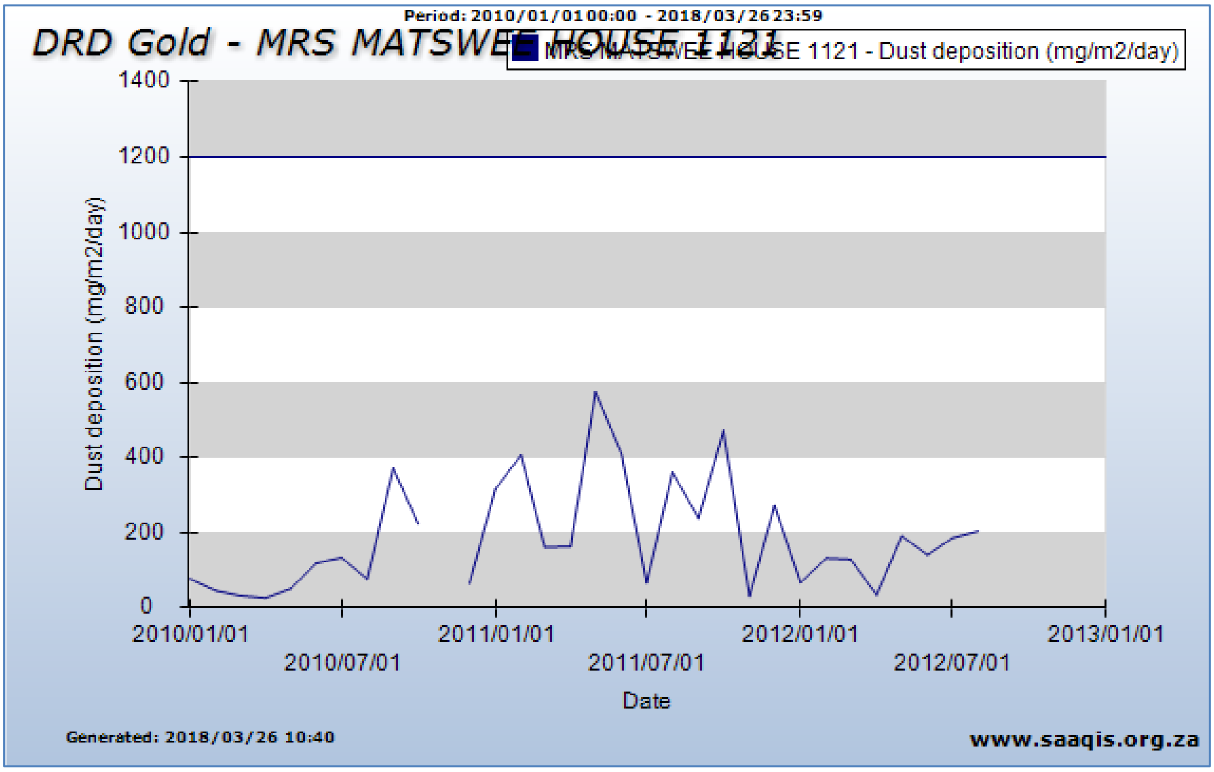

Figure 8: Monthly dustfall rate, Mrs Matswe House monitoring station (Blue line indicates NDCR for non-residential)

3.4.3 Modelled Regional Ambient Air Quality

The proposed development is situated in an area within Gauteng Province that has been identified as characterized with poor air quality. As discussed in Section 1.3, windblown dust from mine waste facilities can be significant sources of dust emissions with high dust concentrations reported near mining sites, affecting both the environment and human health.

A comprehensive emissions inventory was completed for the region as part of the baseline study for the City of Johannesburg (CoJ) Air Quality Management Plan (AQMP) ((CSIR Climate Studies, 2016)). These results of the inventory were used to carry out a comprehensive dispersion modelling study over the area using the CALPUFF model. Based on these dispersion modelling results, the AQMP identified Baseline Hotspots for PM_{10} where the proposed development area is already elevated with respect to PM_{10} concentrations. The ambient monitoring data available for the area, as discussed in the previous section, confirms the potential for high PM_{10} background concentrations.

The construction of the proposed development should therefore also ensure minimal contribution to PM_{10} concentrations.

4 IMPACT ON THE RECEIVING ENVIRONMENT

4.1 Atmospheric Emissions

A discussion on the expected activities is provided in the sections below.

4.1.1 Construction Phase

Construction operations are potentially significant sources of dust emissions that may have a substantial temporary impact on local air quality. Construction air emissions would result from general site preparation for the developments. Construction activities that contribute to air pollution typically include: land clearing and demolition activities, excavation, material handling activities, wheel entrainment, operation of diesel or petrol engines etc. If not properly mitigated, construction sites could generate high levels of dust (typically from concrete, cement, wood, stone, silica) and this has the potential to travel for large distances.

Construction dust may be grouped into TSP with impacts generally close to the construction activities and are more responsible for soiling than health issues. Health impacts are more associated with the finer PM_{10} and $PM_{2.5}$ fractions, both of which are invisible to the naked eye. Research has shown that PM_{10} and even more significantly $PM_{2.5}$ penetrate deeply into the lungs and therefore has the potential to cause a wide range of health problems including respiratory illness, asthma, bronchitis and even cancer.

Combustion engines also emit emissions of CO, HC, NOx and CO_2. A potentially source of $PM_{2.5}$ on construction sites comes from the diesel engine exhausts of on- and off-road utility vehicles and heavy equipment as well as stationary combustion sources. These particles are known as DPM, and consist of soot (unburnt organic material), sulfates and silicates, all of which may readily combine with other compounds in the atmosphere, increasing the health risks of particle inhalation. Other noxious vapours may also originate from oils, glues, thinners, paints, treated woods, plastics, cleaners and other hazardous chemicals that may be used on construction sites.

A significant amount of the dust emissions result from construction vehicle traffic over temporary roads at construction sites. Dust emissions can also vary substantially from day to day, depending on the level of activity, the specific operations, and the prevailing meteorological conditions.

Air quality impacts will be associated with the construction phase of the proposed development; however, this will be of a short duration.

4.1.2 Tailings storage facilities (TSFs)

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 friction 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). Thus, the likelihood exists for wind erosion to occur from open and exposed surfaces, with loose fine material, when the wind speed exceeds at least the friction velocity.

Literature indicates a friction velocity of 9 m/s to initiate erosion from two gold tailings storage facilities in in New Brunswick and Ontario, Canada (Mian & Yanful, 2003). A case study conducted for a gold tailings facility in South Africa, indicated dust mobilisation for wind speeds above 3 m/s (dust flux), with most dust emissions when winds were above 6.7 m/s (Liebenberg-Enslin, 2014). Thus, the likelihood exists for wind erosion to occur from open and exposed surfaces, with loose fine material, when the wind speed exceeds at least 6.7 m/s. Wind speed data used in this study indicate exceedances of 6.7 m/s for 60% of the time and emissions resulted from wind speeds exceeding 6.7 m/s. The majority of the emissions (90%) occur with wind speeds over 7.7 m/s.

Six gold TSFs have been identified in the vicinity of the proposed development and are included in this study to determine their contribution to ambient concentration levels. These operations are depicted in Figure 1 as 1 to 6 respectively.

Sources of emissions generally associated with these TSFs include windblown dust and radon gas. A summary of emission sources quantified, estimation techniques applied, and source input parameters are included in Table 5 and Table 6.

Table 5: Tailings content and particles size distribution for three particle size bins of $PM_{2.5}$, PM_{10} and PM_{75} (CSIR Climate Studies, 2016)

Source	Clay	Silt	Sand	Normalised percentage of $p_m(d)$ fractions		
	(<2 µm)	(2-63 µm)	(63-2000 µm)	$PM_{2.5}$	PM_{10}	PM_{75}
	(%)	(%)	(%)	(d < 2.5 µm)	(d < 10 µm)	(d < 75 µm)
TSF	2.35	57.75	39.90	3.56	13.34	83.10

Emission quantification was done using the in-house modelled ADDAS (Burger *et al*., 1997; Burger, 2010). This model is based on the dust emission scheme of Marticorena and Bergametti (1995) referred to as MB95 (from this point forward) and Shao *et al*. (2011) (referred to as SH11). For the purpose of this study, the MB95 dust flux model was used.

The model inputs include material particle density, moisture content, particle size distribution and site-specific surface characteristics such as whether the source is active or undisturbed.

A summary of emissions is given in Table 7.

Table 6: Emission estimation techniques and parameters

Source Group	Emission Estimation Technique	Input Parameters and Activities
TSFs 1 to 6	**<u>Windblown dust</u>** The calculation of a windblown dust emission rate for every hour of 2014 was carried out using the ADDAS model, which is based on the dust emission model proposed by Marticorena & Bergametti (1995). A literature review on the model is provided in Appendix C. **<u>Radon gas</u>** Airshed modelled a unit release rate of radon gas, and together with the radon exhalation rates, the radon specialist will complete the radiological impact study for the impact of the TSFs on the proposed development.	**<u>Windblown dust</u>** Exposed stockpile area was included in emission estimations based on google earth images: • 1 = 27 829 m² (assumed 5 % vegetation on exposed area) • 2 = 12 855 m² (assumed 50 % vegetation on exposed area) • 3 = 176 743 m² (assumed 50 % vegetation on exposed area, assumed 75% for mitigated scenario) • 4 = 188 933 m² (only exposed areas included – no vegetation assumed – assumed 75 % for mitigated scenario) • 5 = 205 758 m² (only exposed areas included – no vegetation assumed) • 6 = 1 499 062 m² (only exposed areas included – no vegetation assumed) **<u>Radon gas</u>** The assumption is made that radon is released from the entire surface area of a source, irrespective of any physical parameters or mitigation measures which could affect the release of particulates. So, for the radon modelling, moisture content of the tailings and vegetation cover <u>was not</u> taken into consideration. The following areas were modelled for the radon gas: • 1 = 37 695 m² • 2 = 12 855 m² • 3 = 176 743 m² • 4 = 331 757 m² • 5 = 205 758 m² • 6 = 2 301 383 m²

Table 7: Estimated annual average emission rates (tpa) from windblown dust

Emission sources	$PM_{2.5}$	PM_{10}	TSP (used for dustfall rates)
TSF 1 (vegetated)	2	8	49
TSF 1 (active)	*3*	*10*	*62*
TSF 2 (vegetated)	0.1	0.5	3
TSF 2 (active)	*1*	*5*	*28*
TSF 3 (vegetated 50 %)	2	7	44
TSF 3 (vegetated 75%)	*1*	*3*	*15*
TSF 3 (active)	*18*	*66*	*391*
TSF 4	19	70	418
TSF 4 (vegetated 75%)	*1*	*3*	*16*
TSF 5	21	76	455
TSF 6	150	556	3 316
Total (current emissions)	**194**	**718**	**4 285**
Total (1,2 and 3 active)	**212**	**783**	**4 670**
Total (mitigated emissions -additional mitigation on TSF 3 and TSF 4)	**175**	**647**	**3 854**

The following scenarios were simulated:

- Scenario 1: active remining of TSF 1, 2 and 3, and TSF 4, 5 and 6 stay as is.
- Scenario 2: post remining of TSF 1, 2 and 3, and TSF 4, 5 and 6 stay as is.
- Scenario 3: no future remining. TSF 1, 2, 3, 4, 5 and 6 stay as is.

The following mitigated scenarios were simulated:

- Scenario M1: active remining of TSF 1 and 2, TSF 5 and 6 stay as is, with additional mitigation on TSF 3 and 4.
- Scenario M2: post remining of TSF 1, active remining of TSF 2, TSF 5 and 6 stay as is, with additional mitigation on TSF 3 and 4.
- Scenario M3: post remining of TSF 1 and TSF2, TSF 5 and 6 stay as is, with additional mitigation on TSF 3 and 4.

The proposed development will likely occur in phases with the following sequence:

- Phase 1 - development on the areas which are currently within acceptable limits (excluding the restrictive zones associated with active remining of TSF 1,2, and 3 individually).
- Phase 2 onwards - development of the respective restriction zones for TSF1,2,3 once TSF 1 and 2 are re-mined – i.e. as these 2 sites are remined the development footprint will expand into these areas. The current plan is only to remine TSF 1 and 2 and then to retain TSF 3 in its current stabilized form but to mitigate with additional vegetation.
- Any future mining of TSF 3-6 would then require mitigation measures from the respective mining rights holders during the remining process.

4.2 Atmospheric Dispersion Modelling

The assessment of the impact of the TSFs on the environment is discussed in this section. To assess impact on human health and the environment the following important aspects need to be considered:

- The criteria against which impacts are assessed (Section 2);

- The potential of the atmosphere to disperse and dilute pollutants (Section 3.2); and
- The methodology followed in determining ambient pollutant concentrations and dustfall rates (Section 1.4).

The impact of the TSFs on the atmospheric environment was determined through the simulation of dustfall rates and ambient pollutant concentrations.

Dispersion models simulate ambient pollutant concentrations and dustfall rates 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.

4.2.1 Dispersion Model Selection

Gaussian-plume models are best used for near-field applications where the steady-state meteorology assumption is most likely to apply. One of the most widely used Gaussian plume model is the US EPA model – AERMOD, which is prescribed by the South African Regulations Regarding Air Dispersion Modelling for level 2 assessments.

AERMOD is a model developed with the support of AERMIC, whose objective has been to include state-of the-art science in regulatory models (Hanna, et al., 1999). AERMOD is a dispersion modelling system with three components, namely: AERMOD (AERMIC Dispersion Model), AERMAP (AERMOD terrain pre-processor), and AERMET (AERMOD meteorological pre-processor).

AERMOD is an advanced new-generation model. It is designed to predict pollution concentrations from continuous point, flare, area, line, and volume sources. AERMOD offers new and potentially improved algorithms for plume rise and buoyancy, and the computation of vertical profiles of wind, turbulence and temperature however retains the single straight-line trajectory limitation. AERMET is a meteorological pre-processor for AERMOD. Input data can come from hourly cloud cover observations, surface meteorological observations and twice-a-day upper air soundings. Output includes surface meteorological observations and parameters and vertical profiles of several atmospheric parameters. AERMAP is a terrain pre-processor designed to simplify and standardise the input of terrain data for AERMOD. Input data includes receptor terrain elevation data. The terrain data may be in the form of digital terrain data. The output includes, for each receptor, location and height scale, which are elevations used for the computation of air flow around hills.

A disadvantage of the model is that spatial varying wind fields, due to topography or other factors cannot be included. Input data types required for the AERMOD model include: source data, meteorological data (pre-processed by the AERMET model), terrain data, information on the nature of the receptor grid and pre-development or background pollutant concentrations or dustfall rates.

4.2.2 Meteorological Requirements

Hourly meteorological data from the WRF data set used for the CoJ AQMP was extracted for the site for 2014.

4.2.3 Source and Emission Data Requirements

The AERMOD model is able to model point, jet, area, line and volume sources. Windblown dust was modelled as area sources.

4.2.4 Modelling Domain

The dispersion of pollutants expected to arise from the TSFs was modelled for an area covering 10 km (east-west) by 10 km (north-south). The area was divided into a grid matrix with a resolution of 100 m, with the proposed development located centrally. AERMOD calculates ground-level concentrations and dustfall rates at each grid and discrete receptor point.

4.2.5 Presentation of Results

Dispersion modelling was undertaken to determine highest hourly, highest daily and annual average ground level concentrations as well as dustfall rates for each of the pollutants considered in the study. Averaging periods were selected to facilitate the comparison of predicted pollutant concentrations to relevant ambient air quality and inhalation health criteria as well as dustfall regulations.

Results are primarily provided in form of isopleths to present areas of exceedance of assessment criteria. Ground level concentration or dustfall isopleths presented in this section depict interpolated values from the concentrations/dustfall rates simulated by AERMOD for each of the receptor grid points specified. Isopleth plots reflect the incremental ground level concentrations (GLCs) for $PM_{2.5}$ and PM_{10}, as well as dustfall rates for TSP.

4.3 Dispersion Simulation Results and Nuisance Screening (Incremental)

Pollutants with the potential to result in human health impacts and assessed in this study include $PM_{2.5}$ and PM_{10}. Dustfall is assessed for its nuisance effects. The impact assessment methodology as discussed under Section 1.4 was followed.

The impacts due to the TSFs are regarded as incremental baseline impacts because they fall under baseline conditions but should not be considered as the overall baseline level for the area. The maximum simulated annual average and highest daily $PM_{2.5}$, PM_{10} and TSP impacts (over the entire modelling grid of 10 km), are presented in Figure 9 to Figure 41. Results are shown for all 6 scenarios. Table 8 gives a summary of compliance with the NAAQS and the NDCR. The different unmitigated scenarios give the same conclusion regarding compliance, however the development areas affected differs for the various scenarios. Scenario 1 is the worst-case scenario assuming all three TSFs (TSF1, 2 and 3) to be actively mined without any vegetation or mitigation in place. Scenario 1 resulted in the highest impact, with the area of non-compliance for a large portion of the proposed development. Even, looking at active remining of TSF 1 to 3 individually, there is a small area of non-compliance in the vicinity of each TSF. For scenario 2 (post remining of TSF 1, 2 and 3, and TSF 4, 5 and 6 stay as is), the area of non-compliance (PM_{10} daily) is for a smaller area covering a portion of the proposed development near TSF number 4 only. For scenario 3, the area of non-compliance (PM_{10} daily) is for an even smaller area of the proposed development – a portion near TSF number 4 and a small portion of the proposed development west of TSF number 1.
For the mitigated scenarios, the impact at the proposed development is significantly reduced due to proposed mitigation on TSF 3 and 4. Scenario 3 results in compliance at the proposed residential development.

Table 8: Summary of compliance with NAAQS and NDCR

Impact Description	Compliance at proposed Spitzland Development (current)			Compliance at proposed Spitzland Development (mitigated)		
	Scenario 1	Scenario 2	Scenario 3	Scenario M1	Scenario M2	Scenario M3
$PM_{2.5}$ daily	X	X	X	X	X	√
$PM_{2.5}$ annual	√	√	√	√	√	√
PM_{10} daily	X	X	X	X	X	√
PM_{10} annual	√	√	√	√	√	√
Nuisance effects due to dustfall deposition	X	X	X	X	X	√
	Active remining at TSF 1, 2 and 3 with no vegetation and no mitigation. Non-compliance area covers large portion of proposed development.	Post-remining at TSF 1, 2 and 3. Non-compliance area covers only portion of proposed development – impacts due to TSF 4.	TSF 1, 2 and 3 remain dormant with existing vegetation cover. Non-compliance area covers small portion of proposed development – impacts due to TSF 4.	Active remining at TSF 1 and 2 with no vegetation and no mitigation. Additional mitigation on TSF 3 and 4 (75%). Non-compliance area covers small portion of proposed development – impacts due to TSF 1 and 2.	Post-remining at TSF 1. Active remining at TSF 2 with no vegetation and no mitigation. Additional mitigation on TSF 3 and 4 (75%). Non-compliance area covers small portion of proposed development – impacts due to TSF 2.	Post-remining at TSF 1 and 2. Additional mitigation on TSF 3 and 4 (75%). TSF 5 and 6 remain dormant with existing vegetation cover.

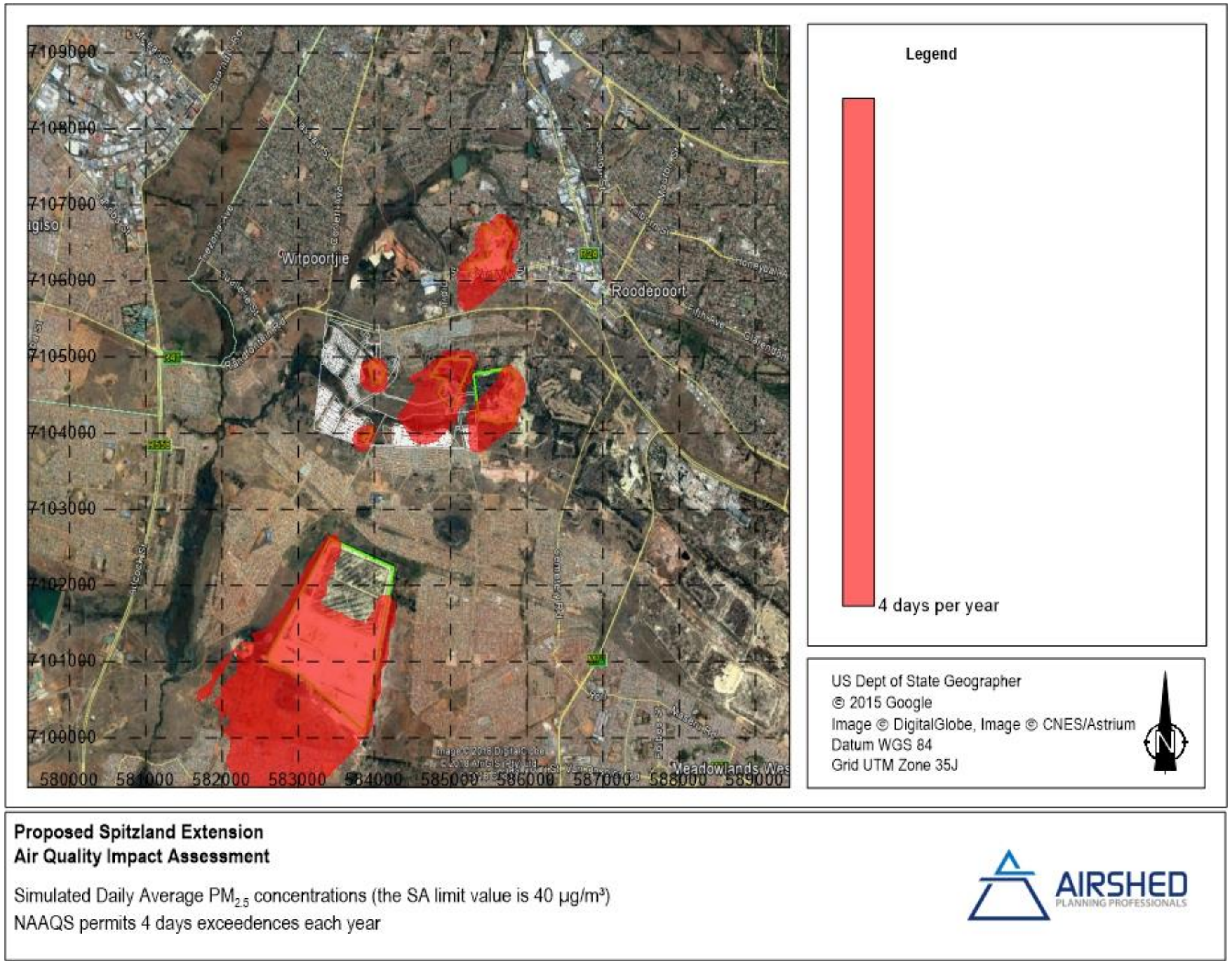

Figure 9: Simulated frequencies of exceedance of ambient daily $PM_{2.5}$ NAAQS – (scenario 1)

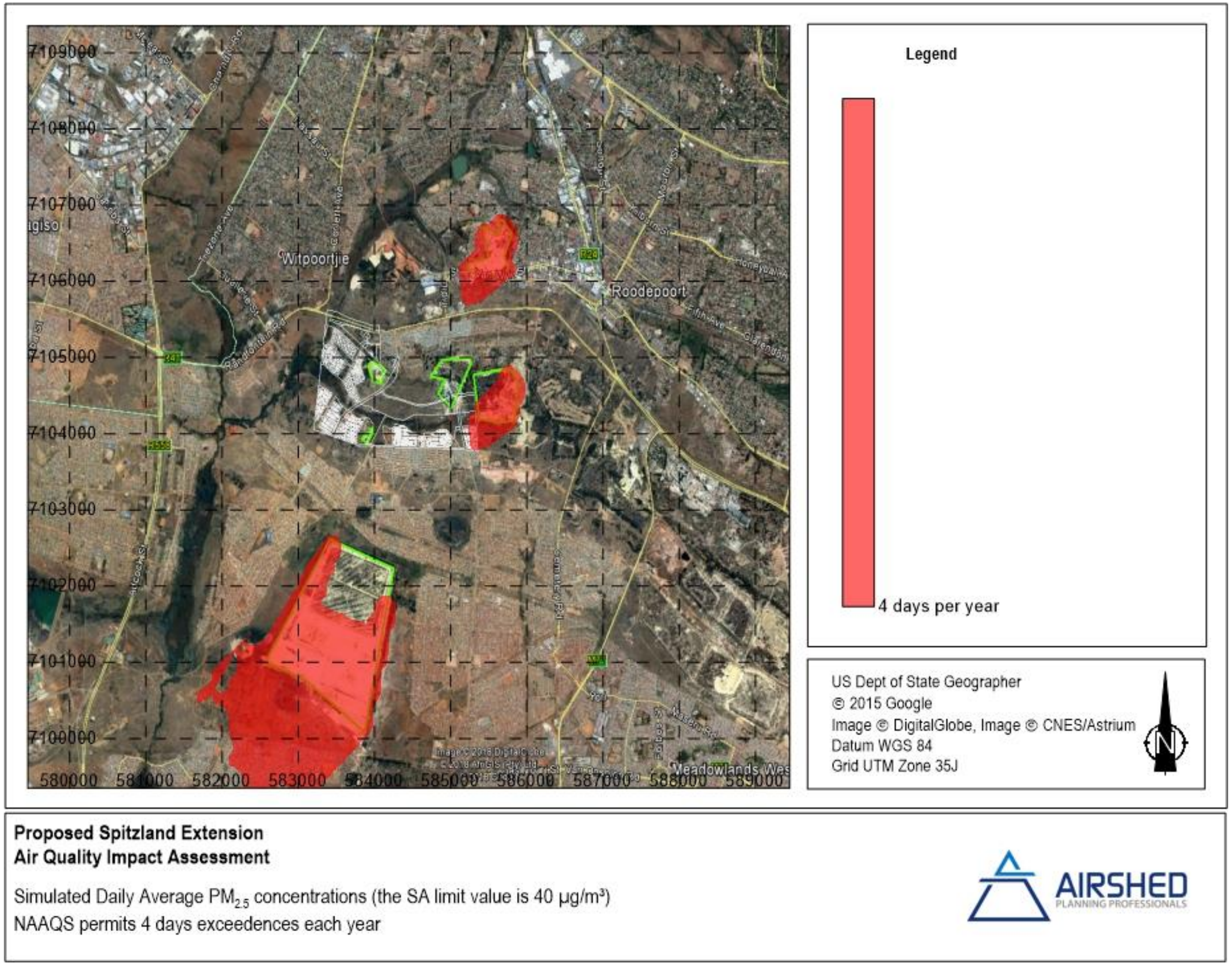

Figure 10: Simulated frequencies of exceedance of ambient daily $PM_{2.5}$ NAAQS – (scenario 2)

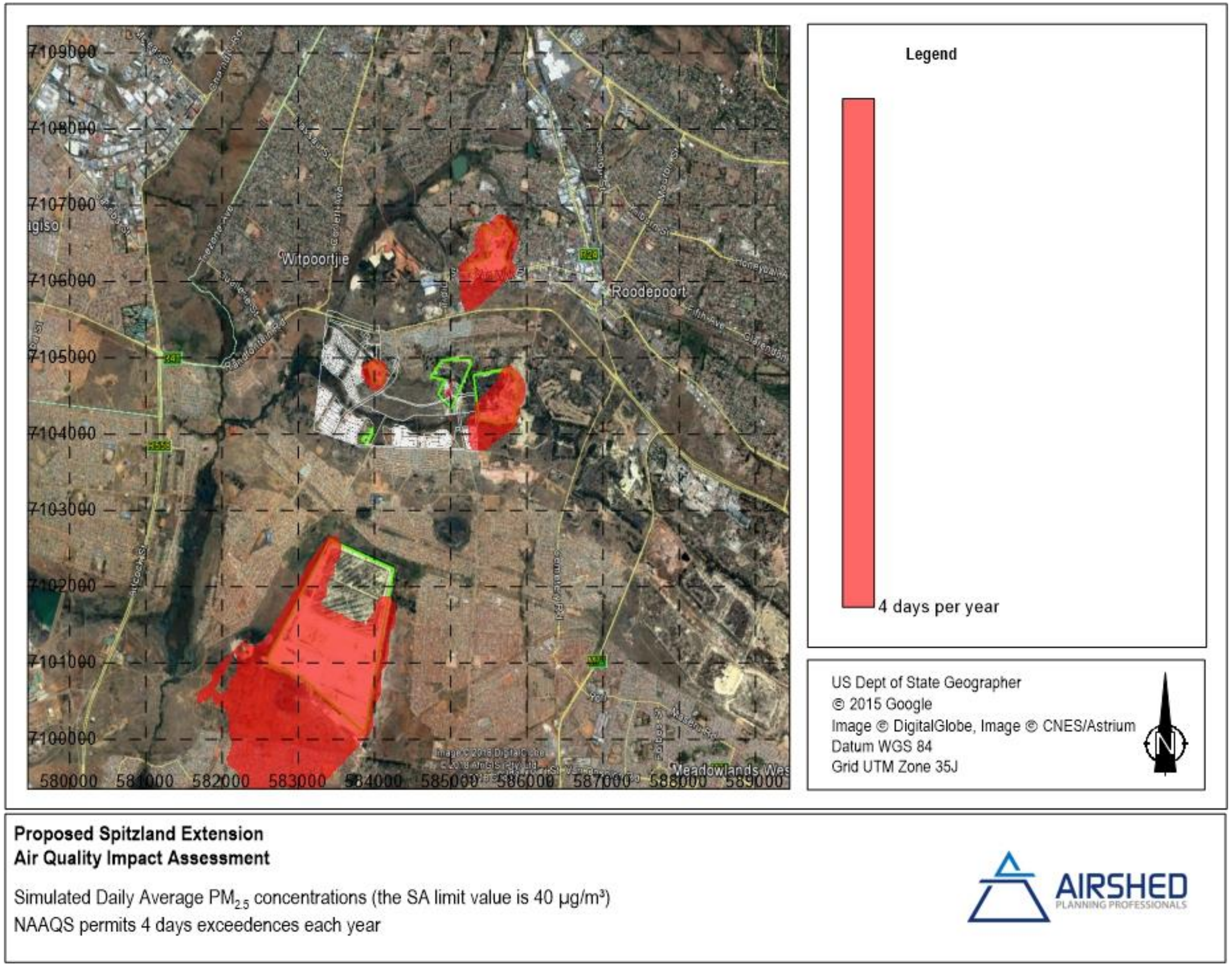

Figure 11: Simulated frequencies of exceedance of ambient daily $PM_{2.5}$ NAAQS – (scenario 3)

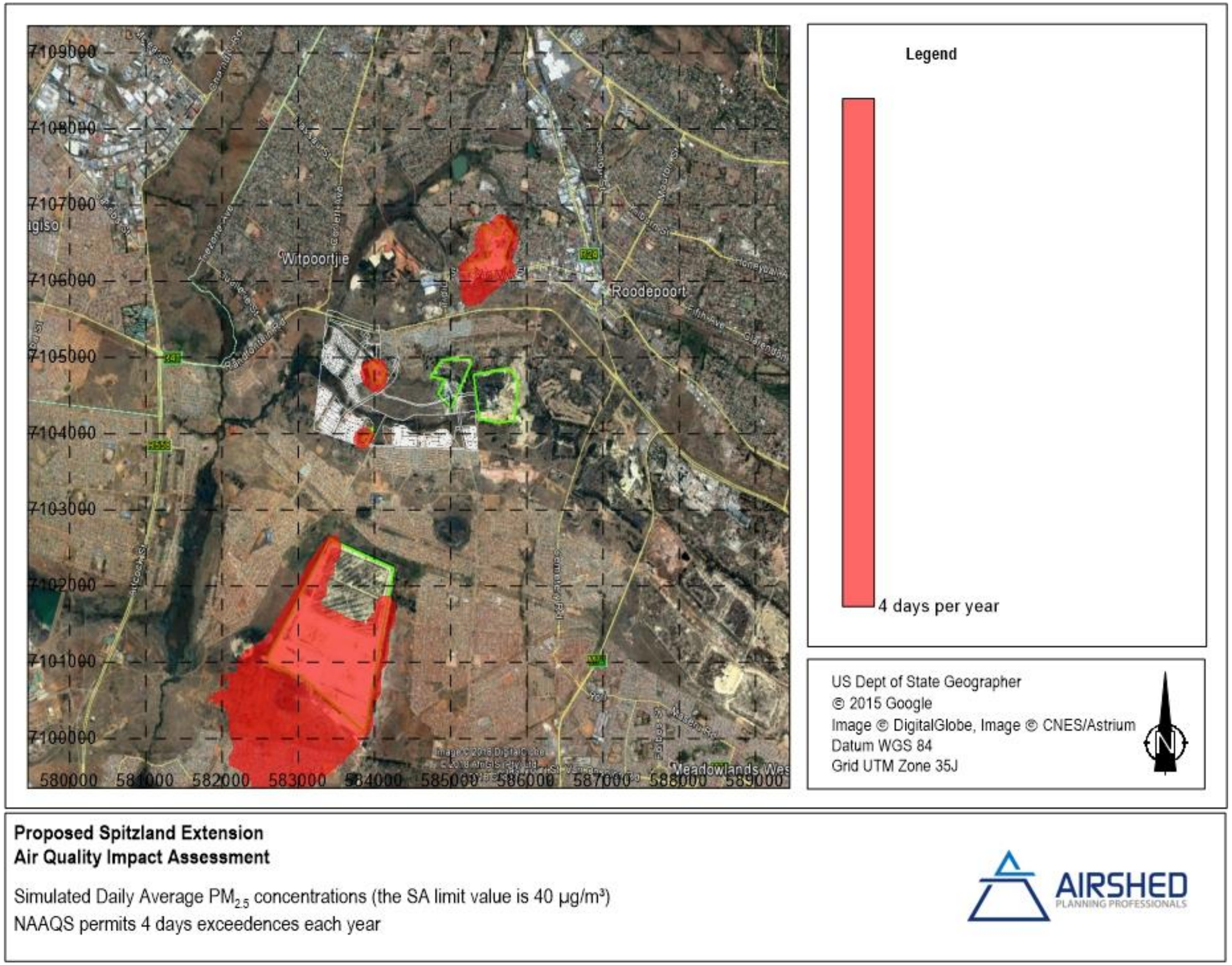

Figure 12: Simulated frequencies of exceedance of ambient daily $PM_{2.5}$ NAAQS – (scenario M1)

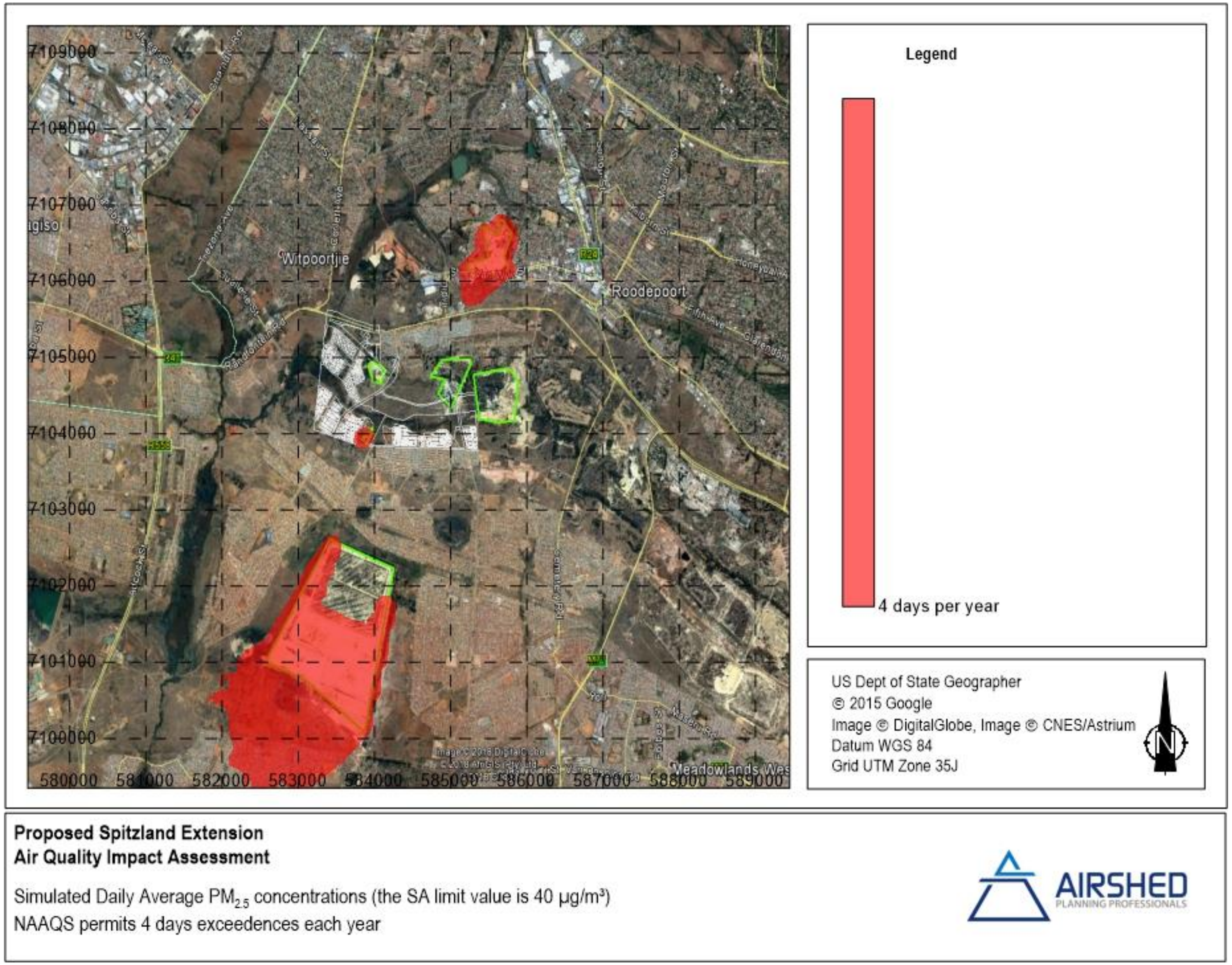

Figure 13: Simulated frequencies of exceedance of ambient daily $PM_{2.5}$ NAAQS – (scenario M2)

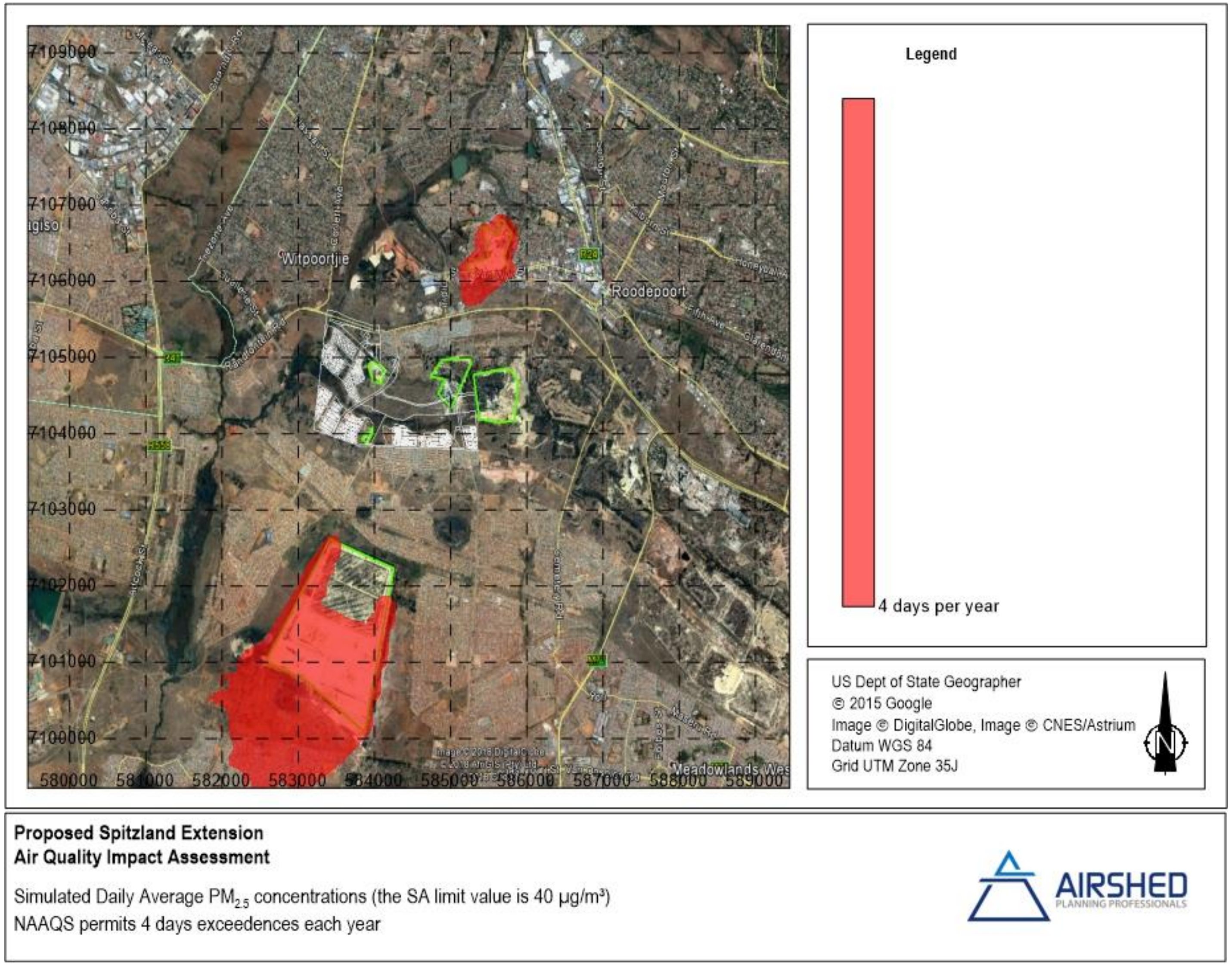

Figure 14: Simulated frequencies of exceedance of ambient daily $PM_{2.5}$ NAAQS – (scenario M3)

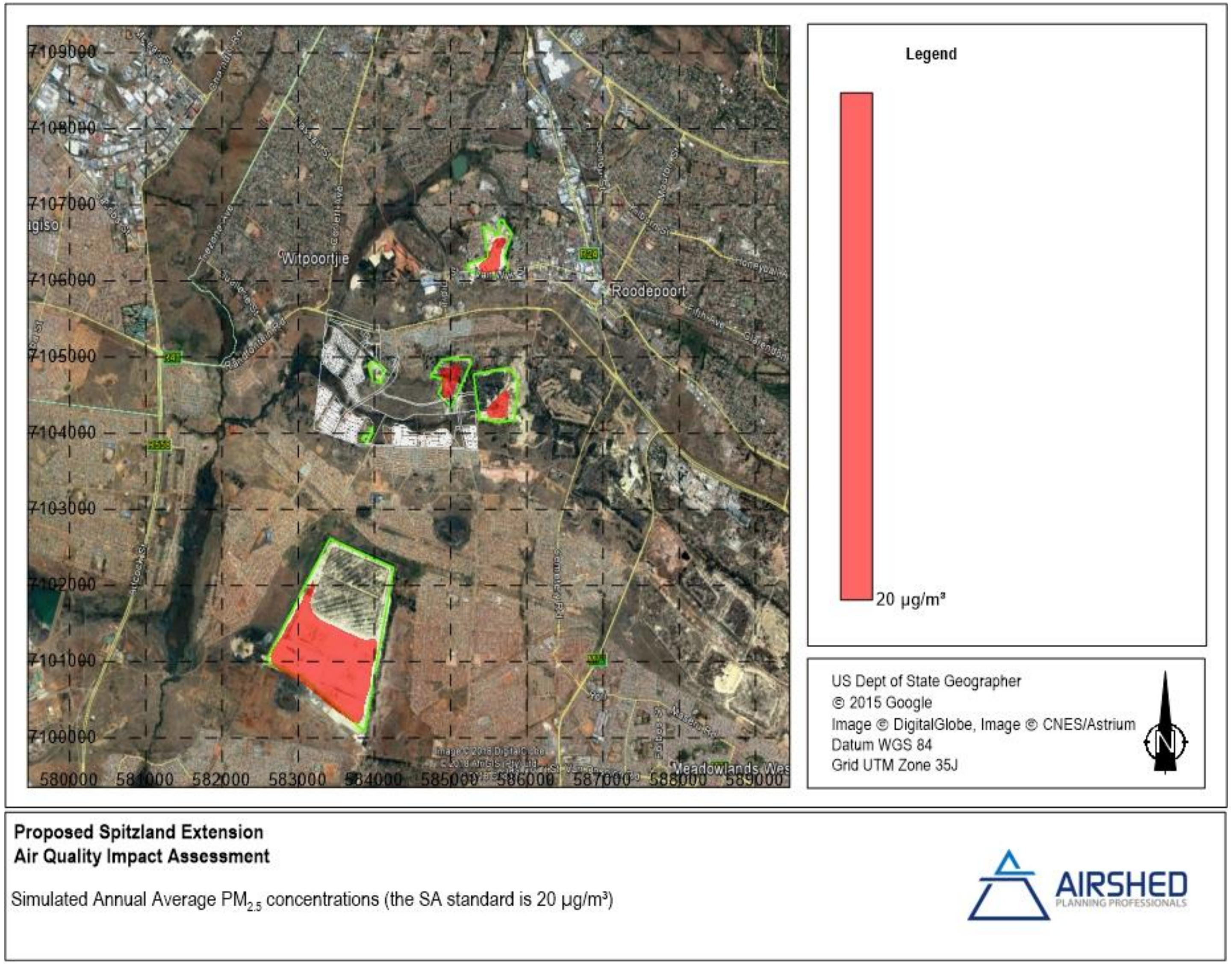

Figure 15: Simulated annual average $PM_{2.5}$ ground level concentration – (scenario 1)

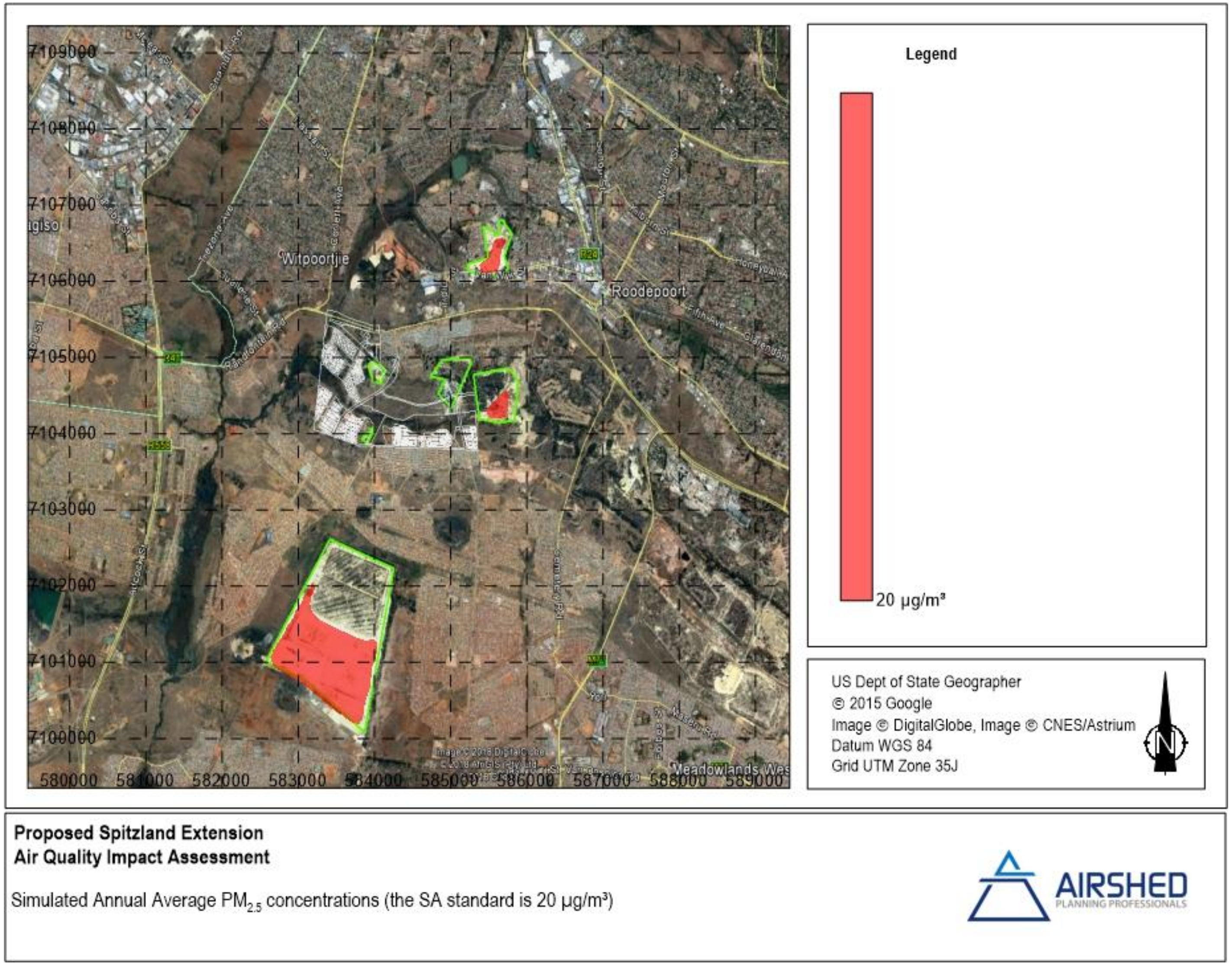

Figure 16: Simulated annual average $PM_{2.5}$ ground level concentration – (scenario 2)

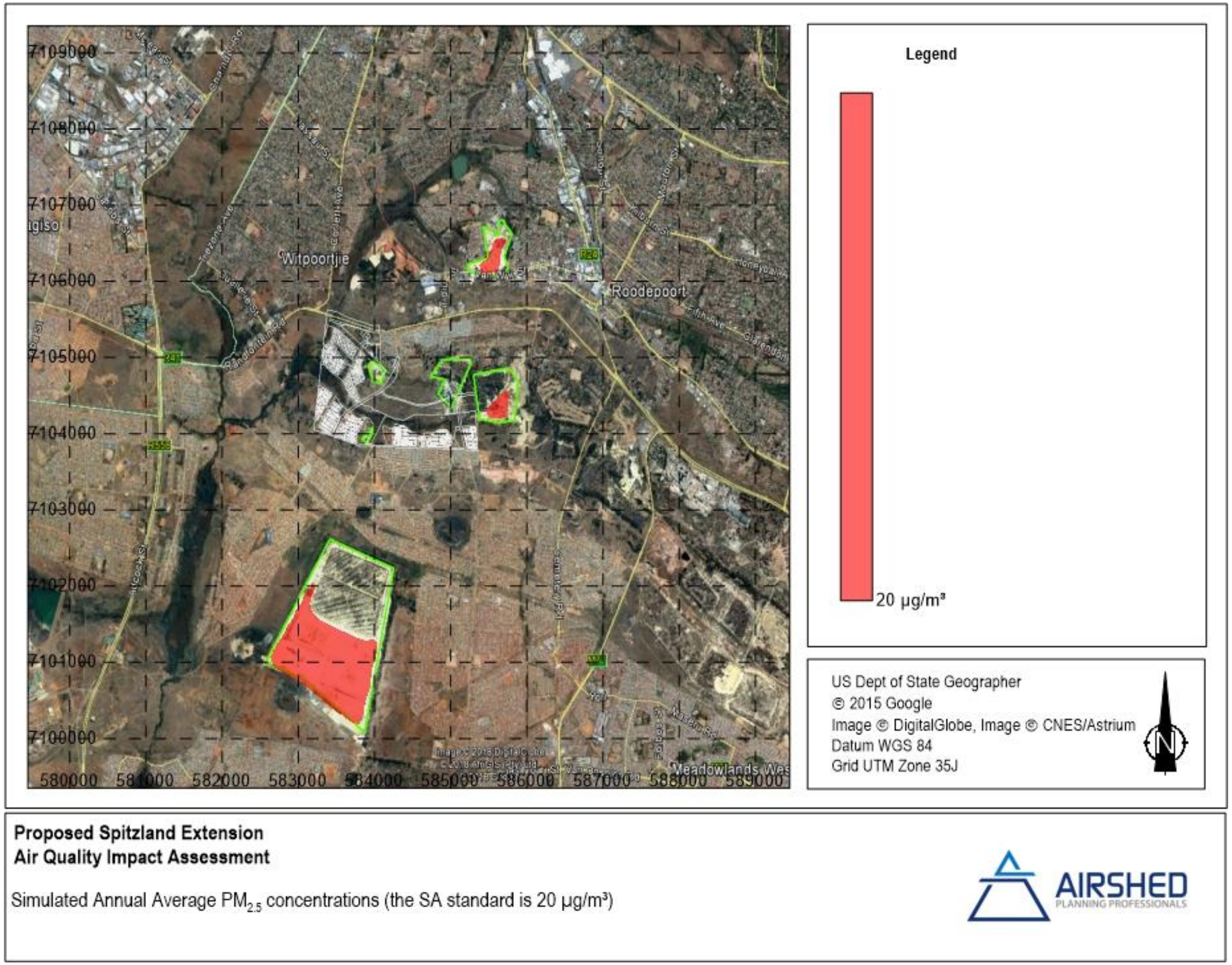

Figure 17: Simulated annual average $PM_{2.5}$ ground level concentration – (scenario 3)

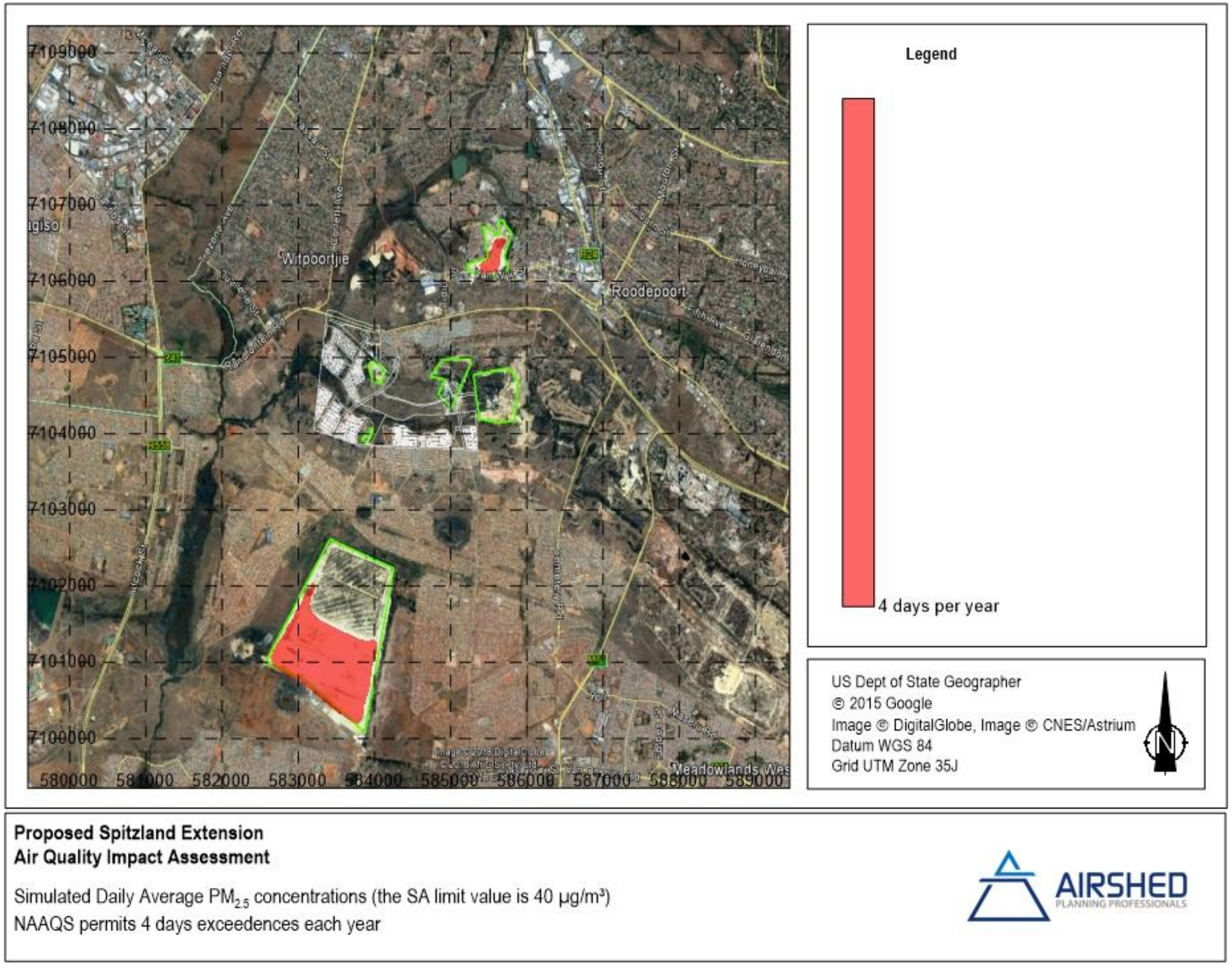

Figure 18: Simulated annual average $PM_{2.5}$ ground level concentration – (scenario M1)

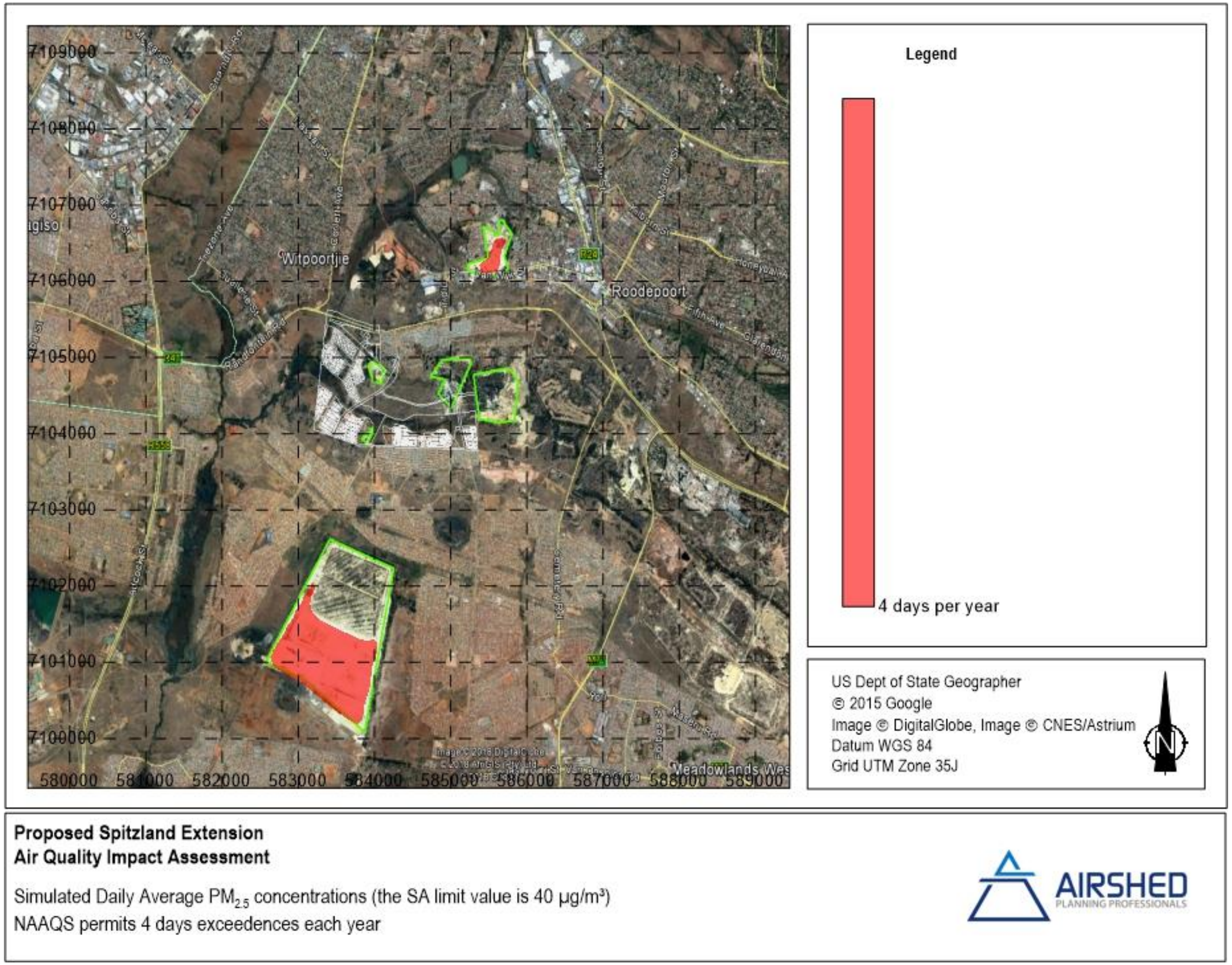

Figure 19: Simulated annual average $PM_{2.5}$ ground level concentration – (scenario M2)

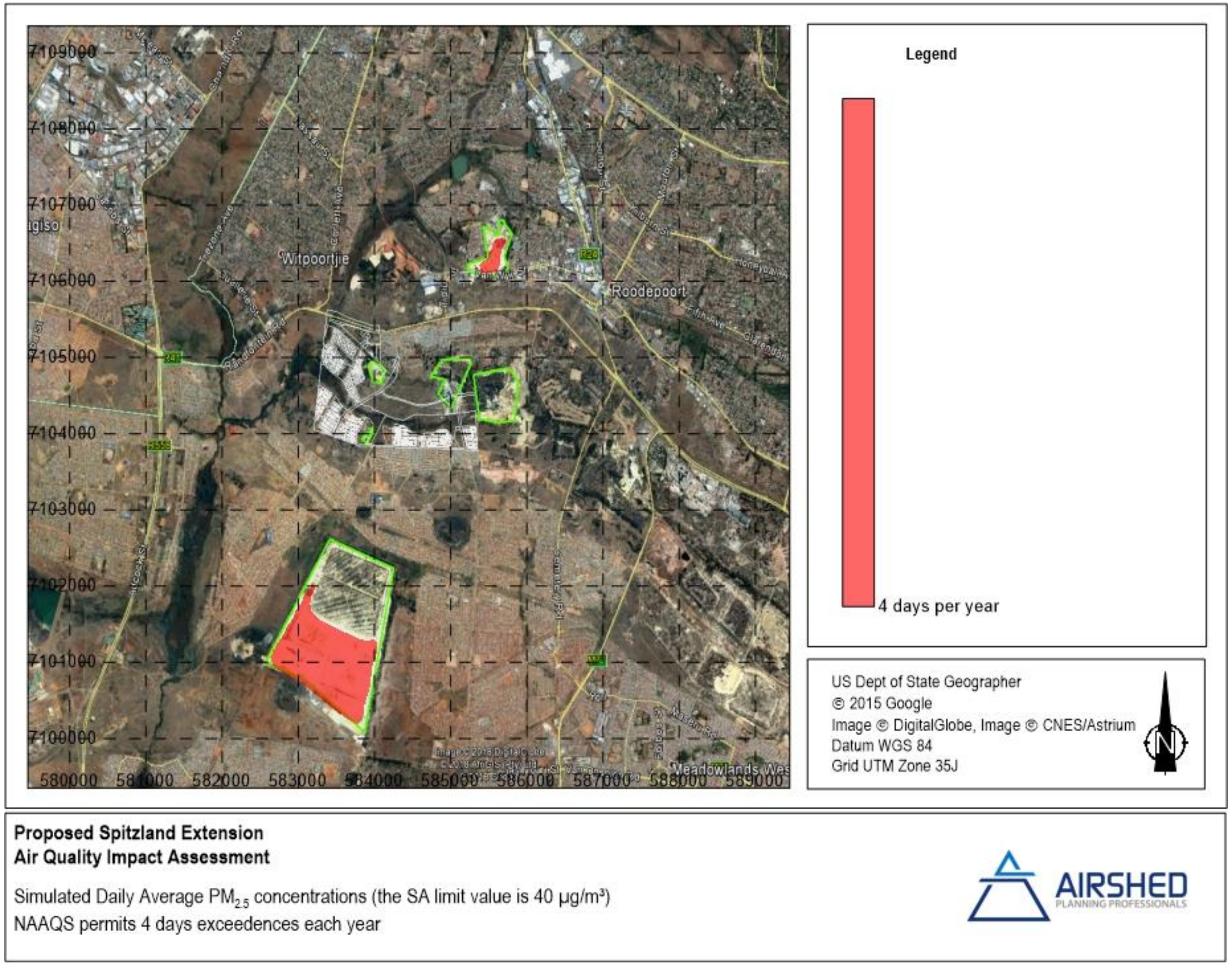

Figure 20: Simulated annual average $PM_{2.5}$ ground level concentration – (scenario M3)

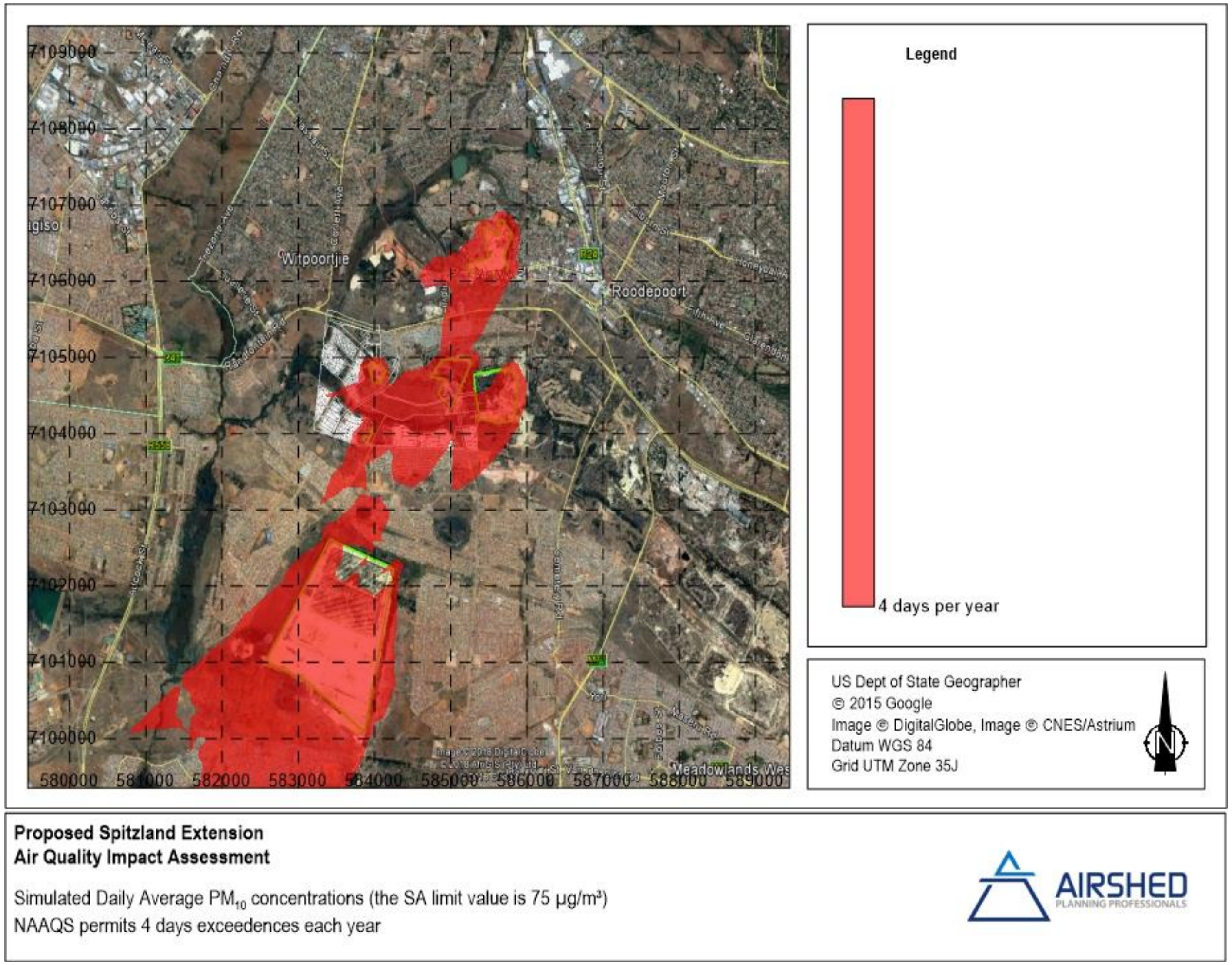

Figure 21: Simulated frequencies of exceedance of ambient daily PM_{10} NAAQS – (scenario 1)

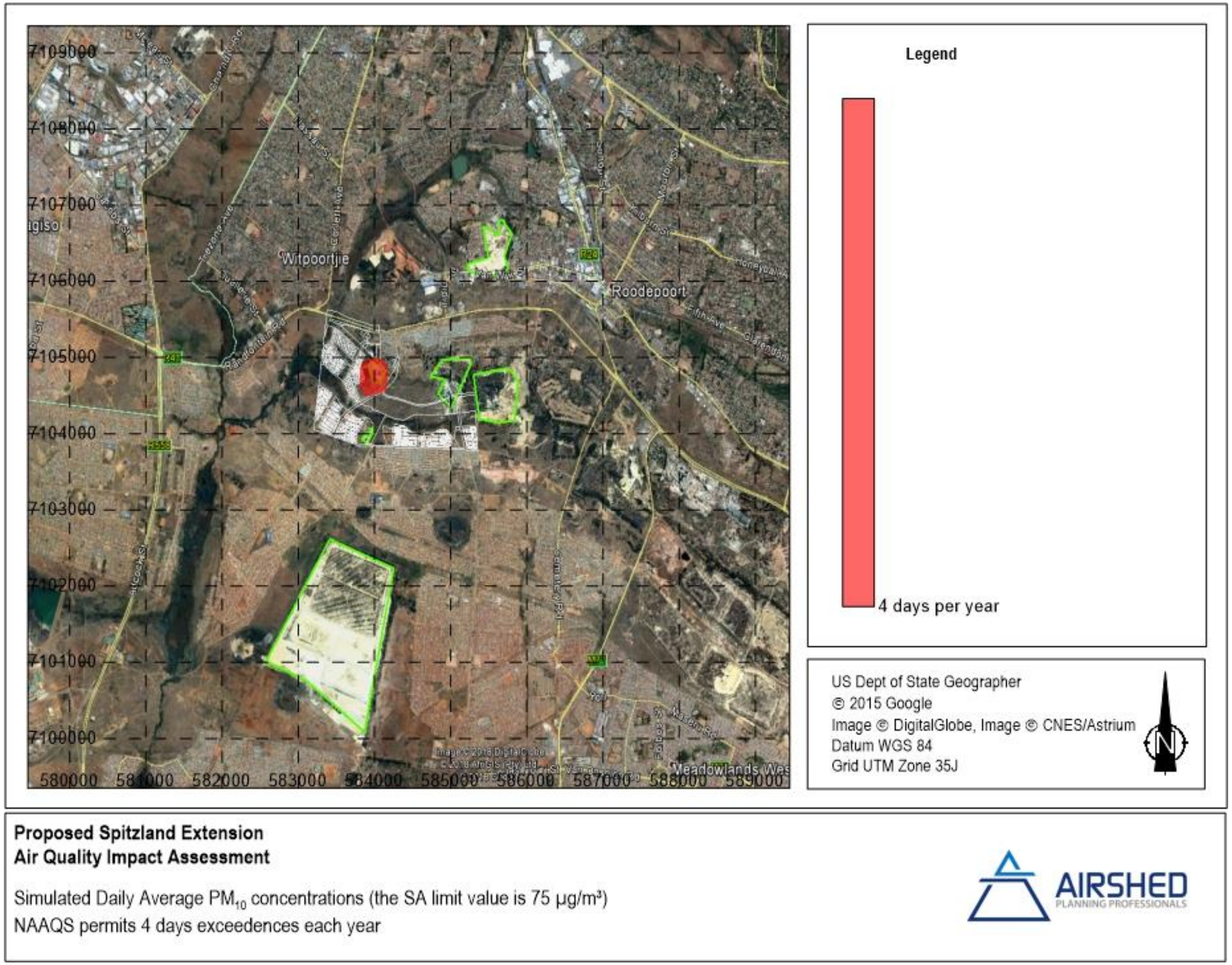

Figure 22: Simulated frequencies of exceedance of ambient daily PM_{10} NAAQS – (scenario 1 – TSF1 only)

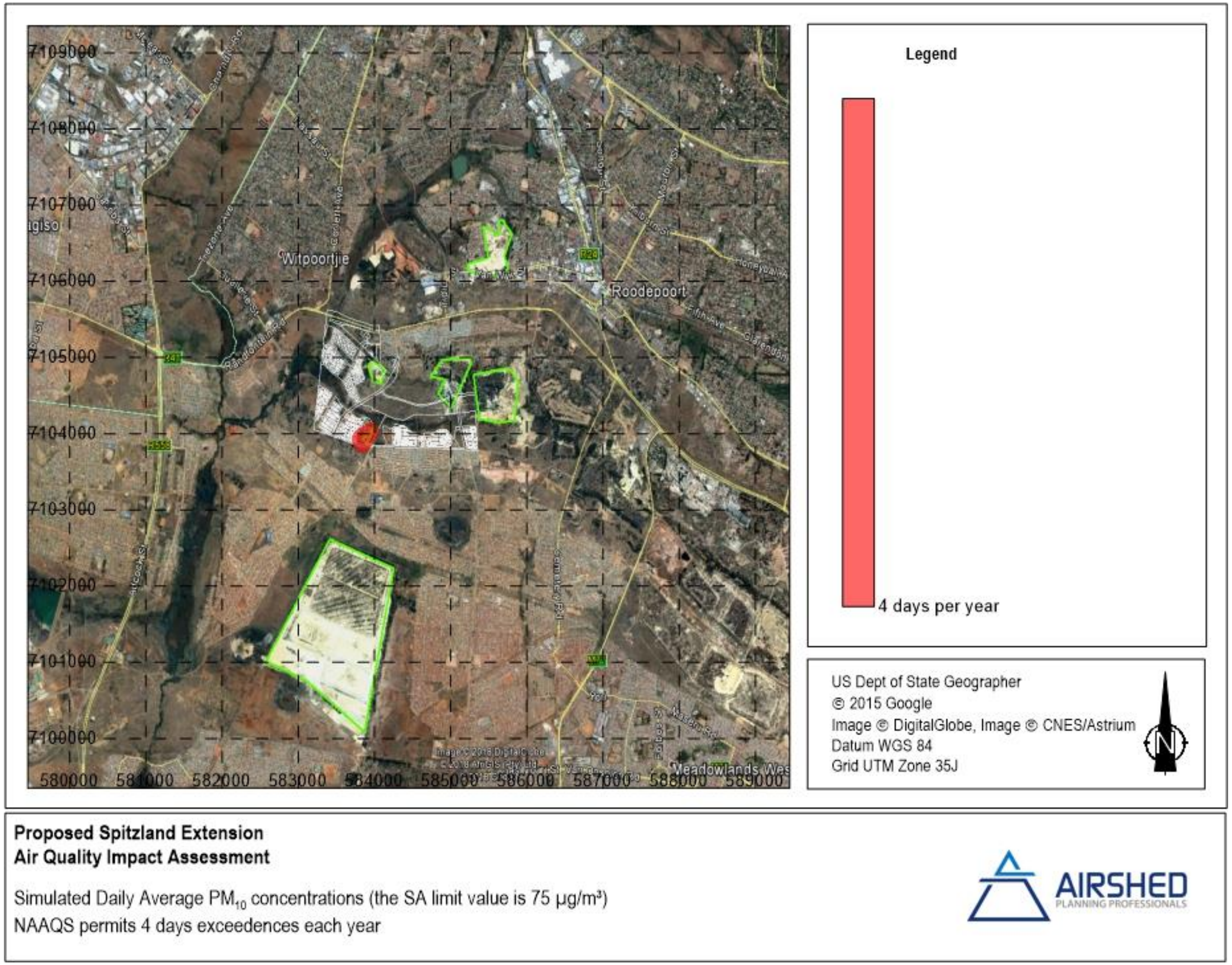

Figure 23: Simulated frequencies of exceedance of ambient daily PM_{10} NAAQS – (scenario 1 – TSF2 only)

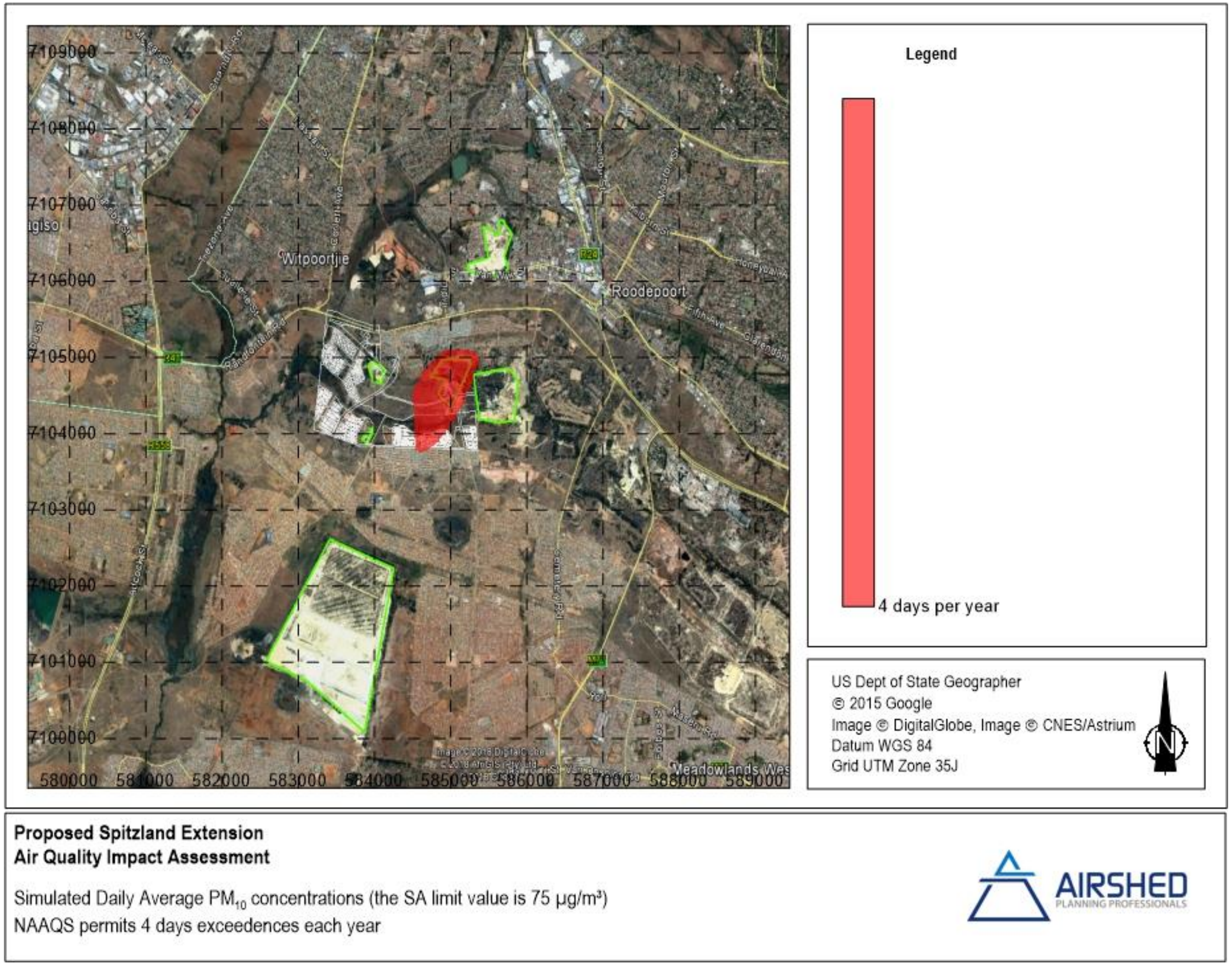

Figure 24: Simulated frequencies of exceedance of ambient daily PM_{10} NAAQS – (scenario 1 – TSF3 only)

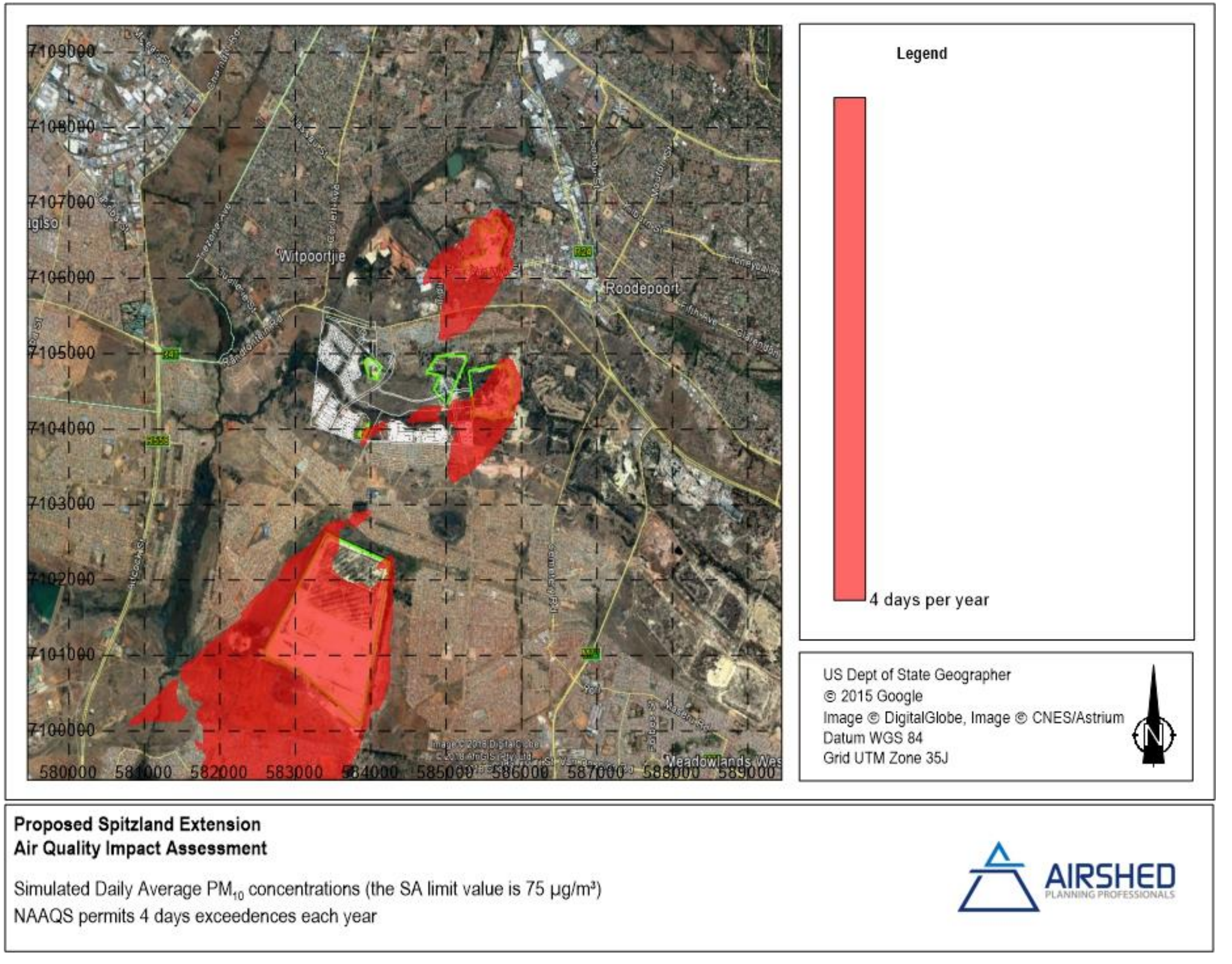

Figure 25: Simulated frequencies of exceedance of ambient daily PM_{10} NAAQS – (scenario 2)

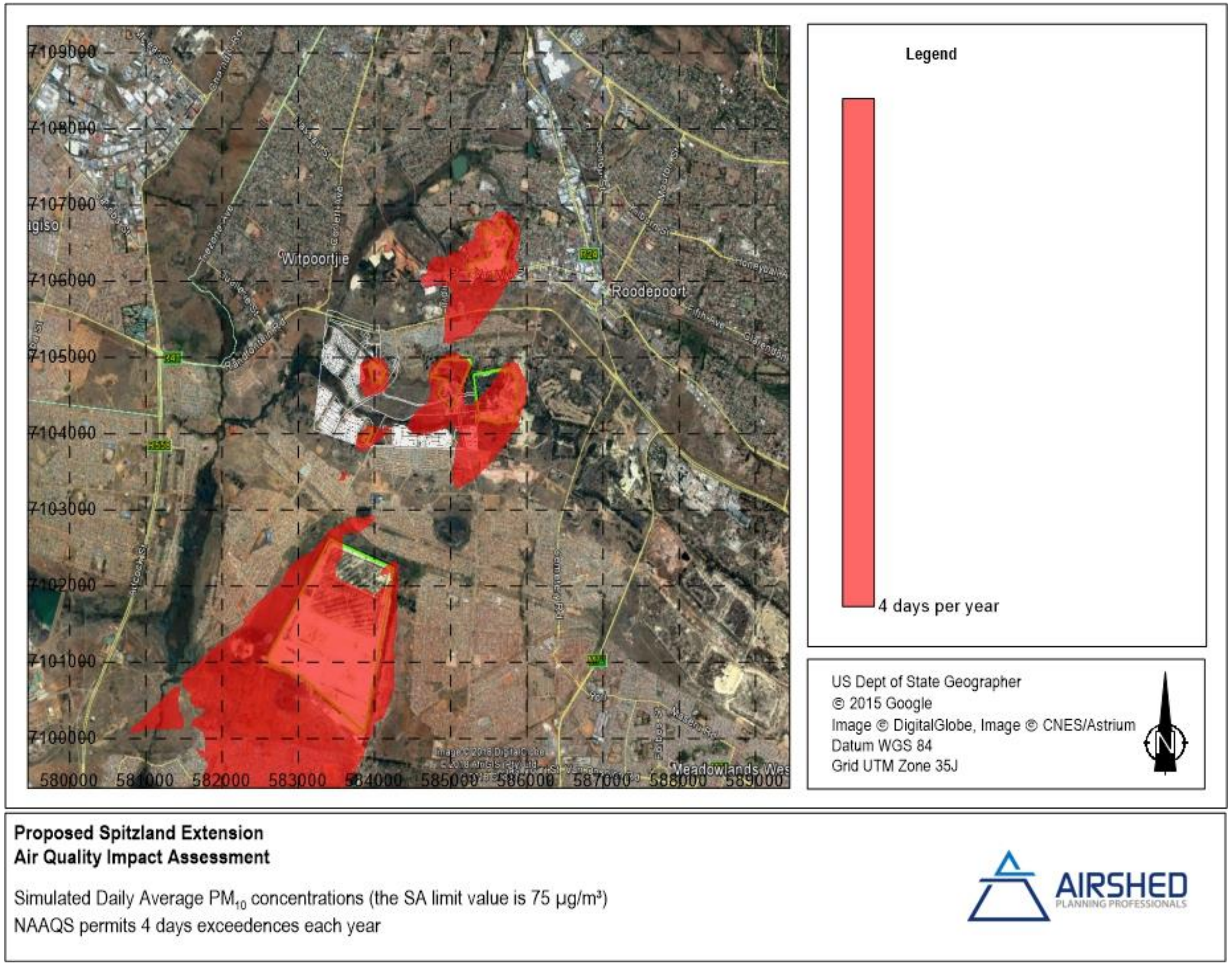

Figure 26: Simulated frequencies of exceedance of ambient daily PM_{10} NAAQS – (scenario 3)

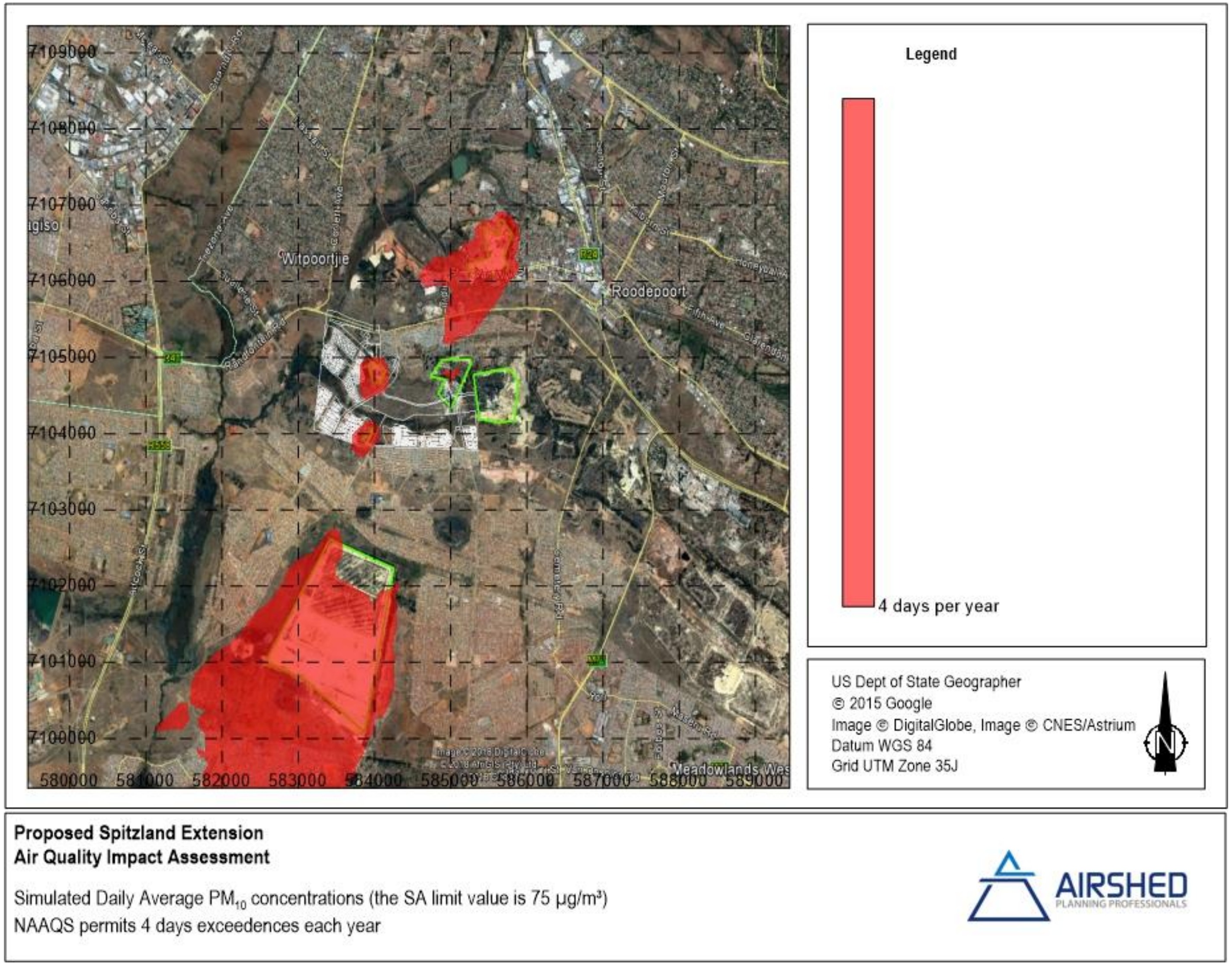

Figure 27: Simulated frequencies of exceedance of ambient daily PM_{10} NAAQS – (scenario M1)

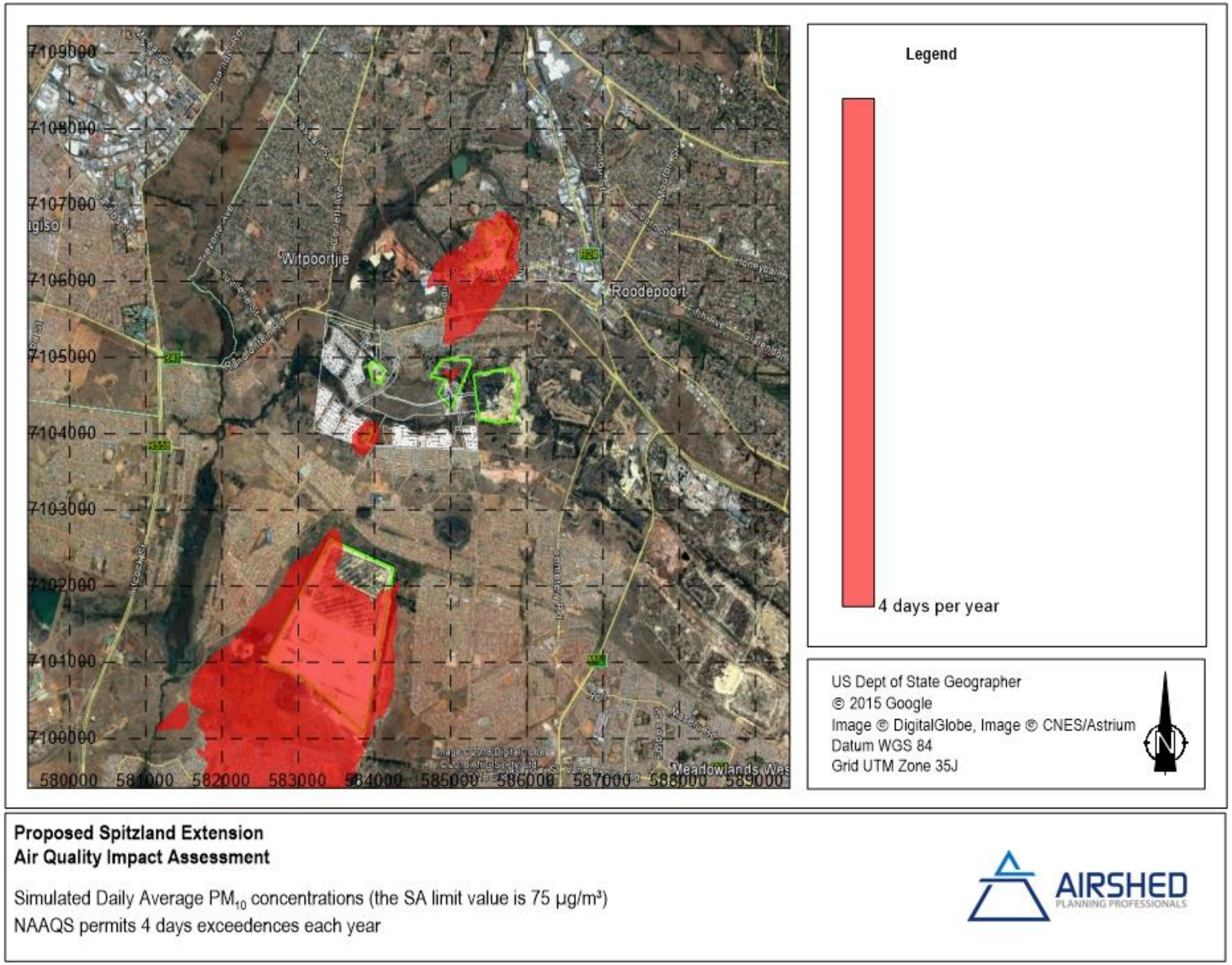

Figure 28: Simulated frequencies of exceedance of ambient daily PM_{10} NAAQS – (scenario M2)

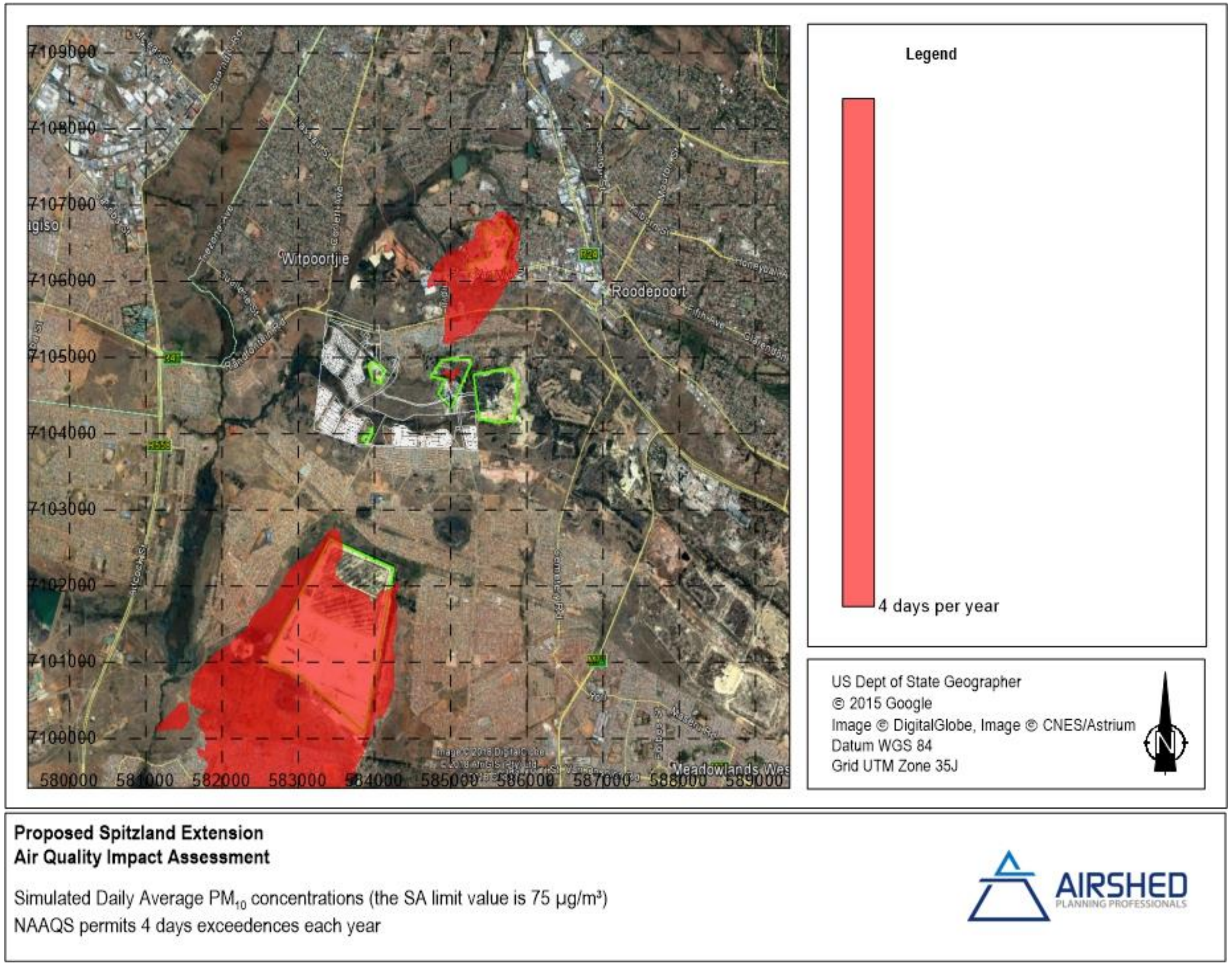

Figure 29: Simulated frequencies of exceedance of ambient daily PM_{10} NAAQS – (scenario M3)

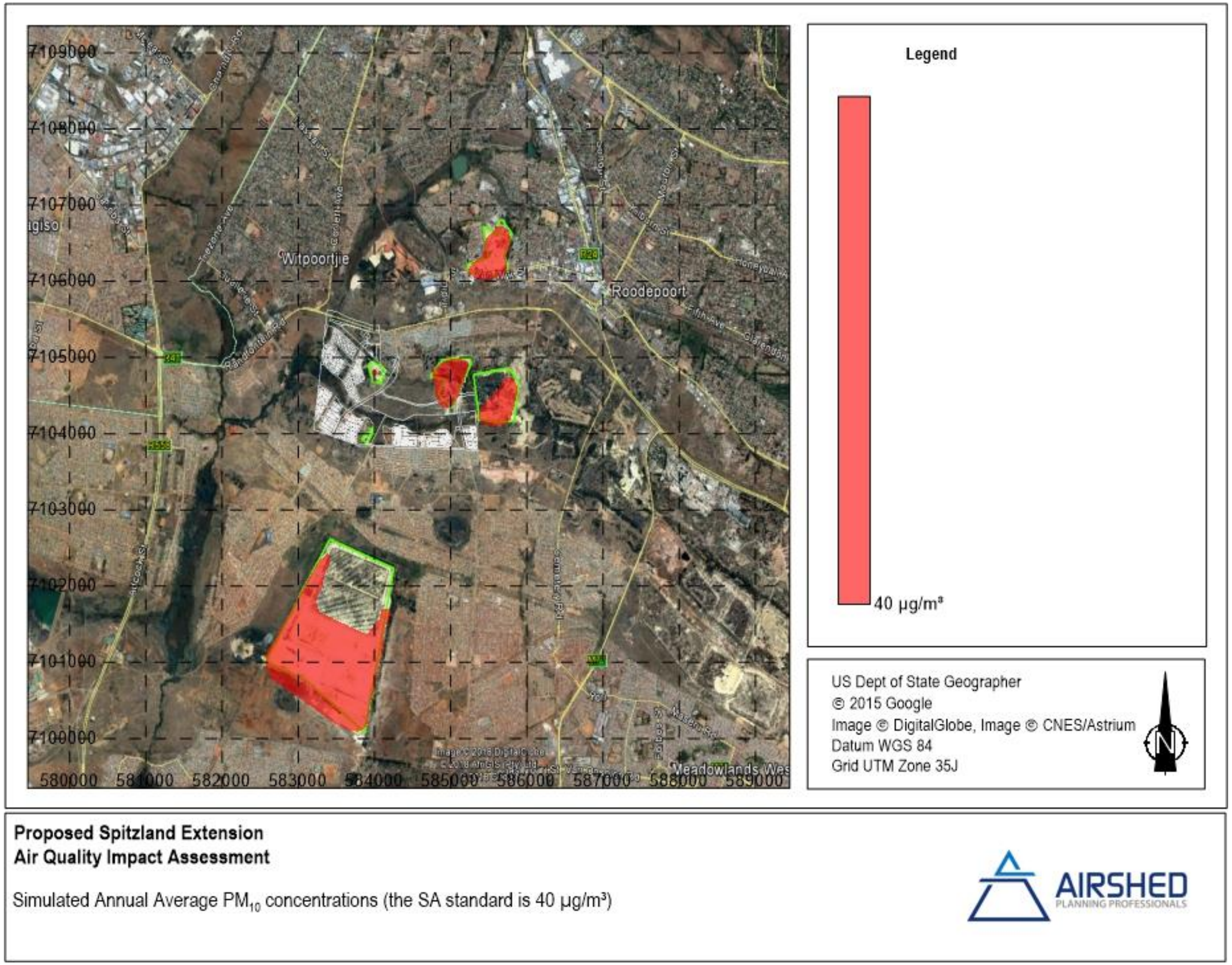

Figure 30: Simulated annual average PM_{10} ground level concentration – (scenario 1)

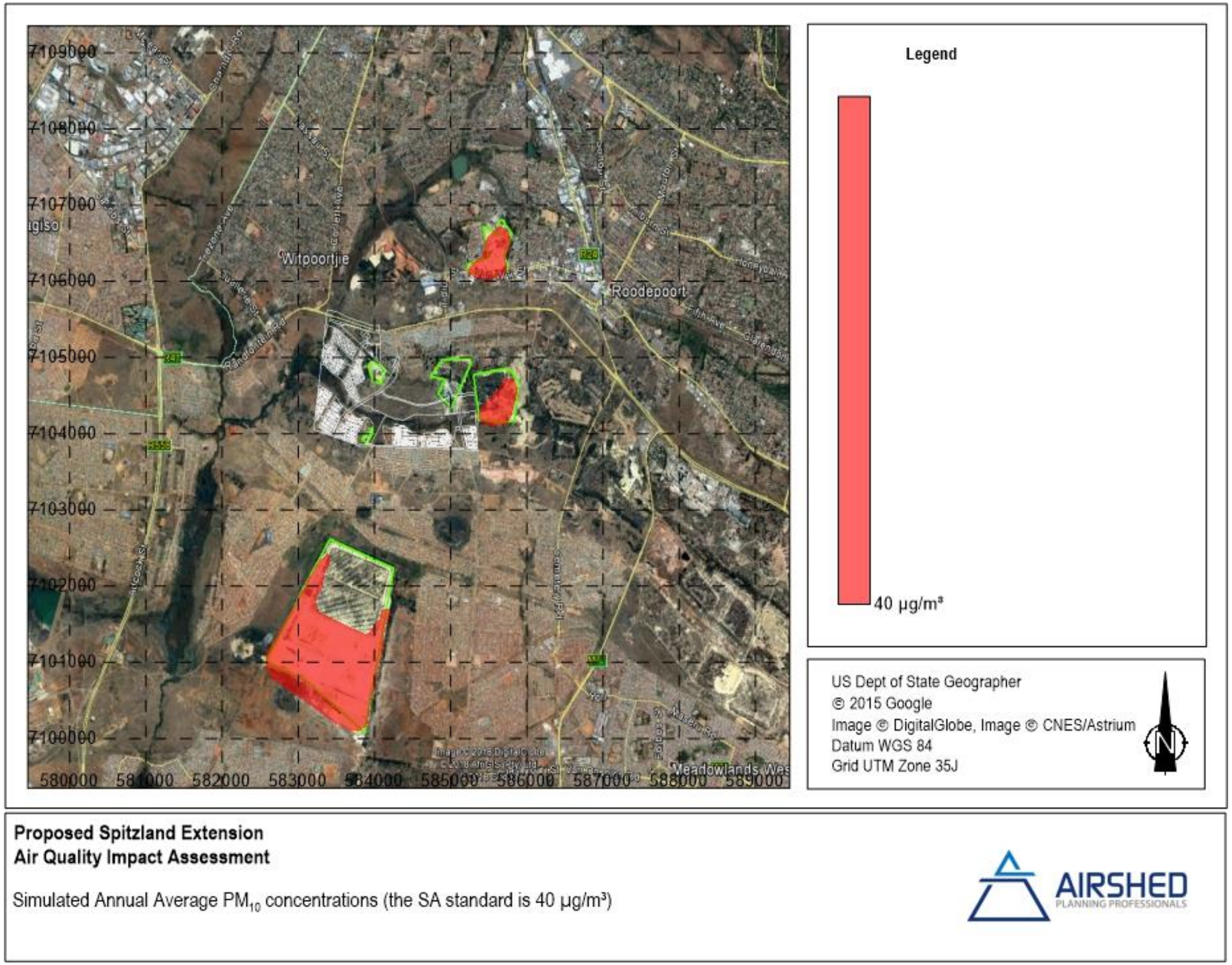

Figure 31: Simulated annual average PM_{10} ground level concentration – (scenario 2)

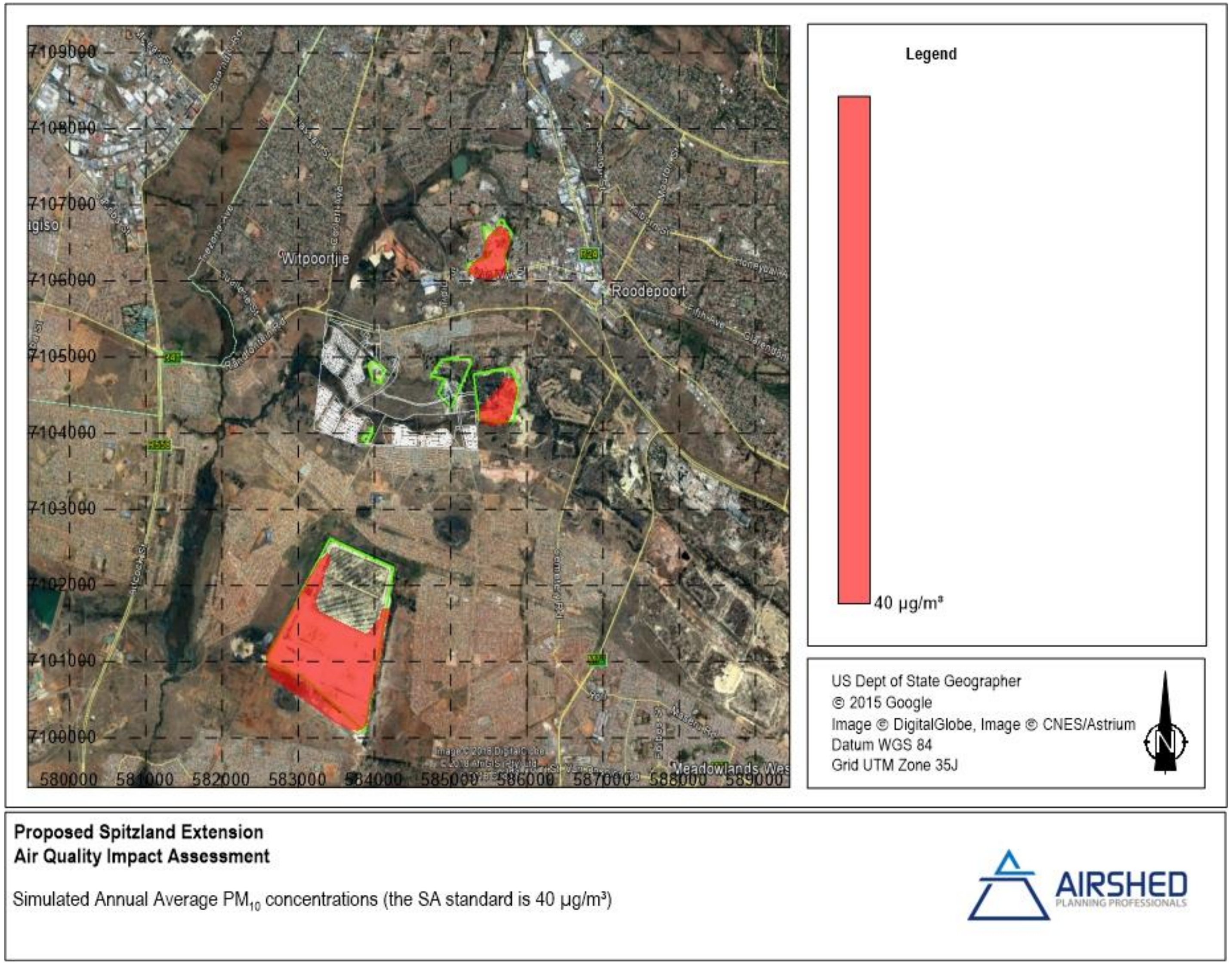

Figure 32: Simulated annual average PM_{10} ground level concentration – (scenario 3)

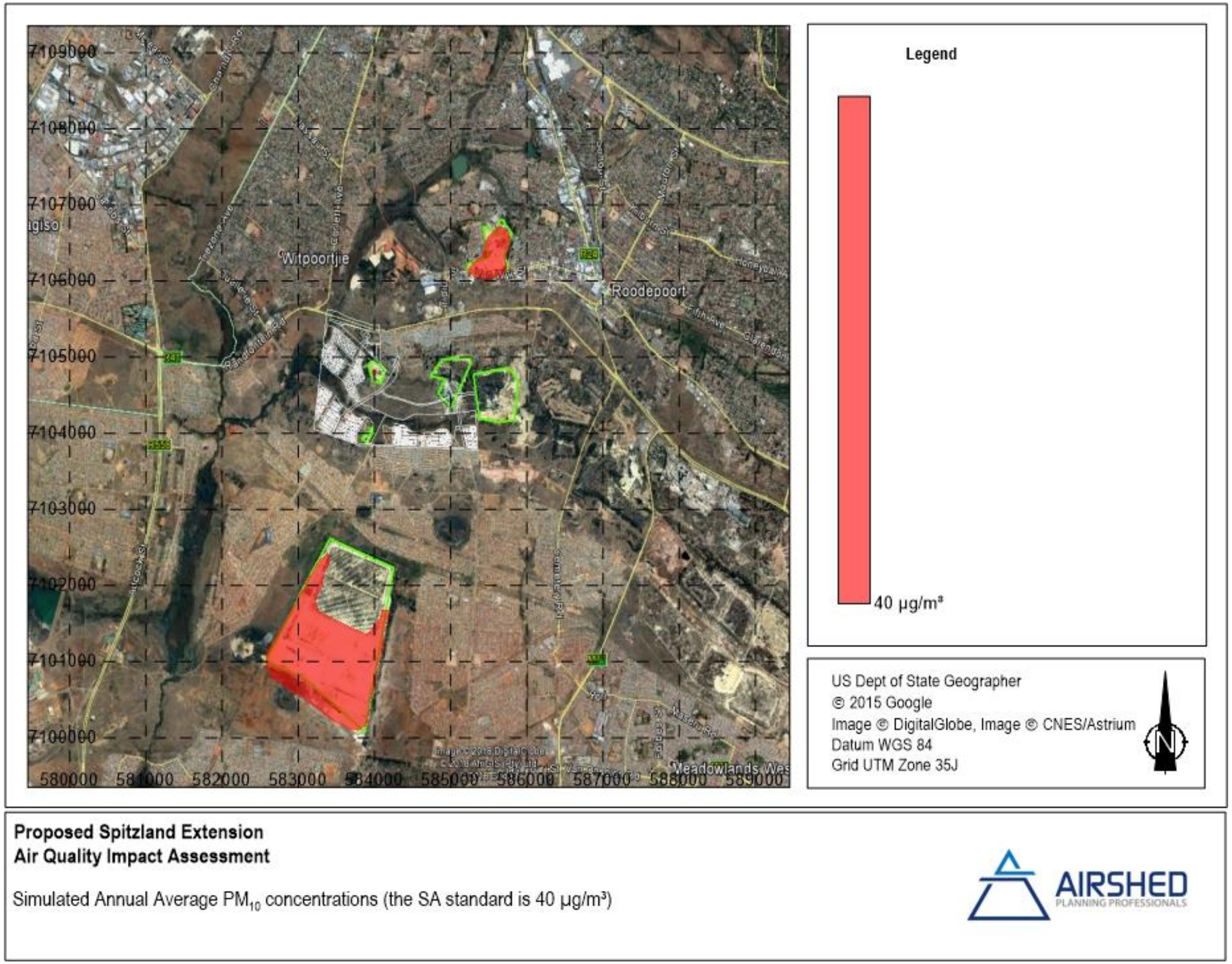

Figure 33: Simulated annual average PM_{10} ground level concentration – (scenario M1)

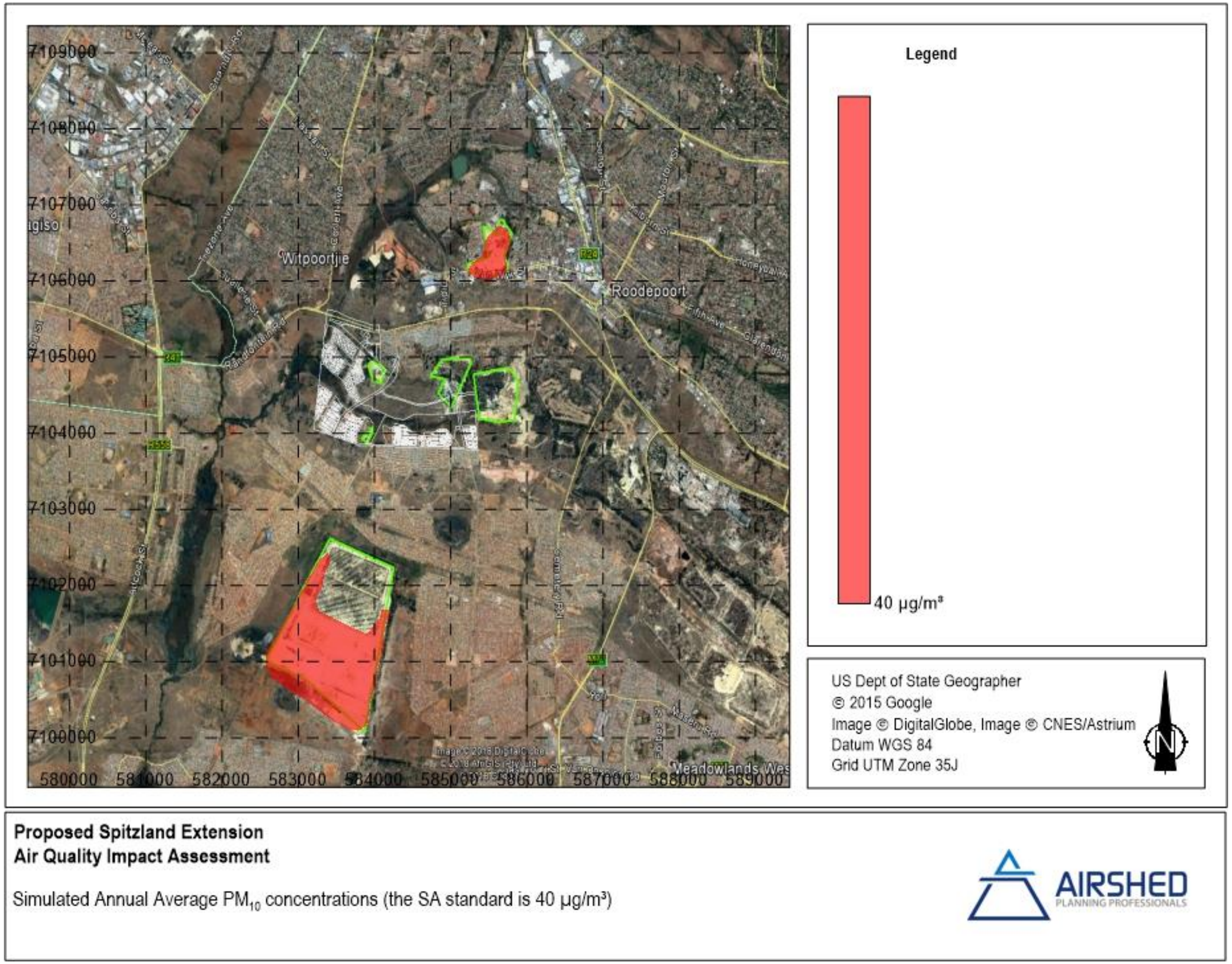

Figure 34: Simulated annual average PM_{10} ground level concentration – (scenario M2)

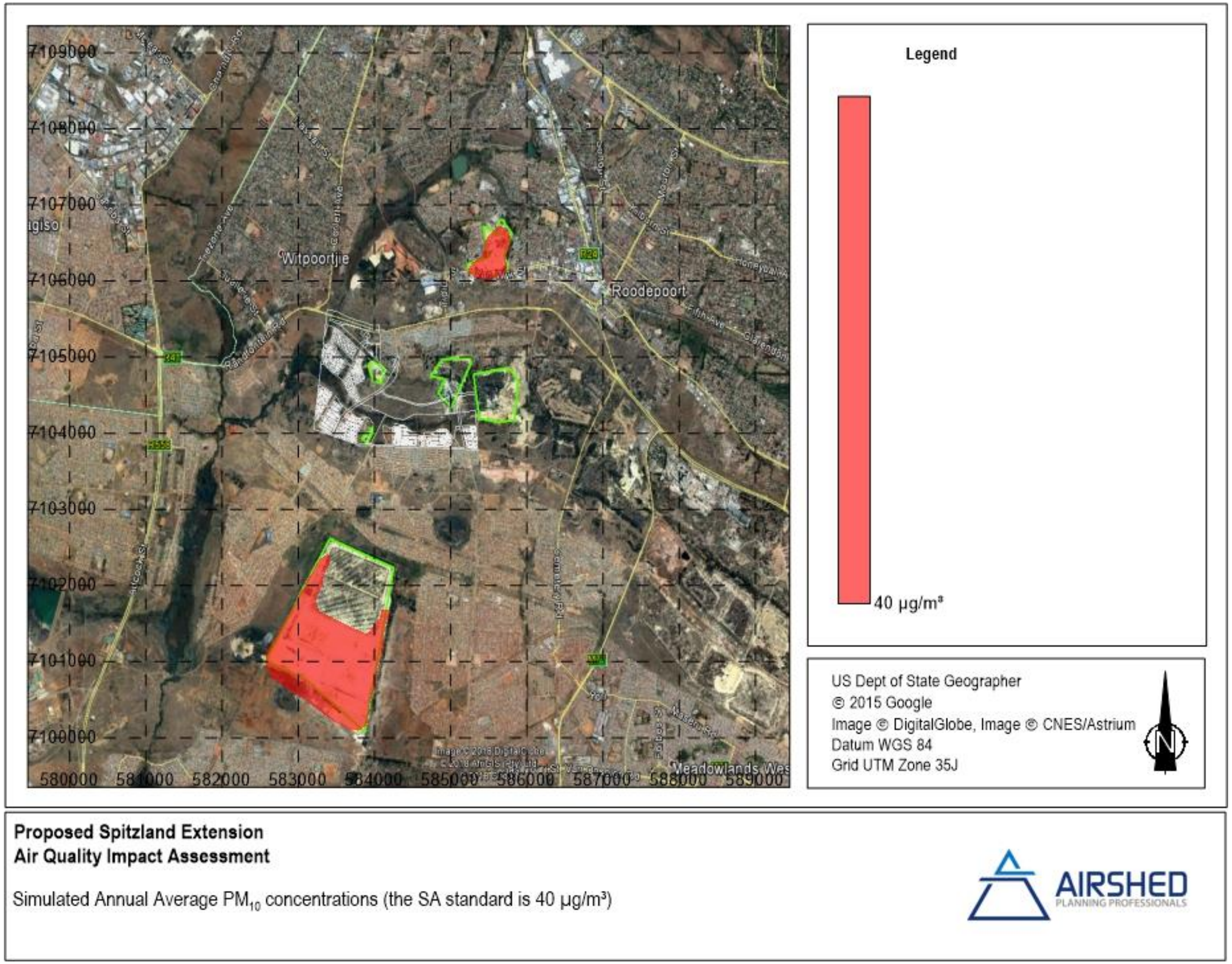

Figure 35: Simulated annual average PM_{10} ground level concentration – (scenario M3)

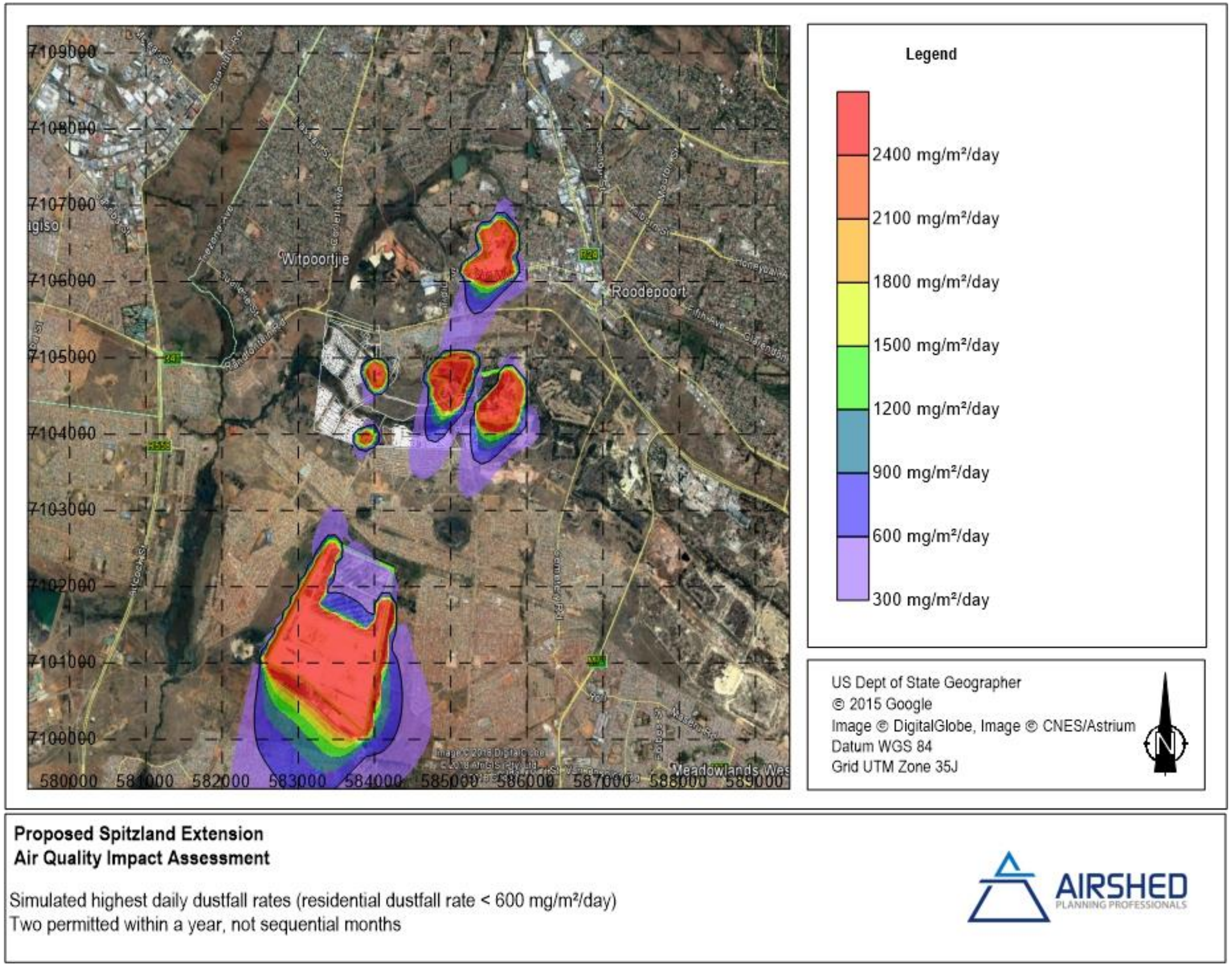

Figure 36: Simulated dustfall deposition rates – (scenario 1)

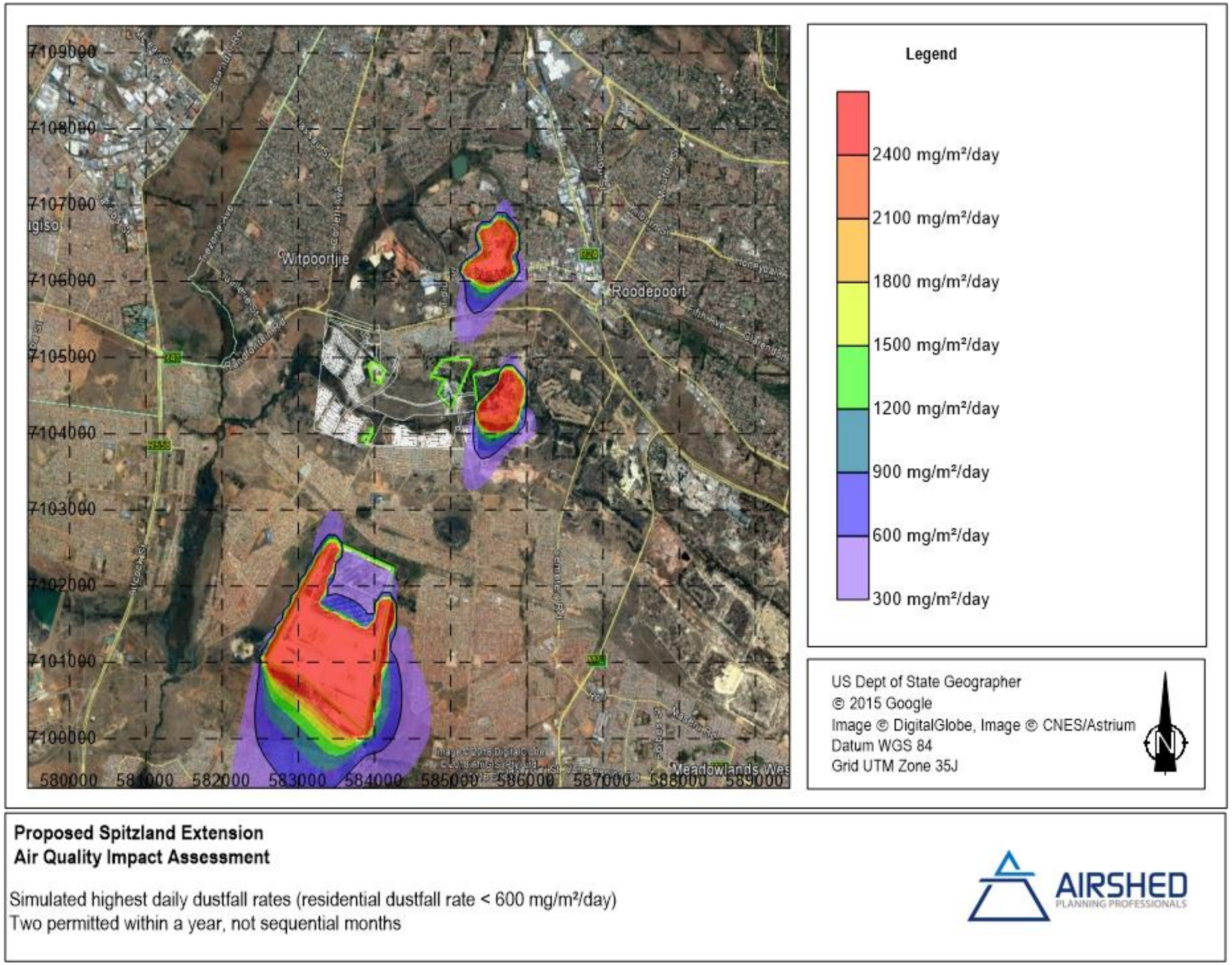

Figure 37: Simulated dustfall deposition rates – (scenario 2)

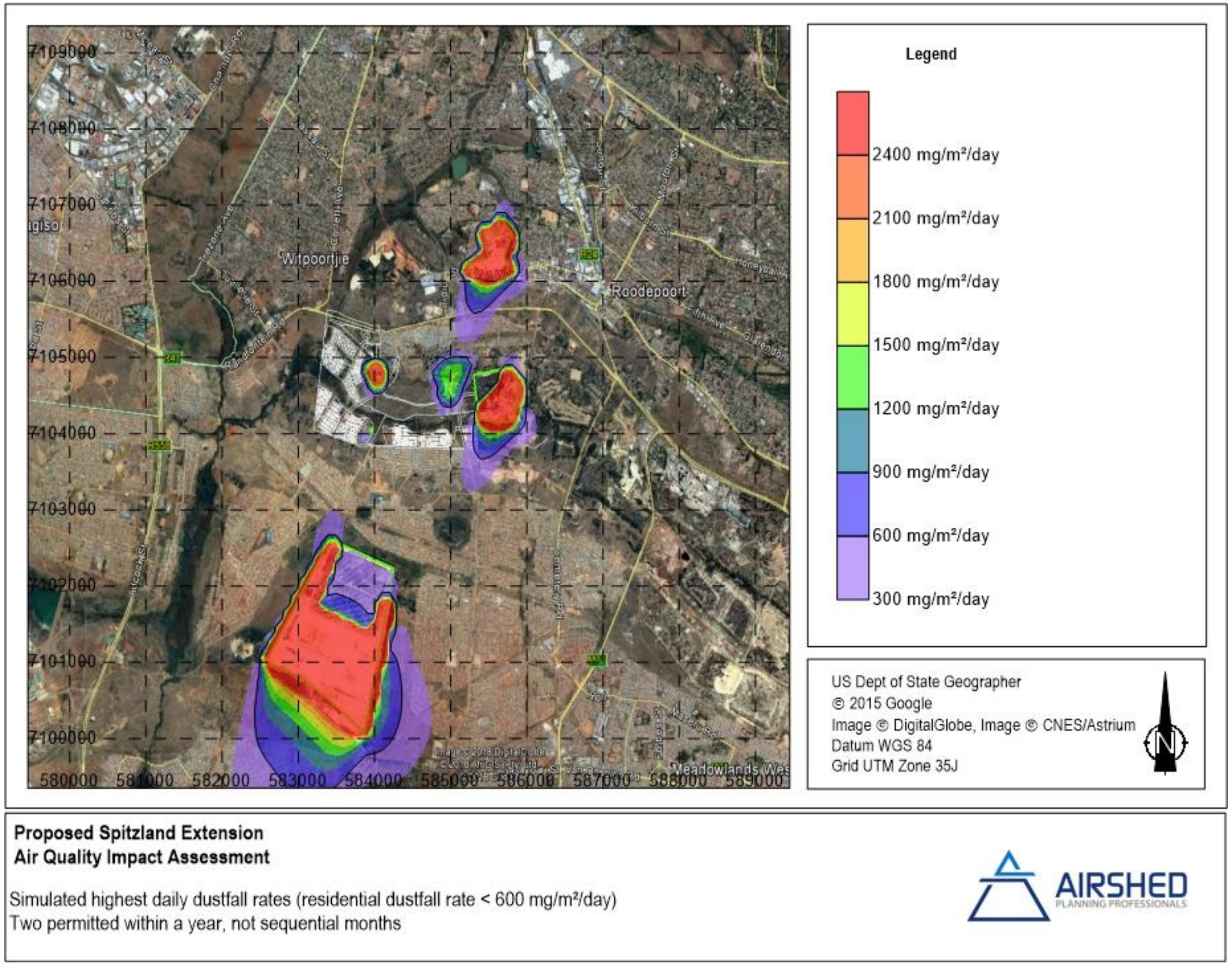

Figure 38: Simulated dustfall deposition rates – (scenario 3)

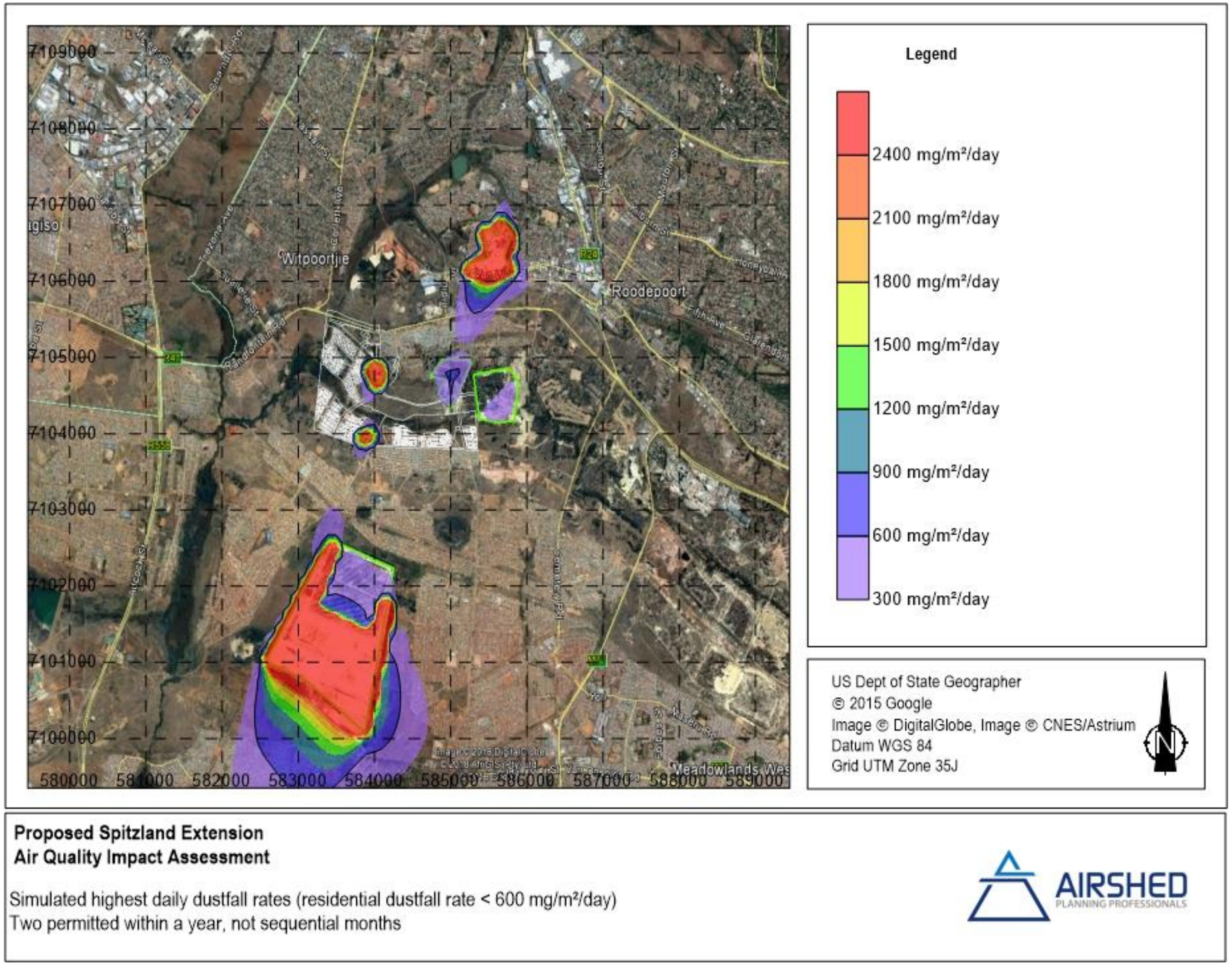

Figure 39: Simulated dustfall deposition rates – (scenario M1)

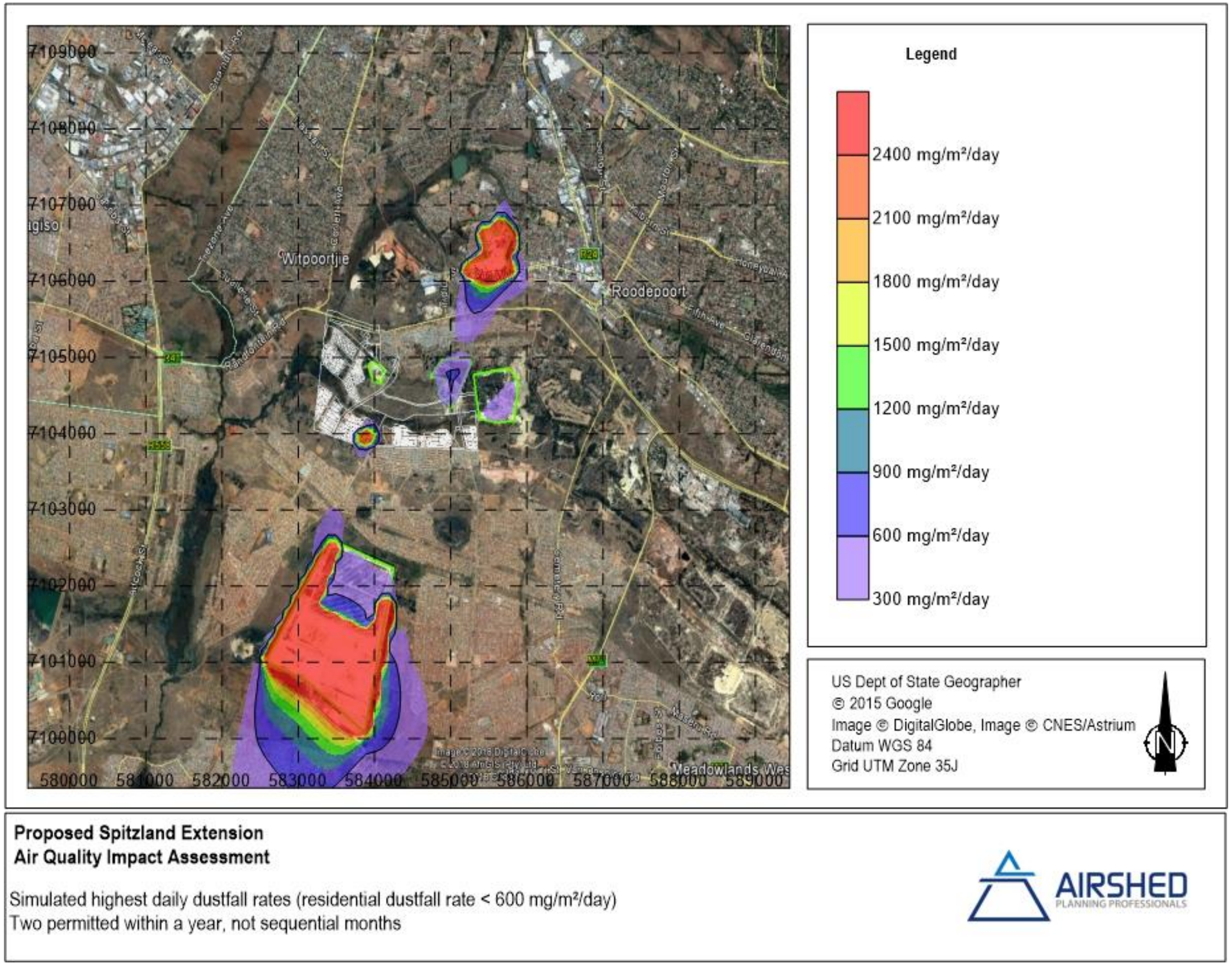

Figure 40: Simulated dustfall deposition rates – (scenario M2)

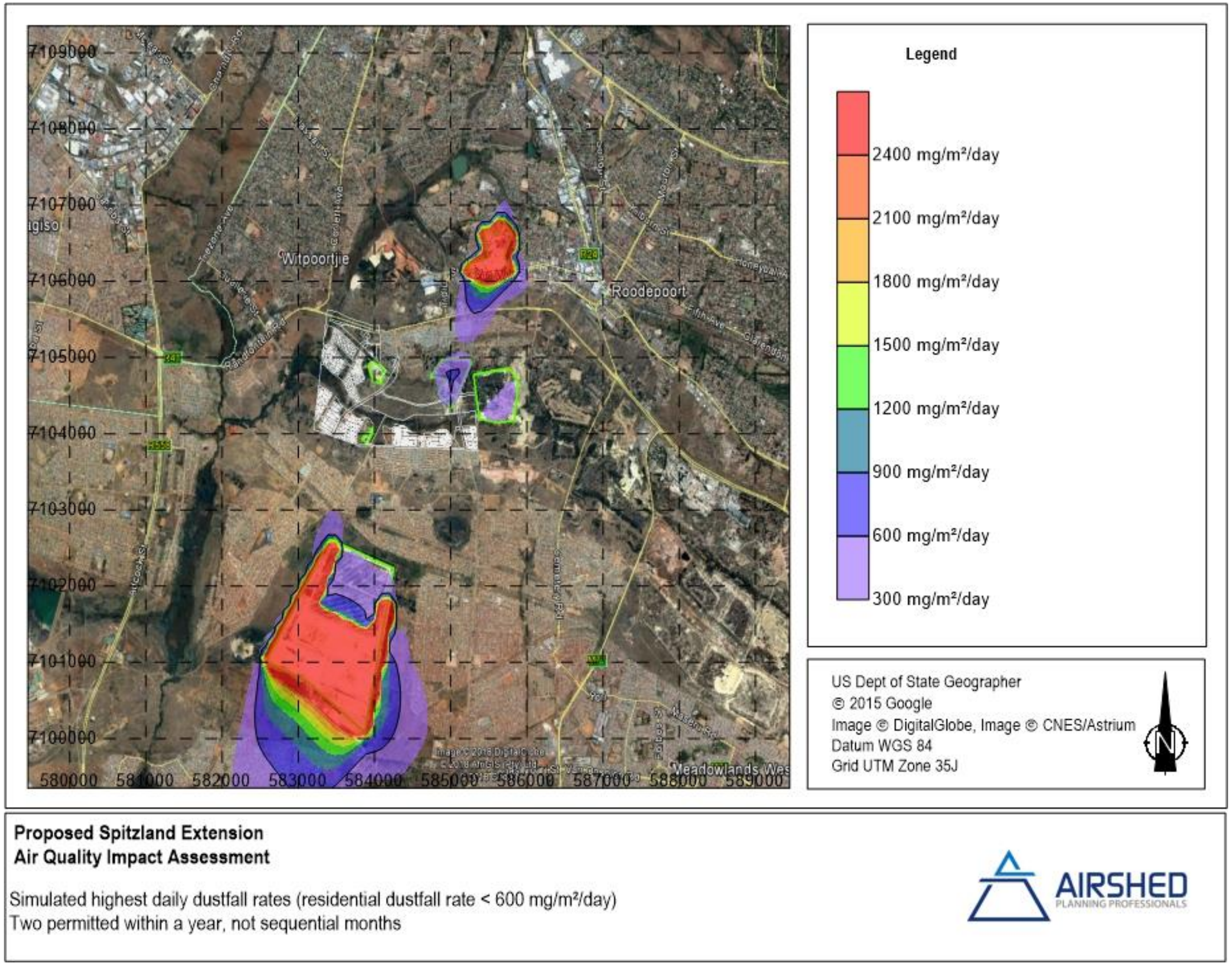

Figure 41: Simulated dustfall deposition rates – (scenario M3)

4.4 Impact Significance Rating

EIA Regulations require that impacts be assessed in terms of the intensity, duration, severity and probability of impacts; as well as the degree to which these impacts can be managed or mitigated.

The impact significance rating for potential impacts due to the TSFs are presented in Table 9 (for TSF 1, 2 and 3 only), Table 10 considering all the TSFs included in the scope (TSF 1 to 6) and in Table 11 considering all the TSFs included in the scope (TSF 1 to 6) with additional mitigation on TSF 3 and TSF 4. All potential impacts (health impacts due to $PM_{2.5}$, PM_{10}; nuisance effects due to dustfall) were assigned impact rating scores equivalent to "**medium"** impact significance. Considering TSF 1, 2 and 3 only, scenario 2 was assigned a low significance rating. With additional mitigation on TSF 3 and 4, potential impacts were assigned impact rating scores equivalent to "**low"** impact significance.

Table 9: Impact significance rating table for TSF 1,2 and 3 only – assuming no mitigation

Source	IMPACT DESCRIPTION		RATING			
	Impact	Associated activities	Extent	Duration	Probability rating	Significance rating
Impacts due to TSFs 1, 2 and 3 – scenario 1	Health impacts due to daily $PM_{2.5}$ emissions	Windblown dust	Medium	Medium	High	Medium
	Health impacts due to daily PM_{10} emissions		Medium	Medium	High	Medium
	Nuisance effects due to dustfall deposition		Medium	Medium	High	Medium
Impacts due to TSFs 1, 2 and 3 – scenario 2	Health impacts due to daily $PM_{2.5}$ emissions	Windblown dust	Low	Low	Low	Low
	Health impacts due to daily PM_{10} emissions		Low	Low	Low	Low
	Nuisance effects due to dustfall deposition		Low	Low	Low	Low
Impacts due to TSFs 1, 2 and 3 – scenario 3	Health impacts due to daily $PM_{2.5}$ emissions	Windblown dust	Low	Medium	High	Medium
	Health impacts due to daily PM_{10} emissions		Low	Medium	High	Medium
	Nuisance effects due to dustfall deposition		Low	Medium	High	Medium

Table 10: Impact significance rating table for all 6 TSFs – assuming no mitigation

Source	IMPACT DESCRIPTION		RATING			
	Impact	Associated activities	Extent	Duration	Probability rating	Significance rating
Impacts due to TSFs – scenario 1	Health impacts due to daily $PM_{2.5}$ emissions	Windblown dust	Medium	Medium	High	Medium
	Health impacts due to daily PM_{10} emissions		Medium	Medium	High	Medium
	Nuisance effects due to dustfall deposition		Medium	Medium	High	Medium

Source	IMPACT DESCRIPTION		RATING			
	Impact	Associated activities	Extent	Duration	Probability rating	Significance rating
Impacts due to TSFs – scenario 2	Health impacts due to daily $PM_{2.5}$ emissions	Windblown dust	Medium	Medium	High	Medium
	Health impacts due to daily PM_{10} emissions		Medium	Medium	High	Medium
	Nuisance effects due to dustfall deposition		Medium	Medium	High	Medium
Impacts due to TSFs – scenario 3	Health impacts due to daily $PM_{2.5}$ emissions	Windblown dust	Medium	Medium	High	Medium
	Health impacts due to daily PM_{10} emissions		Medium	Medium	High	Medium
	Nuisance effects due to dustfall deposition		Medium	Medium	High	Medium

Table 11: Impact significance rating table for all 6 TSFs – assuming no mitigation

Source	IMPACT DESCRIPTION		RATING			
	Impact	Associated activities	Extent	Duration	Probability rating	Significance rating
Impacts due to TSFs – scenario M1	Health impacts due to daily $PM_{2.5}$ emissions	Windblown dust	Medium	Medium	High	Medium
	Health impacts due to daily PM_{10} emissions		Medium	Medium	High	Medium
	Nuisance effects due to dustfall deposition		Medium	Medium	High	Medium
Impacts due to TSFs – scenario M2	Health impacts due to daily $PM_{2.5}$ emissions	Windblown dust	Medium	Medium	High	Medium
	Health impacts due to daily PM_{10} emissions		Medium	Medium	High	Medium
	Nuisance effects due to dustfall deposition		Medium	Medium	High	Medium
Impacts due to TSFs – scenario M3	Health impacts due to daily $PM_{2.5}$ emissions	Windblown dust	Low	Medium	Low	Low
	Health impacts due to daily PM_{10} emissions		Low	Medium	Low	Low
	Nuisance effects due to dustfall deposition		Low	Medium	Low	Low

It is probable that the TSFs will have an impact. The duration will last for the lifespan of the TSFs. Mitigation would reduce the extent of the impact to low (within site boundary of the TSF). If the mitigation of the TSFs 3 and 3 was implemented and the TSFs were removed (1 and 2), the significance rating could be reduced to low.

5 Conclusions and Recommendation

An air quality impact assessment was conducted for the impact of the TSFs on the proposed development.

5.1 Main Findings

The main findings of the assessment are summarised below:

- The receiving environment:
  - The proposed development area is dominated by winds from the northerly sector. An average wind speed of 4.1 m/s was extracted for the site from the WRF data set with wind speeds exceeding 6.7 m/s (the threshold wind speed likely to result in dust emissions from gold TSFs) 12.5% of the time.
  - Surrounding areas where ambient air quality data is available show PM_{10} concentrations exceeding the NAAQS. Simulated PM_{10} concentrations from the CoJ AQMP study also showed elevated levels for the region.

- Impact of the TSFs:
  - Sources of emissions quantified included windblown dust from the TSFs surrounding the proposed development.
  - PM emissions ($PM_{2.5}$, PM_{10} and TSP) were quantified using verified methods and utilized in dispersion simulations.
  - For wind erosion to occur, the wind speed needs to exceed a certain threshold, called the friction velocity. Literature indicates a wind speed of around 6.7 m/s to result in windblown emissions from gold TSFs. The threshold wind speed for this study is 7 m/s.
  - Simulated annual average $PM_{2.5}$ and PM_{10} concentrations, as a result of windblown dust from the TSFs, are low and below the respective ambient air quality standards.
  - The different unmitigated scenarios give the same conclusion regarding compliance, however the development areas affected differs for the various scenarios:
    - Scenario 1: The scenario with the highest impact assuming TSF 1, 2 and 3 are active (i.e. no vegetation). The area of non-compliance (on a daily basis) is for a large portion of the proposed development. Even, looking at active remining of TSF 1 to 3 individually, there is a small area of non-compliance in the vicinity of each TSF.
    - Scenario 2: The area of non-compliance (on a daily basis) is for a small portion of the proposed development only (the most eastern area) near TSF number 4.
    - Scenario 3: The area of non-compliance (on a daily basis) is for a small portion of the proposed development (the most eastern area) near TSF number 4 and a small portion of the proposed development west of TSF number 1.
  - The different mitigated scenarios give the following:
    - Scenario M1: The area of non-compliance (on a daily basis) is for a small portion of the proposed development only near TSFs number 1 and 2.
    - Scenario M2: The area of non-compliance (on a daily basis) is for a small portion of the proposed development only near TSF number 2.
    - Scenario M3: This scenario results in compliance at the proposed residential development.
  - A significance rating of 'medium' was assigned to potential inhalation health impacts and dustfall effects. With mitigation measures in place, such as vegetation or rock cladding, the significance should reduce to 'low'.

5.2 Conclusion

In conclusion, active remining of TSF1, 2 and 3 are likely to result in the highest impacts from all three unmitigated scenarios evaluated if no mitigation measures, such as water sprays, are applied. Similarly, post-remining and leaving the TSFs as is, could also have unacceptable impacts, although in smaller areas of the proposed development. Even with mitigation in place at TSF 1, 2 and 3 for any of the three scenarios, the impacts from TSF4 will still result in non-compliance at a small portion of the development. Thus, either rehabilitation of TSF4 or exclusion of the development area affected by TSF4, would be required to ensure compliance at the proposed development.

5.3 Proposed recommendations for the development

Based on the dispersion modelling results, the following is recommended to ensure compliance with NAAQS and NDCR within the residential development.

- Development 1: Exclude areas that fall within the restriction zones applicable to the remining of TSF 1 and 2 individually (because they will not be mined concurrently). Exclude areas that fall within the restriction zones applicable to TSF 3-6 remaining as they are.
- Development 1a: Same as phase 1 except with the restriction zones for the remining of TSF 1 and 2 adjusted to compensation for mitigation measures. The dispersion modelling conservatively assumed that during remining of the TSF, the entire area would be exposed and susceptible to wind erosion. If it is remined from one end to another the area of disturbance will be smaller and therefore the area of non-compliance will also be reduced. If additional mitigation measures are implemented, such as water suppression and nets for shielding dust, the impacted area can also be reduced.
- Development 2: expand the development 1 area into the restriction zones applicable to TSF1- assume that this TSF has been mined.
- Development 3: expand development 1 into restriction zones applicable to TSF 2- assume that this TSF has been re-mined.

If in future the remining of TSF 3 to 6 is proposed, it is recommended that the respective mining company would need to apply mitigation measures to the remining of these dumps to ensure acceptable exposure to the proposed development community.

It is the specialist opinion that the proposed development may be authorised, however it is recommended that the development area is adjusted to exclude the most eastern section directly adjacent to TSF number 4 unless TSF number 4 can be mitigated (vegetation would significantly reduce the impacts) and the development occurs in phases as discussed. See the recommended exclusion zone in the Figure 42 below (red dotted line for area of daily PM_{10} non-compliance simulated to be exceeded).

It is recommended that a short term ambient monitoring campaign be carried out to verify the ambient levels at the site and also to determine if additional vegetation is sufficient to meet ambient NAAQS and NDCR at the proposed development.

Figure 42: Proposed exclusion zone for the unmitigated scenario

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7 APPENDIX

7.1 Appendix A – Description of Wind Erosion Estimation Technique

Emission quantification was done using the in-house modelled ADDAS (Burger *et al*., 1997; Burger, 2010, Liebenberg-Enslin, 2014). This model is based on the dust emission scheme of Marticorena and Bergametti (1995) referred to as MB95 (from this point forward) and Shao *et al*. (2011) (referred to as SH11). A study conducted by Liebenberg-Enslin (2014) set out to establish a best practice prescription for modelling aeolian dust emissions from mine tailings storage facilities. Site specific particle size distribution data, bulk density and moisture content were used in the dust flux schemes of MB95, and SH11 to test the effects on a local scale. This was done by coupling these schemes with the US-EPA regulatory Gaussian plume AERMOD dispersion model for the simulation of ground level concentrations resulting from aeolian dust from mine tailings facilities. Simulated ambient near surface concentrations were validated with ambient monitoring data for the same period as used in the model. Coupling the dust flux schemes with a regulatory Gaussian plume model provided simulated ground level PM_{10} concentrations in good agreement with measured data.

The model inputs include material particle density, moisture content, particle size distribution and site-specific surface characteristics such as whether the source is active or undisturbed. All input parameters that were not measured as part of this work, have been drawn from or calculated using referenced methodologies (Liebenberg-Enslin, 2014).

For the purpose of this study, the MB95 dust flux model as schematically represented in Figure 43 is used.

Meteorological data from the WRF model, run for the year 2014, were extracted for locations close to each of the TSFs and used to determine the friction velocity and threshold friction velocity. Parameters of importance include wind speed, wind direction and temperature.

The relationship between particle sizes ranging between 1 µm and 500 µm and threshold friction velocities (0.24 m/s to 3.5 m/s), estimated based on the equations proposed by (Marticorena & Bergametti, 1995), is illustrated in Figure 44.

1 Input parameters

u^* (m s^{-1}): friction velocity

u^*_t (m s^{-1}): threshold friction velocity

η_c (%): clay content

θ (%): total soil moisture

w' (%): adsorbed soil moisture

z_0 (m): surface roughness length

z_{0s} (m): smooth roughness length

D_{ls} (m): mean distance between roughness elements

f : fraction of erodible area

psd (m): particle size distribution

p_b (kg m^{-3}): bulk soil density

pa (kg m^{-3}): air density

g (m s^{-2}): acceleration due to gravity

$p(di)$: dust mass fraction of j^{th} particle-size bin

2 Threshold friction velocity

2a *Threshold friction velocity over smooth surface*

$$u_t^*(d) = \frac{0.129 \times K}{(1.928 \times Re^{0.092} - 1)^{0.5}} \qquad 03 < Re < 10$$

$$Re > 10$$

$$u_t^*(d) = 0.129 \times K[1 - 0.0858\, exp(-0.0617(Re - 10))]$$

$$\text{where: } K = \left(\frac{P_p g d}{P_a}\right)^{0.5} \times \left(1 + \frac{0.006}{P_p g d^{2.5}}\right)^{0.5}$$

$$Re = 1331\, d^{1.56} + 0.38 \qquad \text{(eq.4)}$$

2b *Drag partition correction* (*R*)

$$R(z_0, z_{0s}) = 1 - \frac{ln\left(\frac{z_0}{z_{0s}}\right)}{ln\left[0.35\left(\frac{D_{ls}/30}{z_{0s}}\right)^{0.8}\right]} \qquad \text{(eq.6)}$$

2c *Moisture correction (H)*

$$\frac{u_{tw}^*}{u_{td}^*} = 1 \qquad w < w'$$

$$\frac{u_{tw}^*}{u_{td}^*} = [1 + 1.21(w - w')^{0.68}]^{0.5} \qquad w > w'$$

$$w' = 0.0014(\eta_c)^2 + 0.17(\eta_c) \qquad \text{(eq.11)}$$

$$u_t^*(d;\lambda;w) = \frac{u_{ts}^*(d)}{R(z_0, z_{0s})}(w)$$

3 Horizontal Saltation Flux (WH79)

$$Q(d) = C_0 \frac{P_a}{g} u_*^3 \left(1 - \frac{u_t^*}{u^*}\right)\left(1 + \frac{u_t^*}{u^*}\right)^2 \qquad C_o = 2.6$$

$$Q = \int_{d_0}^{d_n} Q(d)$$

(kg m^{-1} s^{-1})

4 Vertical Dust Flux (MB95)

$$F(d) = 10^{(0.134\, x\, \eta c - 6)} \times Q \times p(dj) \times \frac{1}{K_h}$$

(kg m^{-2} s^{-1})

***4a* Crusting correction (K_h)**

$$F_{crusted} = \frac{F_{uncrusted}}{K_h}$$

$$K_h = -0.03\left(\frac{\tau}{10}\right)^6 + 0.42\left(\frac{\tau}{10}\right)^5 - 2.17\left(\frac{\tau}{10}\right)^4 + 4.88\left(\frac{\tau}{10}\right)^3 - 3.35\left(\frac{\tau}{10}\right)^2 + 0.85\left(\frac{\tau}{10}\right) + 1 \qquad \text{(eq.14)}$$

***4b* Accounting for emissions per particle size group (*p(di)*)**

$$p_m(dj) = \frac{1}{d} \times \sum_{j=1}^{N} \frac{w_j}{\sqrt{2\pi}\sigma_j} exp\left[-\frac{(lnd - lnD)^2}{2\sigma_j^2}\right] \qquad (\text{m}^{-1})$$

(eq.15)

Figure 43: Schematic diagram of parameterisation options and input parameters for the Marticorena and Bergametti (1995) dust-flux scheme (Liebenberg-Enslin, 2014)

The wind speed variation over the storage piles is based on the work of Cowherd et al. (1988). With the aid of physical modelling, the US-EPA has shown that the frontal face of an elevated pile (i.e. windward side) is exposed to wind speeds of the same order as the approach wind speed at the top of the pile. The ratios of surface wind speed (us) to approach wind speed (ur), derived from wind tunnel studies for two representative pile shapes, are illustrated in Figure 44 (viz. a conical pile, and an oval pile with a flat top and 37° side slope). The contours of normalised surface wind speeds are indicated for the oval, flat top pile for various pile orientations to the prevailing direction of airflow (the higher the ratio, the greater the wind exposure potential). These flow patterns are only applicable with piles that have a height to base ratio of more than 0.25.

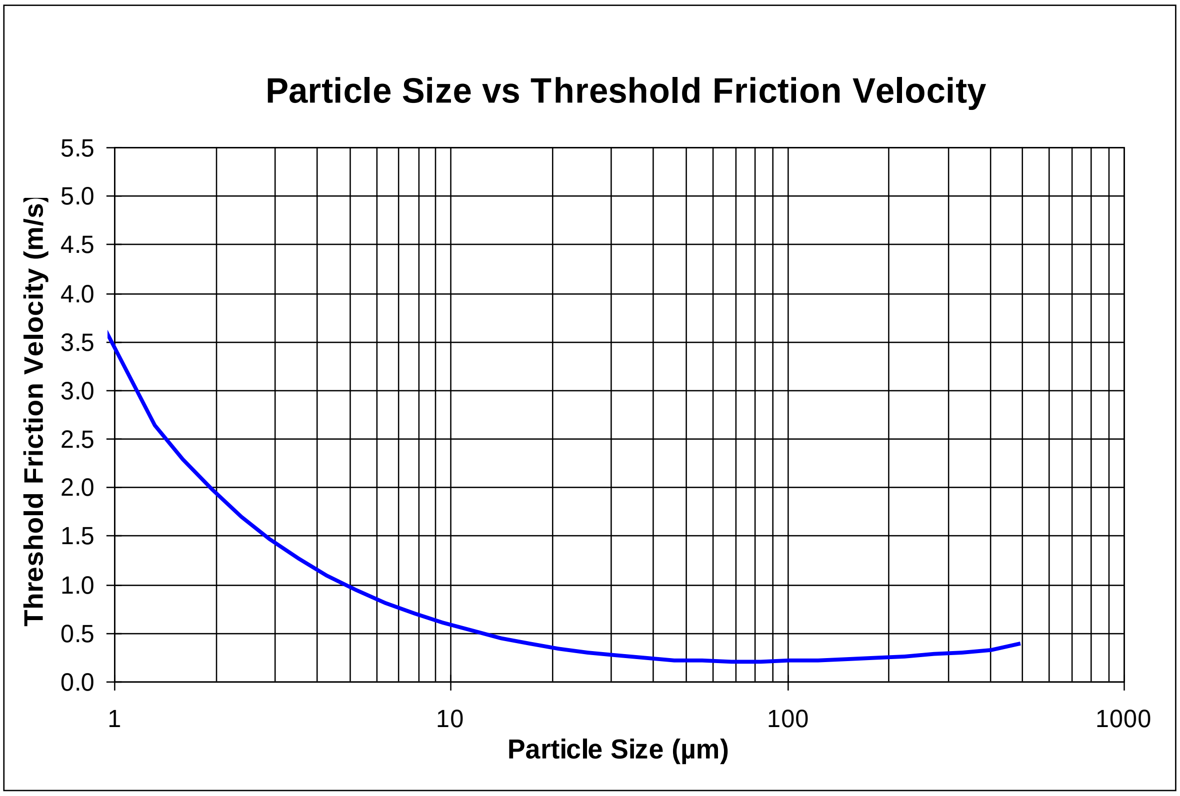

Figure 44: Relationship between particle sizes and threshold friction velocities using the calculation method proposed by Marticorena and Bergametti (1995)

7.2 Appendix B – Generic Management Measures for Tailings Storage Facilities

Substantial research has been done on erosion from gold mine tailings. 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 (Burger *et al*., 1997).

Any binding properties would reduce the potential for wind erosion. One of the most effective measures of minimizing wind erosion emissions from tailings storage facilities is re-vegetation. The control efficiency of vegetation is given as 40% for non-sustaining vegetation and 90% for re-vegetation. Secondary rehabilitation would up the control efficiency to 60% for non-sustaining vegetation (NPI, 2012).

Reclaimed/ remined slimes dams also have the potential to result in wind-blown dust emissions due to the surface areas being disturbed and resulting in loose wind-erodible material. However, should water be used for reclaiming the slimes, this would significantly reduce the potential for dust generation. Once the slimes dam has been removed, and provided vegetation is established on the exposed footprint, the potential for wind erosion would reduce significantly, around 80% if vegetated properly.

7.3 Appendix C – Curriculum Vitae of Author

CURRICULUM VITAE

Name	Gillian Petzer (née Möhle)
Date of Birth	1 December 1975
Nationality	South African
Employer	Airshed Planning Professionals (Pty) Ltd
Position	Principal Consultant and Project Manager
Profession	Chemical Engineer employed as an Air Quality Assessment Consultant
Years with Firm	15 years

MEMBERSHIP OF PROFESSIONAL SOCIETIES

- South African Institute of Chemical Engineers, 2003 to present
- Institution of Chemical Engineers (IChemE) - Membership number 99964317
- National Association for Clean Air (NACA), 2003 to present
- Professional Engineer – Registration number 20170315

EXPERIENCE

Gillian has fifteen years of experience in air quality impact assessment and management. She is an employee of Airshed Planning Professionals (Pty) Ltd and is involved in the compilation of emission inventories, air pollution mitigation and management, and air pollution impact work.

A list of projects competed in various sectors is given below.

Air Quality Management

- Richards Bay Air Quality Management Plan
- Tshwane Air Quality Management Plan
- Dust Management Plan for various mines

Mining Sector

Lusthof Colliery, South Deep Mine, Kangra, MacWest, Sishen Iron Ore Mine, SA Chrome, Esaase Gold Project (Ghana), Mampon Gold Mine (Ghana), Mittal Newcastle, Navachab (Namibia), Skorpion Zinc mine (Namibia), Debswana Diamond Mines (Botswana). Quarries: Afrisam Pietermaritzburg, AMT operations (Rustenburg and Wonderstone)

Industrial Sector

Various Brickworks, Middelburg Ferrochrome, Impala Platinum (Springs), Delta EMD Project, PetroSA, Alfluorco Aluminium Fluoride Project, PPC, Rand Carbide, Vanchem, BCL incinerator, AEL, Namakwa Sands Plant, Liquid Natural Gas Refinery (Equatorial Guinea), Phalaborwa Mining Company, Asphalt plants, Ceramic facilities

Energy Sector

Walvis Bay Power Station Project (Namibia), various small power stations (Eritrea, Nigeria, Mauritania, Kenya), Matimba Power Station, Mossel Bay OCGT Power Station, Sese Power Station (Botswana), Geothermal Power Station (Kenya)

Waste Disposal and Treatment Sector

Rosslyn and Chloorkop Waste Disposal Sites, Organic waste disposal site

Transport and Logistics Sector

Kolomela Iron Ore Railway Line, Guinea Port and Railway Project (Guinea), Grindrod Coal Terminal, VALE Port Project (Mozambique).

Ambient Air Quality and Noise Sampling

- Gravimetric Particulate Matter (PM) and dustfall sampling
- Passive diffusive gaseous pollutant sampling

SOFTWARE PROFICIENCY

- Atmospheric Dispersion Models: AERMOD, ISC, CALPUFF, ADMS (United Kingdom), CALINE, GASSIM, TANKS
- Graphical Processing: Surfer, ArcGIS (basic proficiency)
- Other: MS Word, MS Excel, MS Outlook

EDUCATION

- BEng: (Chemical Engineering), 2002, University of Pretoria

COURSES COMPLETED AND CONFERENCES ATTENDED

- Conference: NACA (October 2003), Attended
- Conference: NACA (October 2005), Attended and presented a paper
- Conference: NACA (October 2007), Attended and presented a paper
- Conference: NACA (October 2008), Attended and presented a poster
- Conference: NACA (October 2009), Attended and presented a paper
- Conference: NACA (October 2012), Attended
- Conference: IUAPPA (October 2013), Attended
- Course: Climate change and carbon management. Presented by Environmental & Sustainability Solutions (July 2014)
- Conference NACA (October 2016), Attended

COURSES PRESENTED

- National Environmental Management: Air Quality Act and its Implementation (course arranged by the North-West University - NWU)

COUNTRIES OF WORK EXPERIENCE

South Africa, Namibia, Botswana, Ghana, Eritrea, Mauritania, Mozambique, Kenya, Guinea, Equatorial Guinea and Nigeria

LANGUAGES

Language	Proficiency
English	Native language
Afrikaans	Full professional proficiency

REFERENCES

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CERTIFICATION

I, the undersigned, certify that to the best of my knowledge and belief, these data correctly describe me, my qualifications and my experience.

28/09/2017